Long Term Ecological Monitoring Program

Monitoring Plan

1997

Denali National Park and Preserve

DRAFT

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1. Introduction

During the past decade, the National Park Service has repeatedly identified the need for preparation of long term data sets which document the condition of park natural resources. Furthermore, park management decisions involve a wide variety of issues affecting resources held in trust for the public. Therefore the National Park Service has also identified the need for comprehensive information to help make management decisions. These data sets need to be consistently developed over a long time span to document the status and trends of park resources and human uses.

In 1991, the Service established a prototype ecological monitoring program to address this issue. At the inception of this program, the Service recognized the need for credible scientific backing if information based decisions were to be effective. In 1992, park-based, other agency, and university scientists were called upon to support various aspects of program development. Subsequently, personnel, first from the National Biological Service and now the Biological Resources Division, U.S. Geological Survey have become involved in program development.

Parks from across the National Park System were provided an opportunity to compete for program participation. A total of ten parks will eventually serve as prototypes with all parks with significant natural resources eventually participating in one way or another.

Denali National Park and Preserve (Denali) was selected as one of four parks to begin participation in the program in 1992.

1.1 Document Purpose

This document serves three primary purposes. First, it spells out the justification, objectives, working parameters, and theories that are the underpinnings of the monitoring program at Denali. In short, it describes the "conceptual design" or "program design" of the park's monitoring initiative. Second, it outlines a strategic framework or process that park staff is going through to bring the monitoring program into operation and application. Finally, it sets the context for developing a Monitoring Implementation Plan, and for requesting funding and personnel needed to assure implementation.

This document has been prepared largely in response to a programmatic review of Denali's monitoring program that occurred in the summer of 1995. One of the primary recommendations of that review was to strengthen the foundation or "conceptual design" of the program. This document outlines the results of those efforts to date. In addition, in February, 1997, a Servicewide monitoring meeting was held at which material weaknesses of the existing prototype monitoring programs were discussed. One major topic of discussion was financial support for the program. In response, an invitation was extended for the prototype parks to submit updated proposals that reflected new financial needs. At Denali, interagency management decisions beyond the control of the park resulted in awkward financial arrangements and continuing fiscal shortfalls. The combination of these factors make it appropriate for Denali to "start over" with a major revision to the original proposal. Park staff recognize the need to summarize program design efforts to date to demonstrate the need for the requests displayed in the new budget. This paper provides the detailed support for what is contained in the new proposal.

At this point, this document is in a draft form. Additional effort must be expended on program design to bring it to closure. Once that work is completed, this paper will be revised and issued in a final form.

1.2 Background

1.2.1 Monitoring Program Experience to Date

During the fall of 1991, park and regional office staff worked together to prepare a proposal for Denali's participation in the prototype monitoring program. Late that year, park staff were advised that they had been chosen to participate in the program.

The original proposal called for monitoring efforts to be organized within a series of watersheds that would be considered representative of the park as a whole. Much of the program was to be implemented by existing park staff with supplemental help from a team of technicians. Large mammals and raptors were excluded from the program and emphasis was placed largely on global climate change monitoring. The original proposal recognized the need for research and development related to individual monitoring protocols (refinement of existing protocols or establishing new ones) but also endorsed use of standard procedures.

Severe budget limitations made implementation of the program in a single watershed with easy access imperative when field programs began in 1992. Five field seasons have been completed during which emphasis has been placed on research and development of a dozen or so protocols.

Thus far the program has been based on the premise that a set of protocols to monitor basic resource attributes in one watershed can be replicated in other watersheds to represent the park overall. Field work has largely focused on intensive watershed studies in Rock Creek, a small second order stream in the eastern end of the park. Protocols are completed for the following parameters: air quality, meteorology, stream hydrology, surface water chemistry, vegetation, aquatic macroinvertebrates, passerine birds, and small mammals. A soils monitoring protocol will be completed in 1997.

Some attributes do not lend themselves well to a sampling design based on a small watershed (less than 1,000 hectares). Certain program elements (i.e. meteorology, glaciers and passerine birds) have been expanded to areas beyond Rock Creek. Stream hydrology, surface water chemistry and aquatic macroinvertebrate sampling have occurred extensively throughout the park to gain information that will be used to stratify aquatic systems into representative categories.

Even before selection of Denali, park staff and others recognized that the park's proposal had shortcomings. As implementation began, many of those concerns manifested themselves.

Shortcomings included inadequate links to park issues, minimal integration with ongoing research and monitoring efforts, a lack of clearly articulated objectives, insufficient documentation of criteria for protocol and watershed selection, insufficient attention to synthesis of findings and the need for long term scientific support, an overly restrictive focus on operations within watersheds, and minimal thought given to reporting mechanisms. These difficulties were compounded by the transfer of program responsibility and research and development to the National Biological Service.

Funding for the monitoring program was initially added to Denali's base budget. NPS staff initiated protocol development or contracted services from independent researchers. With creation of the National Biological Service (NBS), program funding was transferred to NBS along with responsibility to develop monitoring protocols for biotic attributes. Some funding has been transferred back to the NPS each year to assist with logistical support, technicians' salaries, and development of physical resources protocols. These funding arrangements preclude efficient program implementation. Lack of NPS base funding has prevented resolution of staffing issues such as conversion of important temporary positions to permanent appointments before key personnel are lost.

Transfer of NPS scientists to the NBS also hampered effective data synthesis and interpretation. Trends in resource conditions which should trigger management action must be identified by a group of qualified scientists. Without this capability, the immediate usefulness of information gained through the monitoring program is limited.

During the summer of 1995, Denali's program underwent a review intended to assess the progress of the program and to determine if park staff opinions expressed about the above mentioned shortcomings were valid. The review team recommended that the park hire a full-time program coordinator and that steps be taken to improve the program's "conceptual design".

During 1996, the coordinator was hired and major progress was made developing the "conceptual design" through contacts with key scientists, literature searches and familiarization, and two workshops. This paper documents the progress made thus far in establishing the program's foundation.

1.2.2 Experiences of Other Prototype Parks

Between 1992 and the present, several other parks have undergone similar developmental experiences. Denali staff members have met with park staff members from those units periodically and learned from their experiences. That exposure has strengthened the program design that is proposed here. Improvements in areas such as data management, communications and information transfer, field operations, and monitoring theory can be readily attributed to the sharing that has occurred.

1.2.3 Associated Activities

Numerous other developments at Denali have served to contribute to better program design including major progress in writing the park's Resources Management Plan, modest improvements in infrastructure (particularly local area computer network installation) specifically to support scientific programs, continued funding from alternate sources, support of monitoring programs by park base funds, institutionalization of a geographic information system at the park, and funding of efforts to improve parkwide resource inventories.

Park staff and cooperating investigators are developing a variety of monitoring programs that also transcend watershed boundaries. These projects measure the status and trends of significant park resources and should eventually be linked to the monitoring program. These include raptors, large mammals, wildland fires, and various vegetation variables.

Although Geographic Information System capabilities were established in 1995, some data backlog problems exist. Historic data from other significant research efforts await integration into the program database.

1.2.4 Current Status

Despite program difficulties, significant work has been completed since 1992. Achievements include successful formulation of the process that will be applied to complete design and implementation program stages, substantial progress in formulating and documenting the program's "conceptual design", five years of experience in field monitoring operations and near closure on a number of protocols, and compilation of data that will be used in sampling design efforts. Complete closure on design is targeted for the end of Fiscal Year 1997. A full-time coordinator is now managing the program and extensive contacts have been made to foster a credentialed scientific community that supports the program. Finally, other resource management programs are now primarily oriented to support the monitoring function.

2. Denali as a Prototype Site

2.1 Opportunity for Contribution Nationally and Globally

Two-thirds of the Nation's parks and refuge lands, or over 131 million acres, are in Alaska. In addition, the Department of Interior's (DOI) Bureau of Land Management manages 93 million acres in Alaska. Many contentious land and resource management debates, of national interest, focus on reaping economic benefit through extraction of Alaska's natural resources or through preservation of its large-scale natural and wilderness integrity.

The subarctic interior of Alaska, where Denali is located, is poised for escalating resource conflicts. The relative accessibility of this region of the state, by Alaskan standards, heightens the interest in developing new resource-based industries, such as timber production and mineral extraction. Continued rapid growth of tourism in and around Denali is predicted. Growth of all of these activities will bring additional settlement, transportation and utility corridors, industrial development, and increasing recreational demands. Therefore, it is essential that the public and land managers have access to high-quality scientific information to formulate and justify decisions and to monitor human-induced effects on the environment.

Denali National Park and Preserve provides a unique opportunity to seek this additional understanding. Many critical ecological and national political discussions are now focused on how to manage large landscapes and ecosystems. Yet, it is increasingly difficult to find intact systems to use as study areas to develop the knowledge necessary to manage or monitor the more prevalent altered systems. Denali provides a special opportunity to study a large, intact, and naturally functioning ecosystem that surrounds complex and diverse geological features such as Mt. McKinley and extensive glaciers. The current park boundary encompasses the largest continuously protected area in the world (Mt. McKinley National Park, an area of more than 2 million acres, was established 80 years ago) and deserves the international significance associated with its International Biosphere Reserve status. Denali is the only class I air quality area of significant size in Alaska. Additionally, most ecosystems the size of Denali are governed by a maze of differing management mandates which further complicate research activities. While not completely free of multiple managerial mandates, Denali's management is relatively straight forward.

Substantial research has been conducted in Denali, and significant Geological Resource Division-U.S. Geological Survey (USGS) and Biological Resource Division-USGS efforts are ongoing including bedrock and surficial deposits studies, glaciological studies, long-term large mammal community dynamics research, and development of techniques to restore placer-mined watersheds. This is in addition to dozens of independent research activities.

The wide array of current research efforts provide a unique foundation on which to build a productive complex of research and monitoring activities. Given adequate stable funding, a strong research alliance could be forged with an array of potential partners, that would allow Denali to be better managed and to serve as an important benchmark for comparison with other lands. A strong focus at Denali will improve the contributions of more extensive research and monitoring throughout the subarctic region. Activities that could be undertaken include: 1) expanding research on critical ecosystem processes and components to distinguish human-induced effects from natural variation; 2) developing sampling methodology to integrate research and monitoring results across local, regional and global scales; 3) integrating biological and physical science components to support an ecosystem-based approach to decision making; and 4) expanding Denali's capabilities to serve as an important component in monitoring global scale anthropogenic ecological changes.

Finally, Denali is a high profile visitor destination. As a result, programs at Denali can receive publicity that will bring attention to environmental problems and the research efforts underway to understand them.

2.2 Monitoring Within Park Management

Denali is a large, complex, and highly political park with a long administrative history. The park's organizational and operational framework reflect these conditions and the many responsibilities of managing a major national park. There are six major park operational divisions, Research and Resource Preservation, Visitor Services, Maintenance, Interpretation, Concessions Management, and Administration. Four of these divisions focus most of their attention on accommodating visitors and providing safe and enjoyable experiences. One, the Division of Research and Resource Preservation, is focused entirely on the protection or park resources.

This Division is a major player in overall park operations. Many operational decisions hinge on information that Division employees are able to supply. This occurs within the context of preparing environmental compliance documentation and in circumstances where day-to-day decisions are made. The Division is also able to influence themes for public interpretation, conditions within which concessionaires are to operate, and influence such things as public use regulations, access closures, and programming for ranger patrols.

Staff in the Division generally organize tasks into categories of research, inventory, and monitoring. Park staff may then suggest tasks that make use of the findings resulting from research, inventory efforts, and monitoring programs. These secondary tasks are generally grouped as mitigation, protection, and public information (a.k.a. interpretation). This organization is clearly articulated in the park's Resources Management Plan.

The primary responsibilities of the Division are to inventory park resources establishing their presence and condition, and to monitor the status and trends of park resources. Figure 1 shows how inventory and monitoring is related to some of the other major activities of the Division. Inventory and monitoring activities have strong links to research. Research is required to develop sound inventory and monitoring methods. Inventory and monitoring efforts create important data that is helpful in framing or answering research questions.

