REPORT OF THE NSF ADVISORY COMMITTEE ON SCIENTIFIC AND TECHNOLOGICAL PLANNING FOR LONG-TERM ECOLOGICAL RESEARCH PROJECTS

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TABLE OF CONTENTS
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This report summarizes the results of two fact-finding meetings of the committee and provides specific recommendations for technological planning for the LTER network. The first meeting was held in early January (1988) with representatives from each of the 15 LTER sites to identify scientific issues of both local and network dimensions with potentials to be addressed through the utilization of newly available technologies. These issues could be categorized as:

1.Research topics in spatial variability.

2.Documenting and interpreting long-term temporal

variability in ecosystems.

3.Developing interbiome comparisons.

4.Developing and validating simulation models, including

new classes of spatial simulators.

A second meeting was convened in late January with technical experts to develop specific recommendations in the area of technological planning to address these issues. The results of these meetings are in the form of several recommendations as to the best use of expected fiscal resources:

1. Acquiring Geographical Information System capability with

some uniformity across the LTER network.

2. Developing a network remote-sensing analysis capability.

3. Augmentation of Wide-area and Local-area computer networks on the LTER system.

These recommendations are an initial step in the development of a coordinated technological augmentation for an interactive network of approximately 20 research sites. Interaction among scientists in the network should be unencumbered by distance. The ability to obtain, transmit, and process data among the LTER network should be easy, readily available and virtually instantaneous.

INTRODUCTION

The National Science Foundation's Long Term Ecological Research (LTER) emphasis provides a number of unique opportunities for investigation of natural processes that occur over long time scales and broad spatial scales. With over 300 scientists currently working at 15 sites around the United States, the LTER program also provides outstanding opportunities for scientific collaboration and intersite and interbiome comparison.

The many scientific opportunities offered by the LTER program also represent a challenge to currently available facilities for data storage, manipulation, analysis, and comparison. As the program continues and its long-term data base grows, it is important to plan carefully how these data will be managed and used in the future. It is especially important to ensure that the technological capabilities for data handling are adequate to meet the long-term research needs of LTER.

To aid in this planning process, the Advisory Committee on Scientific and Technological Planning for Long-Term Ecological Research Projects has created. The specific charge to the committee was to assist in the planning for increased use of computer-based hardware and software in the LTER program. In a series of two meetings at NSF headquarters in Washington, the Committee met with LTER scientists and with experts in computer technologies to review the current status and future needs of LTER. The recommendations in this report are a product of those meetings.

SCIENTIFIC ISSUES AND TECHNOLOGICAL NEEDS

After an overall review of the LTER program on November 5-7, 1987, the long-term scientific needs of the program were discussed in a meeting on 7 January, 1988. A large number of issues were discussed (see Appendix), with those related to spatial variability and especially spatial patterning most frequently mentioned. This category of issues includes the problems of understanding overall correlations between environment and ecosystem variables as well as specific "neighbor" and "patch" effects. With respect to these issues many of the scientists in the LTER network appear to have clear ideas of a rich variety of research topics that relate to ecosystem ecology, landscape ecology and the scaling up of local studies to more regional or even global implications. The scientists feel that they are limited by the availability of appropriate computing capability. They appear to be eager to improve their own experience with geographic information systems (GIS), remote sensing, and data management packages. There is also a recognized need to develop and maintain an inter-compatibility of data sets and software packages across the LTER network to provide the substrate for future cross-LTER site research comparisons.

A second category of scientific issues centered around temporal variability and identification of both long-term and short-term trends in ecosystem data. This category includes the analysis of continuously collected, long-term multivariate data sets as well as the detection and interpretation of ecosystem changes from remotely sensed and historical data. Here again, a rich array of scientific questions appears to have developed among the LTER scientists and there appears to be a healthy interest in these topics at several sites. As in the case of GIS systems in general, it appears that the technology is unfamiliar to many scientists and there is a perceived need to obtain and efficiently use state-of-the-art analysis algorithms.

Interbiome comparisons are a third area where there was a generally recognized need for greater research. It was also recognized that such cross-site comparisons were important in furthering both general understanding and theoretical advancement in ecosystem science. There was a perception among the scientists that technological augmentation could serve to make this less difficult. There is an obvious need for compatibility in the coding of fundamental data as well as in the data management systems that manipulate these data. It is important to eliminate difficulties of data exchange and to assure that the sites in the LTER network have an appropriate level of experience in electronic communications (data set exchange, interactive manuscript development, etc.) among investigators at

geographically separated sites. There is no shortage of scientific questions that might be addressed through interbiome comparisons. Such comparisons should be facilitated to the greatest degree possible - particularly in cases in which the technological advances in data processing, computer networking and information exchange could "clear the way" for the challenging intellectual problems of comparing and understanding the dynamic responses of the wide range of ecosystems in the LTER network.