Inventory, monitoring, and research have strong ties to mitigation, protection, and public information activities. Research may set the thresholds that will trigger additional research, protection, or mitigation actions. Monitoring helps management determine when thresholds have been reached that require action. Monitoring also determines if those actions were successful, must be continued, or must be modified. Research is directly linked to mitigation and protection activities because proper techniques must be developed and tested. Inventory and monitoring, as well as research, provide information that can be communicated to the public through park interpretive activities.

2.3 Unique Circumstances

Along with the decision to use Denali as a prototype park came an acknowledgment of a number of circumstances that will force the monitoring program in somewhat different directions than in the other prototype areas. A relative lack of information about subarctic systems will require broad-based monitoring for sometime until the system is better understood and specific components or process can be developed as indicators. The lack of information also means that continued inventory activities will have to occur. Assistance will be needed from the national Inventory Program to obtain basic data such as a base geology map and flora and fauna lists for new park and preserve additions. The spatial scale is dramatically different in Alaska parks which brings up logistical differences and complex sampling design questions. A relative lack of infrastructure means a need to increase some key facilities to support staff and attract partnerships with researchers.

2.4 Strategic Framework

Development and implementation of a large long term monitoring program is a complex task that involves many types of activities that must be conducted in a certain order. The following strategic framework groups these activities into programmatic units that also describe the steps that are thought to be necessary for the successful development and implementation of a long term program at Denali. These units will also be used in the development of program budgets and other discussions of the program.

2.4.1 Program Design

The development of a sound conceptual design is a fundamental task that must be accomplished in this phase of the program. A clear justification of why the monitoring program has value and how it will lead to an improved management response should be presented. The objectives of the program must be defined in a manner that shows what information it will provide and what rationale will be used to determine the attributes that are to be measured by monitoring. The design should establish the necessary working parameters or programmatic standards that will ensure the programs longterm success. And finally there should be a through discussion of the theories that will be used to construct ecological models, sampling designs, and establish thresholds for management action, etc..

While some work still remains for the Denali program, a revision to the original design for the program that follows these guidelines is nearing completion. Many of the major attributes have been selected, and protocols that document how they will be measured have been developed. The substantial work that has been accomplished so far is presented in this document and is the basis for budgetary projections. A workgroup strategy for selecting the remaining attributes for monitoring is also described.

2.4.2 Protocol Development

Protocols that describe the methods for measurement must be developed once the monitoring attributes have been selected through the conceptual design process. The development of new protocols will require significant research in many cases. Frequently partnerships and contracts with other agencies or academic institutions must be developed to supplement the work that will be done by monitoring program staff. In these situations, a primary task of the monitoring staff will be to determine the research that is needed as well as develop and oversee the contracts or partnerships that are selected to accomplish the required research.

2.4.3 Protocol Implementation

While it is already clear, based on current revisions to the conceptual design, that several new protocols will be needed, there are also many protocols that have already been developed for the Denali program through previous monitoring funding and other research activities. This situation will allow the program to progress on parallel tracks, the development of new protocols as well as the implementation of existing ones.

As protocols are developed, they must be consistently implemented for the long term in order to realize the benefits of monitoring. Ensuring continued funding to support the staff, infrastructure, and contract services necessary to accomplish this is a critical portion of the program. Other funding sources in addition to the monitoring program will be used. Significant support is currently provided by Denali park base funds to implement many existing protocols. Monitoring funding will allow the addition of other protocols and provide a comprehensive program.

2.4.4 Information Management and Transfer

The quality assurance and quality control of program data as well as its storage in a manner that allows integrated analysis is a critical activity. The major expense of field data collection will be wasted if it cannot be transferred through regular reports. Developing this information transfer link is essential to assisting managers with decision making as well as for developing a better understanding of the value of long term monitoring.

2.4.5 Integration and Review

The integration of information from different aspects of the program will be the first task in this portion of the program. This important organizational activity will facilitate the analysis and synthesis that can then provide new understanding of the subarctic ecosystem and how it is responding to human use. This information, combined with regular reviews of the protocols and the entire program, provides the "feedback" needed to revise the activities described in the other programmatic units. Significant interaction with the scientific community will be needed for integration, synthesis, and review.

3. Program Design

It is now possible to make several revisions to the original conceptual design for monitoring at Denali based on the field activities and workshops conducted during the last few years. These changes will make the program more effective and defensible. The fundamentals of the revised design are explained in this section.

3.1. Program Purpose and Objectives

3.1.1 Program Purpose

The overall purpose of the Denali Long Term Ecological Monitoring (LTEM) Program is to develop broadly based, scientifically sound information on the current status and long term trends in the composition, structure and function of the Denali National Park and Preserve ecosystem.

This information will be used to:

- Improve management decision-making on park resource preservation concerns that are primarily local and regional in nature;
- Provide a source of information for others working on ecosystem related studies in the subarctic: and
- Enhance national and international monitoring networks by representing a naturally functioning and intact subarctic site.

3.1.2 Objectives of the Denali LTEM Program

- Document the ranges of natural variation in key ecosystem processes and structural elements:
- Develop information that can be used to identify cause and effect relationships:
- Discriminate natural change from that which is human-induced:
- Provide information upon which management responses are based when pre-determined thresholds of resource condition are reached;
- Obtain information useful in predicting change prior to undesirable environmental effects;
- Provide control sites and benchmark data for comparative subarctic ecosystem research;
- Share resource status information, monitoring methodologies and program development strategies with NPS and other entities.

3.2 Design Principles

3.2.1 Working Parameters

The NPS has strived to develop a long term ecological monitoring program of the highest caliber. In doing so, park managers recognize that the following standards are key to a successful long term monitoring program. It must be:

- **Utilitarian**: Develops linkages between scientific knowledge of ecosystem condition and management needs and actions
- **Adaptable**: Responsive to newly identified issues and to changes in the current state of knowledge of the structure and function of intact ecosystems as well as technological advances
- **Foundational**: Provides background information for other park programs and research
- **Prospective**: Anticipates the causes, mechanisms and indicators of human-induced change
- **Unbiased**: Based on good science
- **Interdisciplinary**: Blends multiple scientific disciplines into a unified approach
- **Integrative**: Correlates data gathered at different temporal and spatial scales
- **Compatible**: Data and methods are consistent with and easily shared
- **Hierarchical**: Functions on multiple programmatic and spatial levels
- **User friendly**: Monitoring and data management techniques are readily understandable, accessible and easily implemented
- **Continuous**: A long term management commitment recognizing that the value of the program increases over time

3.2.2 Definitions

It is necessary to define several terms that will be used throughout the following discussion of the conceptual design. These definitions follow Noon (1997)

- **Attribute**: Any biotic or abiotic feature of the environment that can be measured.
- **Indicator**: A measured attribute that infers the quality, health or integrity of the larger system to which it belongs
- **Stressors**: Intrinsic (natural) and extrinsic (human induced) disturbance processes that result in alterations to structure, composition, and function of the ecosystem.

3.3 Monitoring Approach

3.3.1 Introduction

As discussed in previous sections, the original conceptual design for the program addressed only a portion of Denali's long term monitoring needs and was based largely on a retrospective assessment approach. Information from the fieldwork and workshops of the last few years provide the basis for the following new program design. A basic premise of the new conceptual design of the Denali LTEM program is to utilize both retrospective and prospective assessment approaches to detect changes in the integrity of the Denali ecosystem.

3.3.2 Retrospective and Prospective Monitoring Approaches

Retrospective assessments are not dependent on a prior identification of stressors. Ecological observations are made on many system components and processes through generalized research or monitoring. Cause-effect relationships are then inferred later and indirectly based on the results of this work (Barber et al. 1994). This approach is useful for some components and processes of the Denali Ecosystem that are not well enough understood at this time to select indicators for very focused monitoring efforts with complete certainty. Well integrated, intensive studies of many aspects of the system in small areas such as watersheds where many system variables can be sampled simultaneously will still be needed to develop an understanding of complex relationships at the Community, Population, and Species level of organization.

A retrospective assessment will remain a part of the conceptual design and monitoring protocols because it can help at times to provide this more broadbased understanding of ecosystem composition, structure, and function. This broader background information on the ecological system is frequently necessary to distinguish the "signal" created by extrinsic stressors from the "noise" of natural variability and intrinsic stressers inherent to the system. It also provides park management with information to deal with unexpected stressors that are not the focus of the current program or are not known at the present time. Developing this background information on the ecosystem is a form of insurance against the unknown threats of the future.

In contrast, prospective monitoring (Figure 2) starts by using existing knowledge to develop a conceptual model that represents the ecological processes as well as key elements of structure and composition that are suspected to be important in the ecosystem. Extrinsic stressors are identified and characterized, and then joined with this conceptual ecological model. The suspected pathways from these stressor(s) to ecological effects are then outlined (Noon 1997; Suter 1993). Monitoring questions and hypotheses are developed to direct the program and to test these assumptions. Monitoring and research results are used to confirm or improve the validity of the model and to develop cause and effect relationships between extrinsic stressors and observed changes. Thresholds of change that trigger management action are set as a result of further research and monitoring on the natural variability of the system. As more information is gathered, the ecological model is improved, and a better understanding of stressor interaction is developed. As the model and the stressor relationships become more accurate, thresholds and the detection of measurements that fall outside the bounds of those thresholds can be made with more certainty. Management actions such as additional research or mitigation are taken when those thresholds are exceeded.

Prospective monitoring is extremely important at the local and regional scale of the Denali program. Its narrower initial focus based on selected extrinsic stressors can provide a more immediate identification of critical cause-effect relationships. Prospective monitoring also attempts to detect effects as they are occurring, rather than describing them after they have occurred, thus allowing a more rapid and directed management response to anthropogenic stress to the environment. It also offers the potential to make the information from the Denali program more transportable to other management units. Human activities affecting national parks are very similar regardless of the ecosystem in question. Stressors such as access, harvest, settlement, etc. occur in or around all areas. Conceptual designs that are built around stressors can be adapted more readily as a result. Many of the attributes that must be monitored will remain the same regardless of species or vegetation type. Prospective monitoring was largely absent in the original conceptual design and this led to a situation where the program has not been able to provide information for park managers on important threats to the Denali system.

3.3.3 Long Term and Tactical Monitoring

Inventory and monitoring is composed of long term (LTEM Program) as well as tactical activities. The LTEM Program is the consistent bass beat that provides the foundation and organization for inventory and monitoring activities in general. It is directed at developing initial baselines of data and evaluating threats or scientific questions that are typically long term in nature and often of a large spatial scale or major influence to park ecosystems.

Tactical inventory and monitoring is generally initiated to answer a very specific question or project that is of shorter duration and frequently at a smaller spatial scale. It is important to remember that some portion of what starts out as a tactical activity may become part of the LTEM Program. For this reason, tactical studies must be designed from the start so that they could contribute to or benefit from the LTEM Program activities. Similar sampling methods and data base structures must be used wherever possible to facilitate this conversion if it is necessary.

Consequently, while the LTEM program does not fund all park monitoring activities, it essentially provides the conceptual coordination for them. Currently there are several monitoring activities underway at Denali that address many present issues, but they do not operate as a coordinated program. Also, many present and potential concerns are not being addressed at all by current research or management programs. The supplemental funding of the LTEM program will be used to strengthen those current monitoring activities which are appropriate for inclusion in the LTEM program and to initiate new long term activities that are currently lacking attention.

This conceptual integration of present and future monitoring activities into a comprehensive program of tactical and long term approaches will be extended beyond just the natural resources primarily addressed. For example, the monitoring of cultural resources and sociological values, while they will not be funded directly by the LTEM program, can clearly benefit from data that may be collected for natural resource issues if a more holistic view of the LTEM program is taken initially and all park information needs are considered at an early stage of the planning process.

3.3.4 Need for Continued Inventory and Research Activities to Support Monitoring

Regardless of the approach, there is also a need for complete resource inventories and a review of past work to provide a foundation for future monitoring. This is particularly important in a large, remote area like Denali where much inventory work is still needed. The national Inventory Program will meet many of these needs, but additional work will be necessary to prepare for protocol development and this must be incorporated into some aspects of the prototype monitoring program at Denali. Certain topics such as geologic mapping that are to be done through the national program, may need to be accelerated in the specific case of Denali in order to allow the LTEM program to move forward efficiently.

Clearly, research is also needed to help develop the basic ecological model, to develop the monitoring protocols, to help determine the true cause of observed changes, and to decide on the threshold values of indicator that will trigger specific management actions.

3.4 Monitoring Focus Areas

Three areas of the diagram illustrated in Figure 2 must be researched or monitored to eventually determine cause and effect relationships or to set thresholds for management actions. They are the Ecosystem Model, Extrinsic Stressors themselves, and the Ecological Consequences of Extrinsic Stressors. Our logic is that if we can measure the extrinsic stressors and the expected consequences of the stressors, and develop an accurate ecological model, then inferences about cause and effect should be able to be made. Developing the information to carry out this analysis process is a primary goal of the monitoring program as well as the research program of Denali.

The sections discussed under the following heading of Ecosystem Model describe the categories of information that would be needed to characterize an ecosystem (Landres 1992). This type of model is needed for Denali and is a major objective of the workgroups that are suggested further on in this document. Ultimately this model will outline the interconnections among key ecosystem components and the strength and direction of those linkages. It will also indicate the pathways of natural disturbances and how the system may acquire resilience to those disturbances. For the purposes of this document the characterization of the system provided in the following sections, along with the knowledge of researchers and staff familiar with the Denali Ecosystem, is felt to be sufficient for the identification of general ecological consequences as a result of the influence of the extrinsic stressors. Other sections below define these extrinsic stressors and list the predicted ecological consequences of those stressors based on their interaction with our conceptual model.

3.4.1 Ecosystem Model

Composition and Structure

. Composition

Composition describes the abiotic and biotic building blocks of the system. Commonly thought of components might included rock types, soil types, stream types, lake types, species, etc..

Structure

Structure is how these components are arranged both spatially on the landscape and into ordered. interrelational levels such as tropic levels, food webs or guilds. It can be described as the physical organization or pattern of a system, from habitat complexity as measured within communities, to the pattern of patches or other elements at a landscape scale.

Critical Inventory Needs for Conceptual Model Building

Inventories that establish this information composition and structure are essential to the construction of an ecological model. There is still a substantial need for more complete resource inventories at Denali, and therefore a continued inventory effort must be integrated into the design of the program. This inventory information is needed to modify existing protocols, to design new protocols, and to develop the sampling strategy for the program. Many geographic areas and ecological components remain largely unevaluated due to the size of the management unit, including the 4 million acres of recent park and preserve additions.

Composition and structure are the primary inventory objectives because changes in those characteristics should reflect many of the changes that may be occurring in underlying processes. Inventory is very important for the components which can modify the environment, that are variable in their effects, or can in turn be affected by human activity.

The NPS national inventory effort will certainly provide some assistance, but in many cases the information is needed much sooner than when this program is currently expected to provide it. Some of the needs can be addressed in the process of developing and implementing the various protocols or through low cost partnerships with interested scientists, but many others cannot. These other, more complex needs will require either an acceleration of the national inventory effort specifically for Denali or a line item increase in the Denali LTEM budget so that this work can be accomplished.

New approaches will be needed to accomplish inventories for the large Alaskan parks. Just as Denali is serving as a prototype for monitoring protocol development, it can also serve as an area where new protocols for inventories could be designed. The following list shows areas where inventory information or techniques are critically needed to advance monitoring program design and implementation, and where new approaches, both technical and logistical, could be developed that would provide useful examples for other large park areas.

Bedrock Geology/Suffical Geology

This information is fundamental to the spatial sampling design of the LTEM program. Stratification and watershed selection will rely heavily on this information. The McKinley Quadrangle, the map unit in the very center of the park, is incomplete and of great importance.

Because of the universal interest in the completion of the mapping in this quadrangle, there is a strong potential for a USGS and NPS cooperative effort that could become a model for work in other Alaskan park areas. Geologic mapping through the national inventory program is still several years away, yet the information is needed now at Denali.

Flora and Fauna

A similar information gap exists for many regions of the park in regards to flora and fauna. The lack of this information is a fundamental problem for the monitoring program. Procedures are needed to evaluate the presence and distribution of these resources in large landscapes. A well designed rapid bioassessment process needs to be developed. This procedure should allow for rapid assessment of biodiversity in vast, remote areas and yet provide the statistical confidence enabling detection of significant change. Application of this procedure would be iterative. Information obtained from one assessment would be used in conjunction with remotely sensed data to predict biodiversity in unknown areas, prediction accuracy would be assessed, the predictive model adjusted, reapplied, reassessed and so forth. A rapid bioassessment protocol of this type would have immediate value for resource managers in need of characterization of biodiversity resources in other large systems where little is presently known.

Landscape Scale Baseline Information on Composition and Structure

The vastness of Alaskan landscapes requires special methodologies when studying ecological conditions. Traditional thinking places primary emphasis on selection of intensive study sites, distribution of those sites across the landscape, and extrapolation of information to draw conclusions about the park or region as a whole. In large landscapes, where relatively few intensive sites can be deployed, this approach often fails to capture significant changes in composition and structure at that scale. This information could be captured via remote sensing or other available technologies. Investigative work in the area of determining appropriate parameters for examination, how to link spatial information to attribute data, and analysis of time series information are lacking. Methodologies are needed to gather information on a landscape level.

Methodologies must be developed to spatially/graphically document resource conditions for such things as habitat patterns, distribution of ecotones and permafrost locations, hydrogeologic conditions, wildfire distribution, forest insect and disease damage, and so forth. The methodologies developed should accommodate attribute data through linkages to other databases (i.e. seismographs, weather stations, or USFS insect and disease reconnaissance flights that are not linked to the LTEM intensive study sites). These methods and their resulting data go beyond baseline inventory efforts currently underway within the Service.

Ecosystem Function

Ecosystem function is the set of processes that result from interactions among the biotic and abiotic components of the ecosystem. Better understanding of the following areas is needed to refine the conceptual model. These topics are thought to be the most important for immediate attention. They have also shown some promise as being measurable and reflective of system health (Landres 1992).

- Nutrient Cycling
- Primary and Secondary Productivity
- Species relationships (competition, predation, symbiosis)

Ecosystem Disturbance - Intrinsic Stressors

The significant intrinsic stressors (natural perturbations) also must be identified and quantified in order to develop the conceptual model and to refine the cause and effect relationships between extrinsic stressors and their ecological effects at the local and regional scale. Monitoring of these will be pursued as part of the LTEM program.

The following are thought to be the most significant intrinsic stressors that operate at a spatial and temporal scale that is relevant to management of the Denali Ecosystem.

- Regional and Local Meteorology
- Hydrologic Processes
- Fire
- Mass Soil Movements
- Disease and Insect Outbreaks

Ecosystem Variation

Variation is a fundamental characteristic of ecosystems. Its expression and importance varies from system to system. These variations in combination with the disturbance regime of the intrinsic stressors must be understood in order to define the "normal" or "acceptable" range of variation in ecosystem and function. The following three areas of variation are considered to be most important in the Denali Ecosystem. These dynamic variations should operate with stable bounds in a sustainable system (Chapin et al. 1996).

- **Cyclic**: Subarctic systems have been shown to be highly cyclic with wide cycle bounds.
- **Stochastic**: Impressive geologic and meteorological processes can produce profound events that can create significant system shifts.

- **Succesional Trends after Disturbance**: Significant primary succession is underway throughout the system as a result of disturbance and climatic change.

These topics as well as the other characteristics of the ecosystem just discussed are primary areas in need of research to help clarify the relationships implied in any ecological model of the subarctic. Many opportunities for partnerships between the LTEM program and researchers exist for these topic areas. As the LTEM data sets develop, they can be used by researchers to address questions about these processes. The presence of these data sets will attract partnerships because they are of great interest to many researchers working in the subarctic. This is the area of the program where there will be strong interaction with USGS-BRD and academic institutions. Also, the LTEM program can attract these partnerships, and as a result accomplish more with less, by just contributing logistical support in the form of office space, transportation, or housing, as well as the availability of a quality, longterm subarctic data base.

3.4.2 Extrinsic Stressors

Extrinsic Stressor Identification

The stressors for the prospective monitoring portion of the program were selected based on their relationship with the significant values of Denali. These values are summarized in the following list which is derived from the Park's enabling legislation, boundary extension legislation, wilderness designation, ANILCA, and management documents such as the 1986 General Management Plan and the 1995 Statement for Management.

- Intact and naturally regulated subarctic ecosystem that is still essentially unfragemented by access routes or boundary effects.
- Outstanding opportunities to view wildlife as a part of a naturally functioning ecosystem.
- Large, intact wilderness that still offers premier wilderness recreational opportunities even though it is more accessible relative to other areas of wilderness Alaska.
- A complex and diverse geology of international interest, including the Central Alaska Terrane Assemblage and the Mt. McKinley massif.
- A range of glacier types that characterize the subarctic and is well suited for the monitoring of global climate change.
- Clean and protected air quality preserving internationally significant viewsheds.
- A combination of management designations (original Mt. McKinley National Park, new park additions, and national preserve) with a range of mandates that provides internationally recognized opportunities for longterm studies of the relationships between human activities and subarctic ecosystems.

The following list of extrinsic stressor groups was determined to have the most potential for impacting the previously listed key park values. Detailed characterizations for each of these stressors has been done. For the level of this discussion of the conceptual design, the general ecological consequences of these stressors are considered to be the same whether they occur inside or outside the park boundaries, so no distinction is made in this list. Some lumping of several distinct and familiar stressors has been done because they cause also have similar ecological consequences. For example, trapping and hunting may differ in some specifics, but they both have the general consequence of animal removal from the system and the potential attributes that would eventually be measured, such as population size, are similar. Protocols to monitor certain components of each of these stressor groups will be developed.

- Animal harvest
- Plant Harvest
- Mineral Extraction (Placer Mining, Upland Mining, Oil/Gas Extraction)
- Settlement
- Agricultural Development
- Regional Industrialization
- Global Development
- Access and Utility Corridor Development
- Access Activities (Motorized)
- Access Activities (Non-Motorized)

3.4.3 Ecological Consequences of Extrinsic Stress

During a conceptual design workshop in October of 1996, the list of extrinsic stressors for Denali was combined with the known information, as understood by work shop participants, on the subarctic ecosystem of Denali (e.g. the ecological model previously described).

Work shop participants then generated a list of ecological consequences which occur at several scales. There is a great deal of overlap between the lists for the different stressors. This information was consolidated into the monitoring concerns that are probably the most relevant to the Denali Ecosystem. These results are shown in Table 1 and in the text below. Specific consequences can be traced back to specific extrinsic stressors through summaries developed from the workshop material. The condensed lists presented in this document represent potential monitoring topics because they are the areas where it is thought that change is most likely to occur as a result of the current and projected extrinsic stress to the Denali Ecosystem. Therefore, monitoring resource attributes that will detect these kinds of changes should be the primary objective of the monitoring protocols.

An iterative process exists for further refinement of these basic topics into attributes and, eventually, actual indicators. As further research and monitoring is done, the basic ecological model for the Denali Ecosystem can be more clearly defined. This clearer understanding of how system components interact will then provide a better understanding of how and where extrinsic stressors will alter the system and the consequences they will produce. This in turn makes it possible to focus monitoring more accurately on the more responsive and sensitive components or processes of the system, making the identification of indicators possible.

As a consequence, the following lists should be viewed as starting points from which further refinements will be made as the program progresses. Much of this refinement will be done through a workgroup process.

Ecological Consequences of Extrinsic Stress by Organizational Level/Scale

The organizational levels used here generally correspond to those described in Noss (1991) with some modifications to better accommodate abiotic features of the ecosystem. The intent is to convey a feeling of both spatial scale and organizational complexity. As with most categorizations of a continuum, some overlap between levels is unavoidable. The objective is to provide a basic framework that can then be used to help illustrate the different levels of complexity and hierarchy in the ecosystem.

- Level I - Multiple Large Watersheds/ Regional Landscape

This level corresponds to Denali NP & P and its surrounding up to a size of 10^7 km^2. It includes multiple large watershed, several different geological terranes or formations, different meteorological regimes, and vegetation that ranges from alpine tundra to lowland lakes and wetlands. The objective of monitoring is to understand how communities, watersheds, and other groupings that represent the integration of biotic and abiotic factors are interacting with one another to create landscape scale properties.