Two issues related to simulation modeling were either discussed or mentioned in the individual site statements. One is the problem of spatially explicit modeling of heterogeneous landscapes, which requires advanced computer capacity but is limited both by access to supercomputers and by inefficiencies in the interaction among tasks best done on supercomputers and tasks best done on mini- or micro-computers. A second modeling-related issue is that of comparing and interpreting the output of models at different scales of complexity -- reconciling the predictions of "bottom-up" versus "top-down" models and using them to constrain each other.

Finally, the potential importance of the LTER program to regional and global issues in ecology was strongly argued by several attenders at the meeting. These issues are becoming increasingly important in the national scientific enterprise and there is a need for ecological insights to be represented in treating global science. It is important that ecologists gain experience in thinking at the regional or global levels, and the LTER network was seen as a research substrate to develop these insights. Ecologists should also become more familiar with the technological tools used at these levels, such as remote sensing, GIS systems, and spatial modeling. The LTER sites individually, as well as the program as a whole, represent probably the richest potential source of ecological information that might be applied to regional and global issues such as climate change.

RECOMMENDATIONS

The scientific needs of the LTER program are directly related to requirements for computer hardware, software and operating expertise. Based on the discussions at its first working meeting, the Committee grouped these technological needs into four major categories: (1) Geographic information systems; (2) computer networks, including both local and wide-area networks; (3) remote sensing, and (4) data management. At its second and final meeting on January 26-28, these four categories of technology were discussed with experts in each field, and the following specific recommendations were made:

GEOGRAPHICAL INFORMATION SYSTEMS

OVERVIEW.

At the January 5th meeting of site PI's, there was a consensus that acquiring a geographical information system (GIS) capability was the single technological addition that would most strongly advance the state of ecosystem science across the entire LTER network. Ecological data, by their nature, are georeferenced so a "system" to reference, layer, and analyze various types of data would be very useful to scientists at the individual LTER sites over the next 3 to 5 years and beyond.By "GIS" we are using a "holistic definition" and are referring to the information (spatially-explicit display and its representation), and computer hardware and software to store manipulate, map and overlay the information.

Through our discussions, it became apparent that to work in both vector and raster systems would be important for the diverse set of problems being considered by the LTER scientists. Although it is critical to be able to work in both systems, each system has its strengths and weaknesses. For example, one cannot make transformations spatially in a vector system as easily as in a raster-based system. Further, there are a number of transformations which are almost trivial in a raster system but exceedingly slow in a vector system. The vector system, however, is easier to visualize and digitize and, usually, is more exact in calculations (depending upon pixel resolution and size). It is generally easier to move information from a vector to a raster-based system, but it is possible, albeit more difficult, to move data in the other direction (i.e., raster to vector).

RECOMMENDATIONS.

Across the LTER network the collective stage of GIS-literacy is in its infancy. In terms of GIS capability and experience, no one site is very far advanced and, although several sites have an ARC-INFO license, few are experienced or sophisticated in use

1 Vector: a line-based system

2 Raster: an area-based system using pixels, where pixels are assigned a value.

3 ARC-INFO: one of several commercially developed GIS systems.

and application. One positive result of this rather early stage in the development of GIS capability at the sites is that the current status of GIS's across the network is more uniform than for other capabilities like data management systems, remote sensing, and modeling. Furthermore, the computer hardware environments at some of the sites are close to what would be needed for the implementation of a GIS system. In particular at such sites much of the prerequisite computer hardware and peripherals are already in place.

Due to the range of existing equipment at the different LTER sites, the committee (in concert with technological experts in the field of GIS system development and application) arrived at 3 different configurations to provide GIS capabilities across the network:

Configuration 1: Remote server with remote users. The remote server would have a mainframe computer with dial up or network (satellite) access; the remote users would have PC size computers with necessary software to link to this computer. The cost for the server would be on the order of $75 K. Cost for each remote user would be on the order of $25k.

Configuration 2: Local multi-user. Minicomputer with plotting devices and other peripheral equipment (e.g. tape drive, digitizing pads). Several users at the site can access the GIS system through a local network. Cost is on the order of $130K ($l00K for computer and hardware plus $30K for ARC-INFO).