- Level II - Ecosystem/Watershed/Community

These are subunits of Level I that define an area of more consistency in terms of major vegetation associations or geophysical variables. Multiple branches are present in the watershed, but the geology and meteorological characteristics are more uniform for this size basin than in Level I. Vegetation can begin to be seen as consistent groupings at the level of conventional aerial photography. Monitoring is trying to measure how the abiotic and biotic components of an area such as a watershed or within a community type are organized and function together.

- Level III - Populations/Species

Monitoring at this level would be targeted at the components that make up Level II. "Species" and "Population" is used in a broad sense to include a similar taxonomic concept and level for abiotic resources. Types of rocks, soils, streams, or lakes, etc. are all levels in abiotic classification systems that could be grouped together to form the next higher level in our hierarchy (Level II). Attributes such as distribution, quantity in a spatial unit, connectivity, etc. all can be used to describe the composition, structure, and function of an individual population or a metapopulation of either biotic and abiotic "species". These attributes would be the objective of monitoring at this level.

- Level IV - Genetic/Chemical

This level is primarily reserved for the properties of the species or population. Chemical or molecular properties of abiotic components would be considered in this level.

Ecological Consequences - Condensed List

The following list consolidates the material presented in Table 1 into recurring themes.

- Habitat Fragmentation and Loss
- Alterations to Native Species Composition or Distribution
- Alterations to Native Species Population Dynamics
- Containment Increases in Atmospheric, Terrestrial, and Aquatic Systems
- Introduction of Exotic Species to Terrestrial and Aquatic Systems
- Disruption of Natural Fire Regime
- Alterations to Hydrologic Structure and Processes
- Alterations to Soil Structure and Processes
- Disruption of Nutrient Cycling and Primary Productivity
- Disruption of Ecosystem Variation (Cyclic, Stochastic, Succesional Trajectory)
- Alteration of Global Climate with Cascading Effects to Local and Regional Meteorology

The topics outlined above will be one of the three primary criteria used to select the resource areas where monitoring is needed and where protocols will be developed as part of the monitoring program. The relationship between these themes and the protocols that are proposed for development is presented in Table 2.

This portion of the LTEM program that is specifically monitoring the predicted consequences of extrinsic stress will be integrated with existing long term monitoring such as population surveys, habitat studies, and contaminant tracking programs that is currently supported by ONPS park base funds. These existing long term efforts will continue to be supported by the park, but will be augmented by the consistency and stability of the LTEM program funding to form a comprehensive program.

3.5 Natural Resources Selected for Protocol Development

3.5.1 Protocol Selection

The concept of selecting only a few resources for monitoring as indicators of the status and trend in the larger system has been criticized a great deal by scientists (Landres et al. 1988; Morrison and Marcot 1995). Unfortunately, the reality of trying to implement a long term program is that only a small subset of the resources of the system can be practically measured. The selection of these indicators is a critical process, but the strategies and processes for selecting them is complex and needs additional study (Barber et al. 1994). The following section presents the rational used to select the resource areas where protocol development is needed for the Denali program.

The natural resource areas where protocols for monitoring are needed are shown in Table 2 and further described in Table 3. These resources were selected for monitoring and protocol development based on the general criteria of a relationship to extrinsic stressors, a contribution to understanding intrinsic influences in the ecosystem, and importance to national and international monitoring efforts. The criteria used are related back to basic program objectives and are derived from available literature on indicator selection. Further justifications based on these criteria are provided in Table 3 for each selected protocol.

Response to Extrinsic Stress

The list of ecological consequences of extrinsic stress just discussed is the primary tool for selecting the resource areas where protocol development is needed. The relationship between this list of ecological consequences and the natural resources selected for protocol development are shown in Table 2. For example, habitat fragmentation, changes in fire regime, or changes in successional patterns appear on the ecological consequences list. It is clear that monitoring these consequences requires the measurement of certain attributes of terrestrial vegetation at a variety of scales, and so this resource area has been selected for protocol development. Once a general list was developed using this logic, additional criteria were applied.

Based on our current knowledge of the Denali ecosystem, the resources that were thought to be the most likely to be affected by extrinsic stress, those most responsive to the presence of stress, or possibly the most measurable were selected. These additional criteria roughly correspond to those used for indicator selection in the EMAP program (Barber et al. 1994). As a result, in some areas where our knowledge of the ecosystem is more complete, individual species, groups of species, or particular abiotic elements such as riverine or lacustrine systems are identified. In other areas such as terrestrial invertebrates which are clearly important, but where little knowledge is available at this time, only a more general recommendation has been made. Monitoring data and consultation with experts through workgroups will provide more specific direction in the future.

These criteria are related to the first major program objective: Improve management decision-making on park resource preservation concerns that are primarily local and regional in nature.

Provide Information on Important Intrinsic Characteristics of the Ecosystem Model

Information about the intrinsic characteristics of the system must also be gathered in order to establish cause and effect relationships and to improve the ecological model for the subarctic. Much of this information can be captured through the protocols that will be used to monitor the topics shown on the list of ecological consequences. For example, characteristics of ecosystem variation such as cycles, stochastic events, or succession will be regularly incorporated in the sampling design for protocols on certain species, abiotic resources, or intrinsic stressors. Where these intrinsic characteristics cannot be clearly accommodated, additional protocols such as meteorological monitoring have been added. The type of measurements that will be made for an intrinsic stressor like meteorology will parallel those made for extrinsic stressors (i.e. frequency of certain events, magnitude, duration, etc.) that are described below.

This criteria is most closely associated with the second program objective: Provide a source of information for others working on ecosystem related studies in the subarctic, and contributes to a better understanding for achieving objective one.

Contribution to National and International Programs

As a site representative of the subarctic, Denali presents a special opportunity for making contributions to national and international monitoring networks. Some resource groups such as passerines, which might not necessarily be selected for monitoring based on the presence of local threats, have been selected because the LTEM program can assist in providing information that may eventually help national or international efforts to protect these species or their habitats in other regions where human development is causing more significant stress. Similarly, glacier monitoring is included because of a similar contribution to broad studies of climate change and landscape processes.

This criteria is associated with the third program objective: Enhance national and international monitoring networks by representing a naturally functioning and intact subarctic site.

Resources not Selected for Protocol Development

While the list of resource areas that are proposed for protocol development is long, it does represent the first major step toward focusing on critical ecosystem components. Many components or processes were not included. For example, species such as shorebirds or waterfowl will only be monitored incidentally during other activities such as Breeding Bird Surveys or Point Counts as opposed to having a specific protocol developed for them because monitoring by other agencies at other locations of higher concentrations is more efficient. Due to the difficulty of monitoring, other avian groups such as owls were rejected. Many other mammals and most fish species have also been eliminated. Additional filtering will occur in some of the broader resource areas as they are assessed through further research.

3.6 Attribute and Indicator Selection for Natural Resource Monitoring Protocols

Measurements of the resources or stressors that have been chosen for monitoring must be made. Certain attributes (any abiotic or biotic feature that can be measured) of these resources and stessors must be selected. Any of these attributes which are assumed to be indicative of the quality, health or integrity of the larger system to which they belong

Until further refinements can be made in the ecological model, monitoring will still have to follow the broadbased approach outlined in Table 2. As more information is gained, it may be possible to focus more on one protocol area and drop back on others as well as refine the number of specific attributes that are monitored within a protocol. The monitoring information from the program in the immediate future will probably be more useful initially for characterizing the ecosystem than it will be for determining cause and effects from anthropogenic stress. This is a reasonable approach because at this time the Denali Ecosystem is felt to be relatively free of extrinsic stress at a level that has significantly shifted the system. Therefore, any information collected now will provide a picture of the natural unstressed composition, structure, and function of the system and provide an important baseline for park management and scientific research in the future.

Work will continue on the selection of specific attributes that will be measured under each of the general protocol topic areas. Attribute lists will be developed in a format similar to the more detailed ecological consequences list that is organized by spatial scale presented in Table 1. Development of this type of chart will be a primary objective of the workgroups discussed further on in this document.

Significant statistical questions related to indicator selection and estimation still exist and will also be addressed by the workgroups. Accuracy and precision of indicator estimation as well as power to detect change must be incorporated into the monitoring design. These concerns will determine many aspects of spatial and temporal sampling design.

3.7 Extrinsic Stressor Selected for Monitoring Protocol Development

3.7.1 Protocol Selection

A critical component of a cause and effect model is the quantification of the extrinsic stressor itself (i.e. stimulus). Protocols to guide the monitoring of the extrinsic stressors previously discussed in Section 3.4.2 will be developed. Much of this protocol development and implementation of extrinsic stressor monitoring is being done as a part of ongoing tactical monitoring that is strongly supported by the park base budget. LTEM funding will be used to augment, not replace, these ongoing efforts and to provide a conceptual framework that will foster a comprehensive and well organized effort.

3.8 Attribute Selection for Extrinsic Stressor Monitoring Protocols

The following attributes of disturbance processes will be used to quantify stressors (White and Pickett 1985).

- Frequency (# of occurrences per unit time)
- Extent (area over which the event occurs)
- Magnitude:
  - Intensity (degree of effect on the system)
  - Duration (length of stressor event)
- Selectivity (portion of the system which is affected)
- Variability (probability distribution for each of the above)

3.9 Thresholds

Management response threshold values must be set for those attributes which are considered to be actual indicators. This will be a difficult step due to the limited understanding of subarctic ecosystems at this time. Available research and expert opinions are being used to give an initial "best guess" for these trigger points. Areas where information is lacking are being identified. This will be a primary task of the workgroups that are proposed. Further refinements of these thresholds will also be possible in the future as monitoring and well focused research data begin to improve our understanding of the variability of important components, structures, and processes in the ecological model for the Denali system.

3.10 Sampling Design

The protocols that have been listed will identify specify sampling procedures at a variety of scales for the attributes that have been selected for monitoring, but there must be a basic sampling design that unifies these protocol specific activities in order to develop a truly interdisciplinary program. A basic design serves as the integrator for the different monitoring activities and facilitates the eventual synthesis of information from various topics that must be done to accomplish program goals. The ability to work with information from various parts of the program is critical for any eventual analysis for cause and effect. It is also essential that the overall design has the flexibility to allow adaptation and growth to deal with new concerns. The variety of stressor concerns and habitats as well as the potential for change at Denali make this even more essential.

While not all attributes for monitoring have been identified, a clear pattern of the types of attributes has emerged as a result of the work to date. The LTEM program will monitor composition, structure, and function of the Denali Ecosystem at a variety of spatial and organizational levels. An important objective of using this matrix approach is to develop a conceptual framework which will help join short term, issue based, intensive studies which often occur in a local area with the broader perspective and larger scales found in regional or national interests.

Enough is known now to outline a basic sampling design for the program that is likely to accommodate the array of attributes that will be identified as useful for long term monitoring. This sampling design for the Denali LTEM program will be to generally proceed from the top down, beginning with a coarse-scale characterization of structure/composition attributes such as landscape pattern, vegetation types , habitat types, geophysical features, species distribution, etc. as well as functional attributes such as disturbance processes, geomorphic processes, hydrologic processes, energy flow rates, etc.. This basic information is necessary to stratify the large Denali landscape into cohesive subunits. It will also provide a base layer of information that can be overlaid with data on stressors to identify biologically significant areas at high risk to future change. Intensive research and monitoring can then be directed toward high risk areas as well as to representative sites within the stratified subunits. At the same time, less intensive monitoring can continue to characterize the changes at higher levels in the overall system and provide a means of extrapolating the results from intensive sites. A strong initial focus on the Regional Landscape and Community/Ecosystem levels is reflected in the proposed phasing of the program. This work in the early phase of the program will also provide an evaluative context for the significant amount of intensive data from many projects that have occurred over several years at the species/population level.

This design fits well with the interest to develop a linkage to the National Framework for Environmental Monitoring and Research recently developed by the Environmental Monitoring Team Committee on the Environment and Natural Resources of the National Science and Technology Council in its basic design. It also is consistent with current efforts by Environmental Protection Administration (EPA) to revise the Environmental Monitoring Assessment Program (EMAP) and to incorporate national park areas as intensive monitoring sites via the Demonstration Intensive Sites Project (DISPRO). It also follows general recommendations for Biosphere Reserves, of which Denali is one (Heal et al. 1992).

The types of sampling within these frameworks are divided into two general classes. "Extensive" sampling will be used to characterize the properties of large landscapes for the validation of large scale landscape models. Typically increasing spatial representation will be achieved through large numbers of sampling sites, but with fewer parameters sampled at any given site at lower frequency. "Intensive" sampling will focus on the properties and processes of specific locations. A smaller number of locations are used, but a greater number of parameters are sampled with a higher frequency to generate new understanding of ecosystem processes that may lead to the development of entirely new ecosystem models.. These sites will be used to integrate the effects of multiple processes and for understanding the causes of changes detected in the network of extensive sites.

Monitoring at Denali will require sampling at both these levels to develop a data base that is responsive to both local park management concerns and more basic scientific research questions. Some intensive site specific information will be required to monitor local park issues or to understand ecological processes, but it is imperative that information at this scale is gathered in a way that allows its integration with more broad scale, extensive sampling data so that issues at the landscape, regional, or global level can also be addressed or that statistically sound extrapolation of the results from intensive sites can occur.

There are many accepted techniques for sampling design and parameter measurement at the intensive level, but the integration of this information over a larger area or the development of larger scale sampling designs and methods to address landscape, regional, or global issues is relatively new. Merging these different scales, which can often have very different objectives, is a substantial challenge for long-term monitoring programs in national parks and is a particular problem in large, remote parks such as Denali. Research activities should be directed at this topic.

Therefore, a fundamental premise underlying the framework of the program is that no single sampling method, such as just an intensive watershed approach, can provide all of the information needed to evaluate conditions and guide management decisions. A conceptual framework that effectively evaluates variations in ecosystem composition, structure, function in the multiple scales that are inherent in a large ecosystem such as Denali demands the use of a combination of approaches.

3.10.1 Extensive Sampling Methods

Extensive sampling methods will be used to detect status and trends at a large spatial and temporal scale and to better understand processes that occur over large areas. Large scale changes can be detected using these approaches, but they generally cannot indicate why a specific change has occurred.

Spatially Continuos Surveys and Monitoring

Remote Sensing

Remote sensing data will be used to survey specific properties simultaneously and uniformly across the entire park area or regions surrounding the park. Large scale or longterm changes in plant phenology, snow melt pattern, freeze/thaw timing, glacial conditions, or plant succession are possible important applications. It is also an important tool for developing the information base needed for sub-sampling and stratification.

Complete Park Aerial Surveys

Complete surveys will be necessary for some wide ranging wildlife species that have distribution patterns which do not work well for sub-sampling. Periodic complete censuses will also be necessary to validate sub-sampling designs.

Spatially Sub-sampled Surveys and Monitoring

In some cases it will be possible to characterize a widely distributed resource or a region by sub-sampling. Also resources or issues that need to be understood may exist in just a portion of a larger area such as the entire park, but there is still a need to relate the information about this subarea back to the context of the entire area. Level III techniques would not be applicable because the subarea in question is still to large for their use. Subsampling will also be extremely useful for the continued development of basic inventories in areas such as the new park and preserve additions where flora and fauna information is still lacking.

Stratification

Generalized stratifications will be developed and used whenever possible for subsampling. It is recognized that all levels of this stratification will not be useful for all studies, but still some integration of information can be achieved if even the most basic levels are used. For this reason, strong emphasis will be placed on the development of this stratification in the first phase of the program.

The primary stratifications will be based on atmospheric, geochemical, and hydrologic properties that have strong influences over ecosystem process. This will form a foundation for all subsequent stratification that may diverge to deal with specific resources or issues. Zones will be developed that reflect large scale climate differences, prevailing weather patterns, distinct precipitation and temperature differences, base geology, geomorphology, hydrologic properties, elevation, slope, and aspect, etc.. Large watersheds that characterize these zones will be identified. These will be further divided into smaller representative watersheds where Level III techniques can be effectively used. Secondary stratification for vegetation or other factors that would help in the distribution of sampling sites for specific questions, would tier off this primary stratification.

While a basic stratification can be done at this time, continued inventories will be needed to improve it. Many regions of the park and the distribution of many park resources are not well understood. Inventory activities and the development of efficient inventory techniques will continue to be a major direction for the program in the foreseeable future. Continued, and if possible, accelerated support from national inventory programs will be required to supplement the LTEM program funding.

3.10.2 Intensive Sampling Methods

Intensive Watersheds

Watersheds will be the focus for process oriented studies and the sites for many of the intensive measurements needed to develop an initial understanding of the interrelationships between system components at the species/ population or community/ecosystem level They will contain more plots at a finer scale. Another level of stratification will generally occur within the watershed to insure that sites selected are representative in that spatial context. This finer stratification will be an outgrowth of the primary level of stratification that was done at the landscape level so that sampling within the watershed can be related to sites outside the watershed. Co-location of plots will be emphasized within watersheds as well. Whenever possible, a set of plots from any long term studies will be included in watersheds.

A primary objective of sample site selection will be to characterize the main sources of variation. Three types of sites are recommended for this (Heal et al. 1992).

- Community focus: Selection of "typical" sites that will allow extrapolation to the wider area of the landscape. These sites are more stable then transition zones and therefore the signal of change will be large relative to the noise cause by environmental fluctuations.
- Ecotone focus: The transition zone between communities is particularly sensitive to environmental change, including land use. Selection of such sites should allow early detection of change but the signal may be obscured by considerable noise.
- Gradient focus: Selection of sites along environmental gradients is designed to capture the variability of communities and can integrate both the Community and Ecotone approaches.

Watersheds have been the primary focus of the LTEM program to date. They do provide a logical sampling "container" for understanding many ecological processes such as primary productivity, decomposition rates, soil/water relationships, vegetation succession, etc. , but they are only one approach of many that will be used in the future. Watersheds alone are not an adequate sampling design method for addressing the many concerns that are found at Denali or any other national park. Many other organisms, processes, and issues have very site specific needs or a degree of variability that can never be characterized by the few intensive watersheds that could be logistically supported within a large park. Many organisms are to wide ranging to be sampled effectively in a few watersheds. Other ways of distributing and grouping sampling must be incorporated into the sampling design to provide a data base that is truly responsive to management needs.

It is still projected that at least five watersheds will be needed to characterize the meteorological geochemical, and hydrologic variability of the Denali Ecosystem, four areas on the north side of the Alaska Range and one on the south side. These will be placed relative to a stratification of the park based primarily on meteorological, geological, and hydrological variables.

Genetic Monitoring

It is difficult to generalize for sampling at this level. Many characteristics and habits of the species must be considered on a case by case basis. Very specific monitoring questions must be developed. All sampling designs at this level will have to be carefully developed so that they can be incorporated with designs from the other levels.

3.10.3 Data Integration Methods

Sampling Linked via Principles of Probability Theory

Intensive, fine scale sampling linked via the principles of probability theory with more extensive, less detailed sampling provides a means to address site specific issues, but still integrate the information from intensive sites such as watersheds into larger scale studies.

Unbiased plot selection using random sampling, stratified random sampling, and systematic sampling will be used to extrapolate information from plots to landscapes and from landscapes to regions and beyond. These probability theory based techniques are regularly used in plot and stand level studies, but also will be incorporated into any system that selects sampling locations across a large landscape like Denali.

Nested Plot Design

The use of nested intensive and extensive plots also provides a way to insure adequate spatial and temporal replication. Extensive plots will contain a subset of the parameters and sampling frequencies that are being collected at the intensive sites. Extrapolation of information from the intensive plots is then possible with a calculable level of statistical confidence if the distribution of the sample points has been based on principles of probability theory. Many of the intensive plots will be located within watersheds which will facilitate a further level of integration by co-location.

Co-location of Plots

This approach will be used to further enhance transferability between the different scales in a study topic and to create linkages between different study topics. Of the many plots that will be distributed over a landscape for a particular study, some of those plots will be co-located with other intensive study sites or plots. Plots of the same study topic, but with slightly different objectives, could be co-located. Conversely the co-located plots could represent completely different disciplines, i.e. bird monitoring plots adjacent to vegetation plots. Whenever it is logistically possible, plots within watersheds will be co-located because of the additional benefits that are possible.

Non Randomly Selected Sample Points

Often, sample plots for studies designed to address specific management issues cannot be placed in a non random manner, yet information from these locations would contribute to other studies or benefit from other studies. Integration of information can be accomplished if some standard data are collected or these non random sites are linked into the stratification process that has been used to select other study sites.

Site specific management issues, experimental work, or retrospective studies such as fire history are frequently tied to non-randomly selected sites. A standardized set of field data will be collected for all sites that might include such things as vegetation type using the Viereck classification system, depth to permafrost, soil type, etc.. This information would be collected at all past and future long-term sites.

Further connections will be made using an overall stratification in a GIS format that will provide a context for viewing a study sites relationship to other sampling. At least a rudimentary context for past and future sample points could be developed using GIS analysis methods regardless of the how their locations were selected.

4. Protocol Development

4.1 Protocol Status - Existing Protocols and New Protocols Needed

Sufficient progress has been made in program design to generate a list of anticipated protocols. This list is displayed in Table 3. This list may be refined via the workshop process explained elsewhere in this document. New protocols will be developed as funds and time allows.

Several of the protocols listed in Table 3 currently exist as a result of the LTEM program or other monitoring efforts. Specific attributes at a variety of spatial scales have already been selected. These protocols are ready for implementation. This provides the opportunity for the program to progress on parallel tracks, implementation and continued protocol development. The implementation of existing protocols will begin building databases while at the same time research and the workgroup process can identify the attributes for the remaining new protocols.

An evaluation of these existing protocols relative to the selection criteria previously discussed was conducted to insure that they fit with the new direction of the program. The existing protocols do correspond well to many of these focuses, but some changes can be made that would improve their integration with other aspects of the program. It is appropriate to continue to implement these protocols as they are written, but several modifications to them are now recommended as a result of this review and these are discussed below.

5. Protocol Implementation

5.1 Introduction

As protocols are developed, they must be consistently implemented for the long term in order to realize the benefits of monitoring. The following strategies will be used to implement the conceptual design. Further refinement or additions to these general strategies are expected, and will made during the preparation of a separate Implementation Strategic Plan for the program once a final funding level has been established. These strategies in combination with the material presented in the previous sections on program design and protocol development generate the many specific actions that are the foundation of the revised budget proposal associated with this document.

5.2 Strategies for Implementation

5.2.1 Phased Approached

The following actions will shift the program focus from protocol development into protocol implementation and from one small watershed into multiple watersheds. Three phases will be used to complete this transition.

- Phase I
    - Complete transition of program funding from USGS-BRD to NPS
    - Complete conceptual design
    - Begin development of additional protocols
    - Develop key information, staffing, and infrastructure needed to expand program to additional watersheds and a landscape scale

- Phase II
    - Continue protocol development
    - Implement new protocols which have been completed
    - Expand program to landscape scale by the addition of two additional watersheds on North Side during this period and the development of a program of remote sensing and other extensive monitoring approaches
    - Add necessary staffing and infrastructure to support data synthesis and full reporting on the program

- Phase III
    - Complete new protocol development

- Implement remaining protocols that have been developed
- Expand to two remaining watersheds
- Add remain staff to facilitate integration, synthesis, and review.
- Produce synthesis products and conduct programmatic review.

5.2.2 Scientific Guidance

Continued scientific guidance will be critical for program success. Several workgroups are proposed to facilitate this. Activities in early phases of program will center around the conceptual design work. Then emphasis will shift to review and synthesis of databases as they become available and modifications to protocols as become necessary

Work Groups

Many new protocols are needed. It is also clear now, based on the experiences of other programs such as Channel Island National Park, that revisions to current protocols and the program design will be required as situations and resources change. Many other decisions on the conceptual design or implementation of the program will require the advice of topic area experts. Because of the importance of this continued connection with the scientific community, the Denali program will incorporate as an integral part of both program design and long term implementation a series of standing work groups to address these current and future needs. These groups will be composed of representatives from Denali staff, other land management or research agencies, and academic institutions.

The following list of general tasks will guide the activities of the groups.

- Provide an evaluation of currently available data sets from all monitoring activities at Denali for possible use as part of the LTEM program. Describe needs for data management, analysis, and synthesis of those data sets.
- Identify attributes and indicators
- Recommend potential methods for measuring selected attributes and indicators as well as spatial and temporal sampling designs.
- Recommend important sites or regions of the park area such as watersheds or areas of high stress for possible intensive measurement related to the primary monitoring focuses of the program.
- Recommend priorities for protocol development related to selected attributes and indicators.
- Recommend possible thresholds that will require management action.

Although the groups will be focused on specific resources and questions, strong emphasis will be placed on looking for potential linkages between the attributes selected within a group's focus area as well as looking for linkages to the potential needs of other groups for information. For example, the Vegetation Workgroup will be responsible for considering how to monitor changes in fire regime and characterize succession processes along with other topics. They would develop a monitoring approach for each of these topics at a series of spatial scales. They would then look for similar attributes to measure, ways to integrate sampling, or similar tools such as remote sensing to use. This should identify a series of attributes that have a potential to be co-located with the measurements that might be needed to characterize changes in hydrologic processes or point out remote sensing products that are a common need with another group.

This type of thinking will require close coordination and communication between groups. Some of the duties of the new staff positions that are proposed are to act as team leaders for these groups. This set of team leaders in the LTEM program and stationed at Denali will facilitate regular interaction and sharing of information between groups.

The following list outlines the workgroups that will be used. Each group will consider several of the protocol areas outlined in Table 2. It is likely that some subgroups or additional groups will need to be formed as the process evolves. Specific tasks in addition to the general tasks discussed above are shown.

Air Quality/Meteorology

- Develop integrated air quality and meteorological monitoring system that links to larger networks and provides basic information needed by other portion of monitoring program to characterize containment effects, regional weather patterns, and influence of global climate changes.

Geology/Soils

- Assemble known information and provide as basic reference for stratification and synthesis work.
- Provide a base map to be incorporated in GIS for use with stratification.

Aquatic Systems

This topic could be broken out as separate units as was done for terrestrial topics, but initially will be kept together because of the strong potential for developing an integrated program. It is likely that subgroups will develop to address topics such as physical hydrology, riverine system, lacustrine systems, aquatic biota, etc..

Terrestrial Vegetation

- Develop list of important species or communities for monitoring.

- Develop a multiscale, integrated monitoring effort that tracks habitat fragmentation, fire regime changes, primary succession changes, the consequences of insect and disease out breaks, and status of exotics.
- Develop a plan for completing park flora in a manner that a statistical confidence level can be assigned to the product.

Terrestrial Vertebrates

- Refine proposed list of important species or guilds for monitoring.
- Develop multiscale monitoring plans for each species.
- Develop research questions to help elucidate species/habitat and predator/prey relationships so that cause and effect relationships to anthropogenic stressors can be more accurately discerned.
- Outline process for completion of faunal inventory, including tracking of exotics.

Terrestrial Invertebrates

- Broken out as separate workgroup due to complexity and specialization of topic as well as major lack of current information.
- Develop list of important species or guilds for monitoring.
- Develop multi scale monitoring plans for each species.
- Outline program for continued inventories including tracking of exotics.

Ecological Model

- Develop better conceptual models of the Denali ecosystem to guide and document the formulation of future research and monitoring questions.
- Describe how major stressors such as contaminants are expected to impact the systems structure and function
- Establish program priorities for addressing these stressor effects.

Anthropogenic Stressor Quantification

- Prioritize current stressors
- Develop multiscale approaches to characterize these stressors using parameters previous discussed.
- Identify overlapping spatial and temporal situation between stressors and important resources that could then become sites for intensive monitoring.

Spatial Sampling Design/Data Analysis and Synthesis

- Develop statistically sound sampling design.
- Provide summary of remote sensing options.
- Layout data formats, temporal and spatial sampling, etc. to allow for the synthesis of data from different protocols.

5.2.3 Program Support

- Obtain long term funding

- Develop management, public, and scientific support for program through information transfer, education, and the availability of quality subarctic databases or collaborative studies.

5.2.4 Partnerships

Partnerships with others must be developed to accomplish research, monitoring, and education needed to implement the program for the longterm.

5.2.5 Volunteers

Developing a program where student interns and other volunteers can work with park staff will be crucial for the implementation of the program. Much of the field work in Denali will require field teams of at least two people for safety and for getting materials to remote sites. Field teams made up of a park staff member and a volunteer will be used extensively. It also provides a possible way that the program can begin to connect with local schools and provide on the job experience.

5.2.6 Infrastructure

Additional infrastructure in the form of office space and researcher housing is needed to efficiently operate the program in the future and to attract partnerships and volunteer staff.

6. Information Management and Transfer

A data management protocol for the LTEM program is near completion. It will facilitate early development of a "data dictionary" so that parameters common to several protocols will be defined and collected in a similar manner. This will greatly aid data analysis and synthesis. The protocol also establishes basic QA and QC standards and data protection procedures that will guide development of more detailed activities within the individual protocols.

The historic data from the 80 year history of research and management at Denali is viewed as an extremely important data base for the LTEM program. National Park Service Monitoring Guidelines (NPS-75) recommend the organization of this type of information as one of the first steps in the development of a monitoring program. Substantial work will be required, and is considered to be a critical activity, to bring this historic database into compliance with the Data Management Protocol.

Yearly administrative reports will be done for the program that describe the financial expenditures and a basic overview of work accomplished. As the data base designs for the various protocols stabilize and routine analysis is possible, standard yearly reporting routines for key program areas will be developed. The data analysis for these yearly reports will generally be the responsibility of the park staff member who is coordinating the implementation of the protocol. Some contracting of analysis as well as for assistance in developing reporting routines using NPS standard software may be necessary. These reports along with other databases will be publish on a sub-area of Denali's current World Wide Web site. Denali's park bibliography will be updated with information about any publications that are produced as a result of the LTEM program. Regular publication of results in professional journals will be encouraged. A yearly State of the Park Resources Report will also be prepared and made available to the public.

(More to be added in future revisions of this document)

7. Integration and Review

The workgroup process outlined in previous sections of this document will continue to provide critical review of protocol. Additional peer review will also be used as needed to ensure scientific credibility for the monitoring activities of the program. Conferences where program investigators can present findings from the program will be sponsored. A review of the entire program will be conducted at least every five years to evaluate program objectives and progress to date.

The integration and analysis of data sets from different protocols is a complex task which will likely require significant assistance from the research community. Hopefully, as the data sets from the program develop, interest in providing this kind of assistance will increase. Contract services for analysis will also be needed.

(More to be added in future revisions of this document)

Acknowledgments

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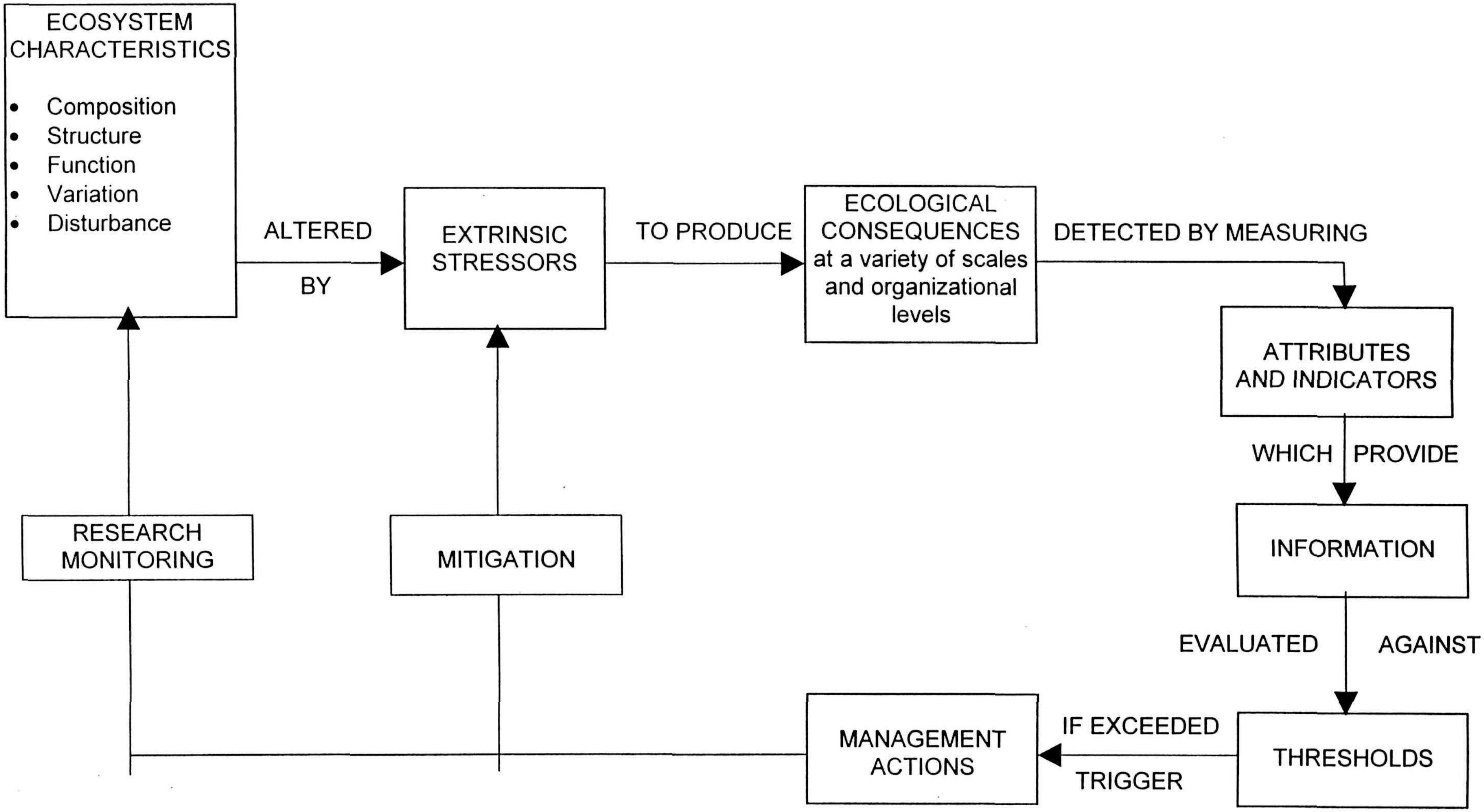
ECOSYSTEM CHARACTERISTICS
• Composition
• Structure
• Function
• Variation
• Disturbance
ALTERED BY
EXTRINSIC STRESSORS
TO PRODUCE
ECOLOGICAL CONSEQUENCES at a variety of scales and organizational levels
DETECTED BY MEASURING
ATTRIBUTES AND INDICATORS
WHICH PROVIDE
INFORMATION
EVALUATED AGAINST
THRESHOLDS
IF EXCEEDED TRIGGER
MANAGEMENT ACTIONS
RESEARCH MONITORING
MITIGATION

Figure 2

Denali National Park & Preserve

Long-term Ecological Monitoring Program

Anthropogenic Sources of Ecosystem Stress
Taken From the LTEM 1997 Workshop Notes

- ANIMAL HARVEST - HUNTING
- ANIMAL HARVEST - TRAPPING
- ANIMAL HARVEST - FISHING
- PLANT HARVEST
- TIMBER HARVEST
- MINING - PLACER
- MINING - "UPLAND" (all mining other than placer)
- OIL/GAS EXTRACTION
- REGIONAL INDUSTRIALIZATION
- AGRICULTURAL DEVELOPMENT
- REGIONAL TRANSPORTATION SYSTEMS
- REGIONAL UTILITY CORRIDORS
- PARK TRANSPORTATION SYSTEMS (physical land development ie roads, airstrips, trails, etc.)
- PARK UTILITY CORRIDORS
- PARK ACCESS (excluding physical development ie buses, trains, etc.) - MOTORIZED
- PARK ACCESS - NON-MOTORIZED
- PARK ACCESS - OVERFLIGHTS (includes military overflights)
- PARK FACILITY DEVELOPMENT (physical structures)
- SETTLEMENT (including inholdings)
- GLOBAL DEVELOPMENT
- INCOMPLETE KNOWLEDGE OF ECOSYSTEMS

Table 1. Ecological Consequences of Extrinsic Stress

Level	Structure and Composition	Function
Level I	-Uniform or regional changes in air quality parameters such as chemistry and visibility as a result of long distance transmission of statewide or international nature. -Wide spread changes in physical and chemical properties of waterbodies, particularly lakes due to atmospheric deposition changes. -Changes in landscape physiognomy -Changes in landscape geometry (disruption of "normal" patterns of connectivity and distribution of patch sizes) -Large scale shifts in frozen/nonfrozen soil zone boundaries, ecotones, typical snow/ice free elevational limits, glacial termini. -Loss of rare habitats/plant communities -Isolation of animal and plant populations -Changes in the large-scale composition and distribution of plant and animal communities	-Wide spread changes in levels of certain wavelengths of light such as UVB reaching terrestrial systems. -Wide spread changes in deposition rates of airborne contaminants. -Disruption of meteorological processes such as precipitation with cascading effects on abiotic and biotic processes -Disruptions in normal geomorphic and hydrological cycles systems -Disruption of normal landscape scale diffusion processes -Mass movements, soil erosion and soil moisture, and soil temperature changes at scales responding to and affecting landscape scale processes -Disruptions in landscape connectivity for both plants and animals -Large scale changes in yearly productivity and decomposition rates due to regional and local meteorological change brought about by climatic shifts or changes in atmospheric properties. -Interferences with large scale natural disturbance processes such as fire -Alterations of nutrient cycling and energy flow throughout entire system.
Level II	-Changes in air quality restricted to portion of park as opposed to whole landscape generally from sources adjacent to park area. -Changes in watershed geomorphology that might define	-Alterations to meteorological properties within a portion of park -Changes in glacial movement rates and ice formation rates -Changes in discharge volume and timing of large streams. -Changes in yearly freeze/thaw timing with cascading effects on

	characteristics of a community. -Changes in physical and chemical properties of waterbodies, particularly lakes due to atmospheric deposition changes in regions of park. -Soil compaction, soil structure, and moisture changes across several soil types and responding to and affecting community scale habitat requirement. -Rare habitat elements significantly impacted -Species deletions (local extinction), or elimination of similar levels of abiotic components (a rock type, soil type, stream type) from a community or ecosystem -Species additions (exotics); similar concept for corresponding taxonomic levels in abiotic resources -Changes in species abundance/distribution; similar concept for corresponding taxonomic levels in abiotic resources	hydrologic properties and biotic communities -Changes in soil processes over several soil types such as diffusion, erosion, decomposition that could control community level processes or processes of a large watershed. -Changes in frequency of soil mass movements at scales affecting community or large watershed processes. -Changes movement/dispersal/migration -Changes the dynamics of predator-prey systems -Alters the competitive equilibrium of communities -Reduces primary/secondary productivity; -Simplification of trophic structure -Changes in succesional dynamics and trajectories
Level III	-Local air quality concern resulting from pollution of limited transmission distance. -Changes in population number -Changes in population structure (e.g., sex and age ratios) -Changes in spatial distribution of individuals -Isolation of populations -Evidence of inbreeding depression -Loss of rare habitat elements	-Alterations to meteorological properties that might define the specific habitat for a species or population (micrometeorology) -Decreased connectivity among individuals within a population -Changes in demographic processes -Destabilization of predator-prey dynamics -Changes in energy flow by simplification of trophic structure -Affects to reproductive cycle of migratory species -Changes in metapopulation dynamics. -Changes in population genetics -Changes in physiology, phenology, growth rates, life history
Level IV	-Alterations to soil physical structure and chemical	-Alterations to soil processes in a soil type that could influence a

	properties within a certain soil type. -Alterations to physical structure and chemical properties of a certain type of stream or lake.-Increased rates of deformities -Changes in gene frequencies changes in the distribution of genotypes -Loss/gain of genetic variability -Declines in effective population size	small stream or define the habitat requirements of a species, -Alterations to physical or chemical processes which control a waterbody type, or stream reach or the habitat of a species or population, but not a community of species. -Alters gene flow via barriers to dispersal and migration -Isolates populations increasing the risk of genetic drift and fixation of deleterious alleles -Generates spatial structure which may increase/decrease genetic variability

Table 2. Primary Focus of Protocols

PROTOCOL DEVELOPMENT TOPICS	PRIMARY FOCUS OF PROTOCOLS: Habitat Fragmentation and Loss	Alteration to Natural Species Composition or Distribution	Alterations to Natural Species Population Dynamics	Contaminant Increases in Atmospheric, Terrestrial, and Aquatic Systems	Exotic Species Introductions to Aquatic and Terrestrial Systems	Disruption of Natural Fire Regime	Alterations to Hydrologic Structure and Processes	Alterations to Soil Structure and Processes	Disruptions of Nutrient Cycling and Primary Productivity	Disruption of Ecosystem Variation (Cyclic, Stochastic, Succesional Trajectory)	Alterations of Global Climate With Cascading Local and Regional Effects	DEVELOPMENT STATUS
Air/Meteorology												
Air Quality				x						x	x	Protocol exists
Meteorology										x	x	Protocol exists
Geophysical												
Glaciers							x			x	x	Protocol exists
Seismic										x		Protocol exists
Mass Movements								x		x		Methods exist, protocol needed
Soils												
Soil Processes				x				x			x	Protocol exists
Aquatic Systems												
Abiotic												
Water Quality				x			x		x	x	x	Protocol exists
Morphometry							x			x	x	Protocol exists

Table 2. Primary Focus of Protocols

PROTOCOL DEVELOPMENT TOPICS	PRIMARY FOCUS OF PROTOCOLS: Habitat Fragmentation and Loss	Alteration to Natural Species Composition or Distribution	Alterations to Natural Species Population Dynamics	Contaminant Increases in Atmospheric, Terrestrial, and Aquatic Systems	Exotic Species Introductions to Aquatic and Terrestrial Systems	Disruption of Natural Fire Regime	Alterations to Hydrologic Structure and Processes	Alterations to Soil Structure and Processes	Disruptions of Nutrient Cycling and Primary Productivity	Disruption of Ecosystem Variation (Cyclic, Stochastic, Successional Trajectory)	Alterations of Global Climate With Cascading Local and Regional Effects	DEVELOPMENT STATUS
Biotic												
Vegetation - General		x	x	x	x				x	x		Protocol exists
Fisheries												
Salmon		x	x	x						x		Methods exist, protocol needed
Grayling		x	x	x						x		Methods exist, protocol needed
Invertebrates		x	x	x	x				x	x		Protocol exists
Microbiology		x	x	x	x					x		Methods exist, protocol needed
Terrestrial Vegetation												
Vegetation - General	x	x	x	x	x	x			x	x	x	Protocol exists
Vegetation - Fire Focus		x	x			x			x	x		Methods exist, protocol needed
Moss/Lichen				x					x			New research needed
Fungi								x				New research needed

Table 2. Primary Focus of Protocols

PROTOCOL DEVELOPMENT TOPICS	Habitat Fragmentation and Loss	Alteration to Natural Species Composition or Distribution	Alterations to Natural Species Population Dynamics	Contaminant Increases in Atmospheric, Terrestrial, and Aquatic Systems	Exotic Species Introductions to Aquatic and Terrestrial Systems	Disruption of Natural Fire Regime	Alterations to Hydrologic Structure and Processes	Alterations to Soil Structure and Processes	Disruptions of Nutrient Cycling and Primary Productivity	Disruption of Ecosystem Variation (Cyclic, Stochastic, Succesional Trajectory)	Alterations of Global Climate With Cascading Local and Regional Effects	DEVELOPMENT STATUS
Terrestrial Fauna												
Mammals												
Large Carnivores												
Bears		x	x							x		New research needed
Wolves		x	x							x		Methods exist, protocol needed
Ungulates												
Caribou		x	x							x		Methods exist, protocol needed
Moose		x	x							x		Methods exist, protocol needed
Dall Sheep		x	x							x		Methods exist, protocol needed
Furbearers												
Lynx		x	x							x		New research needed
Marten		x	x							x		New research needed
Wolverine		x	x							x		New research needed
Beaver		x	x				x			x		New research needed
Small Herbivores												New research needed
Snowshoe Hare		x	x							x		New research needed
Marmot		x	x							x		New research needed

Table 2. Primary Focus of Protocols

PROTOCOL DEVELOPMENT TOPICS	Habitat Fragmentation and Loss	Alteration to Natural Species Composition or Distribution	Alterations to Natural Species Population Dynamics	Contaminant Increases in Atmospheric, Terrestrial, and Aquatic Systems	Exotic Species Introductions to Aquatic and Terrestrial Systems	Disruption of Natural Fire Regime	Alterations to Hydrologic Structure and Processes	Alterations to Soil Structure and Processes	Disruptions of Nutrient Cycling and Primary Productivity	Disruption of Ecosystem Variation (Cyclic, Stochastic, Successional Trajectory)	Alterations of Global Climate With Cascading Local and Regional Effects	DEVELOPMENT STATUS
Ground Squirrel		x	x							x		New research needed
Red Squirrel		x	x							x		New research needed
Microtines		x	x	x						x		Protocol exists
Avian												
Raptors												
Golden Eagle		x	x							x		Methods exist, protocol needed
Gyrfalcon		x	x							x		Methods exist, protocol needed
Merlin		x	x	x						x		Methods exist, protocol needed
Goshawk		x	x							x		Methods exist, protocol needed
Shrike		x	x	x						x		New research needed
Gallinaceous												
Ptarmigan		x	x							x		New research needed
Grouse		x	x							x		New research needed
Passerines		x	x	x						x		Protocol exists
Shrike		x	x	x						x		New research needed

Table 2. Primary Focus of Protocols

PROTOCOL DEVELOPMENT TOPICS	Habitat Fragmentation and Loss	Alteration to Natural Species Composition or Distribution	Alterations to Natural Species Population Dynamics	Contaminant Increases in Atmospheric, Terrestrial, and Aquatic Systems	Exotic Species Introductions to Aquatic and Terrestrial Systems	Disruption of Natural Fire Regime	Alterations to Hydrologic Structure and Processes	Alterations to Soil Structure and Processes	Disruptions of Nutrient Cycling and Primary Productivity	Disruption of Ecosystem Variation (Cyclic, Stochastic, Succesional Trajectory)	Alterations of Global Climate With Cascading Local and Regional Effects	DEVELOPMENT STATUS
Amphibians												
Wood Frog		x	x	x						x		New research needed
Invertebrates		x	x	x			x	x		x	x	New research needed

Table 3. Protocol Justification and Status

AIR QUALITY/METEOROLOGY

PROTOCOL	JUSTIFICATION	ACTION NEEDED
Air Quality	-Primary potential source of contaminant introduction to Denali System -International influence (Arctic Haze) -Likely to change significantly as Alaska shifts from rural to more industrialized -Local issue of coal fired power plant on park boundary -Valuable data point for national/international networks -Legislative mandate (Class I area) -Changes in air quality can have major effects on park values	-Current protocol oriented toward single sampling site, protocol must be modified to address multiple, remote sites to detect suspected different pollution profiles in different regions of park. -Protocol needs to be modified to included additional parameters to detect effects of important stressors that have been identified or to link with national/international programs (UVB, visibility, long range pollutants, volcanic ash, nuclear fallout)
Meteorology	-Dominant influence on ecosystem structure, composition, and function	-Current protocol needs to be modified to measure meteorological properties at multiple spatial scales.

GEOPHYSICAL

PROTOCOL	JUSTIFICATION	ACTION NEEDED
Glaciers	-Extremely important force in subarctic system that can control landform and hydrologic regime. Glacial "surges" are typical of several major glaciers	-Current protocol needs to be modified to include the use of additional index glaciers -An "extensive" sampling component needs to be

	and occur in a relevant time scale. -Potential contribution to understanding of global climate change and local meteorological shifts.	added to the protocol which utilizes remote sensing and aerial photography to a greater extent.
Seismic	-Denali region is on tectonic plate boundary and is extremely active area of great scientific interest. -Due to great amount of seismic activity, event time scale is short enough that it is an important force in influencing landscape scale processes.	-Current protocol developed and implemented by USGS is adequate, equipment and maintenance personnel are supplied by other agencies. -Funding is needed only for yearly transportation to sites for servicing.
Mass Movements	-Steep relief, seismic activity, unstable soils, presence of frozen ground subject to thawing, and geology all combine to make mass movements occur with enough frequency and magnitude that they are major habitat, hydrologic, and park management influence.	-Current protocols are very site specific, modifications needed to provide watershed and landscape scale understanding of mass movement occurrences.
Soils	-Modifications to frozen ground through climate change or more direct human influence have potential for profound terrestrial habitat shifts and alterations to aquatic systems in the subarctic. -Long term information about shifts in other soil properties and processes are of fundamental importance to discerning cause/effect relationships for other monitoring topics at the community/watershed scale of park management.	-An "extensive" sampling component needs to be added to current protocol to provide a context for extrapolation from the very intensive, site specific data presently gathered.

AQUATIC SYSTEMS - ABIOTIC

PROTOCOL	JUSTIFICATION	ACTION NEEDED
Aquatic Systems - Morphometry and Water Quality	-Likely areas that will reflect many anthropogenic activities in terrestrial environment by changes in physical or chemical properties of the waterbody. -Potential to provide information to regional or national networks. -High bedload, glacial streams are prevalent in Denali and their large movement spatially over short time periods is major driver in habitat and successional patterns. -Denali 10,000 plus lakes and ponds are a fundamental part of ecosystem with connections to terrestrial components and processes.	-Currently only a Riverine protocol exists for measurements in a single watershed. -Protocol for Lacustrine systems needs to be added.

AQUATIC SYSTEMS - VEGETATION

PROTOCOL	JUSTIFICATION	ACTION NEEDED
Aquatic Systems - Vegetation	-Changes in composition, distribution, and primary productivity in aquatic system have been shown to provide useful indicators of anthropogenic stressors such as contaminants.	-New Protocol

AQUATIC SYSTEMS - FISH

PROTOCOL	JUSTIFICATION	ACTION NEEDED
Salmon	-Major system component that has a fundamental role in energy flow and nutrient cycling in the system. -Resource of great management concern. -Vulnerable resource to human activities such as access corridors, mineral extraction, or plant harvest that disturb aquatic systems.	-Existing methods need to be linked more closely with other aquatic monitoring in order to be able to eventually determine role of anthropogenic stressors.
Greyling	-Primary fish in much of upland regions of the park. -Has been used as an indicator of stream health and contaminant presence in areas of former mineral extraction. -Instream movements sensitive to interruption by access corridors.	-Repeated surveys of potential greyling streams have been done, but protocol needs to be refined

AQUATIC SYSTEMS - INVERTEBRATES

PROTOCOL	JUSTIFICATION	ACTION NEEDED
Aquatic Invertebrates	-Important intrinsic variable that must be quantified in order to determine if an observed change in fish populations are the result of anthropogenic stress or natural response to food resources. -Integrators of physical and chemical variables that may be changed by anthropogenic stress.	-An "extensive" sampling component needs to be added to current protocol to provide a context for extrapolation from the very intensive, site specific data presently gathered in just one small watershed. -Additional peer review needed to determine if other methods may be more appropriate and efficient for Alaskan conditions.

AQUATIC SYSTEMS - MICROBIOLOGY

PROTOCOL	JUSTIFICATION	ACTION NEEDED
Aquatic Microbiology	-Human health concerns related to pollution from many stressors	-New Protocol

TERRESTRIAL VEGETATION

PROTOCOL	JUSTIFICATION	ACTION NEEDED
Terrestrial Vegetation - General	-Fundamental component of terrestrial habitat that integrates many abiotic properties and processes. -Changes in terrestrial vegetation have cascading effects throughout entire ecosystem and landscape. -Many different vegetation variables are significantly affected by anthropogenic stressors in easily measurable ways.	-Current protocol limited in scale and scope, only really addresses growth rates and community composition change in one limited ecological context. -Scope of protocol needs to be expanded to more clearly evaluate habitat fragmentation and loss, contaminant effects, exotic introductions, global climate change, stochastic events, insect and disease outbreaks, exotics, and primary productivity. -Protocol must be altered to ensure a multiscale approach and to reflect variables important to other monitoring attributes (i.e. forage species for wildlife).
Terrestrial Vegetation - Fire Focus	-Fundamental ecological process in subarctic systems that controls vegetative habitat patterns.	-Current protocols only track fire occurrence, size, duration, etc. -Protocol must be modified to measure intensity and then linked to meteorology to understand the relationship between this factor and the others

		currently being monitored. -Better link to vegetation protocol must be developed to aid in understanding succession and landscape scale habitat patterns.
Mosses/Lichens	-Fundamental component of habitat in the subarctic -Lichens are a critical food item for caribou, another major component of park fauna. -Mosses/Lichens have been used successfully to measure contaminant increases	-new protocol needed that addresses containment concentration in these groups specifically in addition to their coverage in the general vegetation protocol.
Fungi	-Fungal associations with plants are known to play a critical role in primary succession of important species in newly disturbance prone habitats of subarctic. -Soil fungus can be used to monitor changes in soil processes that may be altered due to changes in temperature or moisture.	-New protocol

TERRESTRIAL MAMMALS - LARGE CARNIVORES

PROTOCOL	JUSTIFICATION	ACTION NEEDED
Bears	-Fundamental component of system -Known to be sensitive to habitat fragmentation -Low reproductive potential -High potential for conflict with human activities -Naturally regulated at this time (only population in subarctic), but subject to harvest in and adjacent to	-New protocol

	park so situation could easily change.	
Wolves	-Fundamental component of system -Management of species is extremely controversial and decision makers need excellent information on status and trend. -Naturally regulated at this time (only population in subarctic), but subject to harvest in and adjacent to park so situation could easily change.	-At implementation, but existing methods could be more clearly linked to other monitoring efforts.

TERRESTIAL MAMMALS - UNGULATES

PROTOCOL	JUSTIFICATION	ACTION NEEDED
Caribou	-Fundamental component of system -Only naturally regulated population in Alaska so its population dynamics of great scientific interest. -Consistent pressure to resume harvest on herd means managers must have excellent information to evaluate this.	-At implementation, but existing methods could be more clearly linked to other monitoring efforts.
Moose	-Fundamental component of system -Only naturally regulated population in Alaska so its population dynamics of great scientific interest. -Harvest levels adjacent to park have potential to be higher then at present.	-Methods are in use at this time in Denali and throughout Alaska, but additional research is needed to improve the accuracy and efficiency.
Dall Sheep	-Fundamental component of system	-Methods are in use at this time in Denali and

	-Only naturally regulated population in Alaska so its population dynamics of great scientific interest. -Harvest levels adjacent to park have potential to be higher then at present.	throughout Alaska, but additional research is needed to improve the accuracy and efficiency.

TERRESTRIAL MAMMALS - FURBEARERS

PROTOCOL	JUSTIFICATION	ACTION NEEDED
Marten, Lynx, Woverine	-Subject to harvest from trapping in and around park. -Marten is heavily harvested, the mainstay of trapping industry. -Lynx is highly cyclic and overharvest at inappropriate times is of extreme concern. -Wolverine is very low density predator with many similar sensitivities to those discussed for bears.	-New Protocol -Work cooperatively with other federal and State of Alaska agencies to develop sound monitoring methods for these harvested species.
Beaver	-Important role in creation and modification of aquatic habitat. -Important food item in the lake and wetlands of nearly a quarter of the Park for predators such as wolves. -Primary species targeted for trapping.	-New Protocol

TERRESTRIAL MAMMALS - SMALL HERBIVORES

PROTOCOL	JUSTIFICATION	ACTION NEEDED
Small Herbivore (Rodents) Snowshoe Hare, Arctic Ground Squirrel, Red Squirrel, Marmot	-Species are fundamental food items for terrestrial and avian predators. -Hares are known to be extremely cyclic which controls population dynamics of other species, therefore imperative to track these cycles. -Little is known about Ground Squirrel, Red Squirrel, or Marmot population dynamics even though they play an important role in the nutrition of other species. Some initial monitoring is necessary to evaluate their importance as potential indicators.	-Recent research has called into question existing protocols for both Hares and Ground Squirrels, new work is needed. -New protocol needed for Red Squirrel and Marmot.

TERRESTRIAL MAMMALS - MICROTINES

PROTOCOL	JUSTIFICATION	ACTION NEEDED
Voles and Lemmings	-Highly cyclic primary food source for smaller terrestrial and avian predators that strongly controls population dynamics of those species.	-Protocol for intensive monitoring of a single species in a single watershed exists, but it needs to be linked with an extensive sampling design to give a better representation of population dynamics at larger scales.

AVIAN SPECIES - RAPTORS

PROTOCOL	JUSTIFICATION	ACTION NEEDED
Golden Eagles	-Denali offers probably the best location in Alaska for longterm monitoring of Golden Eagles due to population density, accessibility, and potential linkage to other monitoring of eagle prey items and habitat characteristics.	-Monitoring protocol nearly complete and ready for implementation
Gyrfalcon	-Denali offers probably the best location in Alaska for longterm monitoring of Gyrfalcons in subarctic due to population density, accessibility, and potential linkage to other monitoring of Gyrfalcon prey items and habitat characteristics. -Only resident falcon.	-Monitoring protocol nearly complete and ready for implementation
Merlin	-Denali offers probably the best location in Alaska for longterm monitoring of Merlins due to population density, accessibility, and potential linkage to other monitoring of Merlin prey items and habitat characteristics. -Species with known contaminant problems.	-Monitoring protocol nearly complete and ready for implementation
Goshawk	-One of few resident forest inhabiting raptors with some potential for reasonably efficient monitoring. -Forest inhabiting species that has shown sensitivity to habitat fragmentation in other areas.	-Existing monitoring protocol needs to be improved with better description of methods and sampling design.

AVIAN SPECIES - GALLINACEOUS

PROTOCOL	JUSTIFICATION	ACTION NEEDED
Willow Ptarmigan	-Other primary prey item for Gyrfalcons and Golden Eagles besides ground squirrels. -Highly cyclic and thought to have a strong influence on population dynamics of these two species. -Highly visible at certain times, may be conducive to efficient monitoring	-Protocols are in use in other areas of Alaska, adaptation needed for use at Denali.
Grouse	-Primary prey species of Goshawk -Information needed to understand if changes in population dynamics of Goshawk are a result of natural food resource changes or other consequences such as habitat fragmentation.	-New protocol -Link closely with forest areas/watersheds that are selected for Goshawk monitoring

AVIAN SPECIES - PASSERINES

PROTOCOL	JUSTIFICATION	ACTION NEEDED
Passerines	-Denali offers some of Alaska's most accessible treeline habitat and can provide an important sample point for national and international networks	-The following protocols are ready for implementation: MAPS Breeding Bird Survey Off Road Point Counts Xmas Counts N. American Migration Count
Shrikes	-National and International concern over the status of this species. -Denali offers probably the best location in Alaska for longterm monitoring of Shrikes due to population density, accessibility, and potential linkage to other monitoring of Shrike prey items and habitat characteristics. -Species with known contaminant problems.	-New protocol

AMPHIBIANS

PROTOCOL	JUSTIFICATION	ACTION NEEDED
Wood Frog	-Only amphibian in the subarctic -Amphibians are suspected to have high sensitivity to changes in atmospheric properties such as UVB or contaminants	-New Protocol

TERRESTRIAL INVERTEBRATES

PROTOCOL	JUSTIFICATION	ACTION NEEDED
Terrestrial Invertebrates	-Insect infestations can have profound effect on habitat -Some groups have shown strong sensitivity to environmental change	-New Protocol -Decisions needed on which groups to attempt to inventory and monitor. -These decisions should be based on monitoring focuses previously discussed