Configuration 3. Local single user. 386-PC machine with plotter and other peripherals. Can be used by one person at a time. Cost $50K.

Our Committee's recommendation is that all three levels be selectively implemented across the network to an initial test set of sites. Price estimates discussed above are high-end estimates. Since the sites already have much of the requisite equipment there may be project-specific cost savings. We suggest that the sites be encouraged to use existing equipment to the greatest extent possible. This will not only stretch the existing funds in the first year to accommodate more sites and increase the GIS capability over the network, but also draw on local expertise to reconfigure (where needed) and expand local systems to accommodate the GIS capability.

Although no endorsement of a single vendor was solicited, it appeared that the ARC-lNFO package was the software of choice. Another system, TERRA-MAR, was mentioned, but it is untested as of this writing. The consensus was that ARC-lNFO was probably a good choice for now, and since all future systems will necessarily be compatible with ARC-INFO, upgrades will not be difficult. There may be some economies of scale to be enjoyed if ARC-INFO were to be purchased for the entire network. However, the strength of the network is also in its diversity, and, hence, the Committee felt no stipulation should be made to absolutely require every site to use ARC-INFO for fear that such a requirement could stifle future creativity.

The issue of education and system training for LTER site staff is not a trivial concern and warrants further discussion. It is clear that such training should neither be overlooked nor minimized. The Committee recommends that concurrent with the purchase of the hardware and software is the need to deliberately include a thorough and repeatable set of training workshops, materials, and hot line(s) support from the vendor. It was felt that ESRI (the vendor for ARC-lNFO system) would be favorably inclined to accommodate and respond to this need - perhaps going so far as to tailor-fit some of the workshops (i.e., a traveling road show for the sites) since we are potentially seeking a network purchase of ARC-lNFO licenses.

It is apparent from discussions with several of the technological specialists with experience with ARC-INFO that this system is not easy to learn. In fact, INFO (the relational data base management system) is quite difficult. Simple reliance on the ARC-INFO mini-training sessions for a half-time data manager from each site will <u>not</u> be adequate. It is important that senior staff (Pl's) at each of the sites need to learn to use and understand the system so as to fully comprehend and utilize its capabilities. Allocating funds to send the Pl's from those sites seriously interested in GIS to a workshop consisting of a "test program'" to give Pl's an appreciation of GIS capabilities is recommended.

The evaluation of this GIS implementation program is important. The initial set of sites should be encouraged to keep a log of their first year experiences to share with those sites attaining GIS capabilities in the future. We recommend the NSF reconvene this Committee (or a subset thereof) with appropriate technical support staff to visit and meet with site representatives at each of the various implementation levels a year from now to assess the pros and cons of each of the three levels of GIS capability. One issue that should be addressed in developing the GIS capability across sites is to make certain that a standardized reference grid system be used across all sites. This is a relatively arbitrary decision at any single site but uniformity from the outset will greatly enhance network level interchange of spatial data.

COMPUTER NETWORKS.

OVERVIEW.

The principal use of computer networks is for electronic transfer of data, manuscripts, and messages between users of different computers. The networks can also be used for remote log-on and job submission at computers distant from the user. A wide variety of computer networks already exist, for both general and special purposes. For convenience we have grouped them into Wide Area Networks (WANs) and Local Area Networks (LANs). WANs are typically used to link large, mainframe or supercomputer facilities separated by long distances, often across the country. LANs are used to link computers within the same building, on the same university campus, or in the same city. At most large university campuses, it is possible to communicate with a WAN through a LAN connection with the main campus computer system.

RECOMMENDATIONS.

Computer networks are already being used by some LTER scientists, but access to WANs is often difficult and inefficient and LANs do not exist at many LTER sites. For example, in order to communicate through a WAN a scientist must often carry data or manuscripts physically to another computer or terminal in a separate office or building, and reload them. Similar situations prevail at many sites where individual personal computers are not linked with each other, or where computers at field sites are not linked with those at a home campus.

The Committee makes the following recommendations:

1) Wide Area Networks: Access to nationwide electronic mail networks (such as BITNET, CSNET, ARPANET, etc.) is already possible through large computers on the home campuses of every LTER site, but is not widely used. An early first step toward improving communication through these networks should be a workshop of data managers from each site, with the goal of establishing an LTER "bulletin board" within one of these networks , and EMAIL addresses for each site . The additional hardware and software costs needed to implement this goal should be minimal, but it is essential that at least one computer or terminal at each LTER site be capable of communicating with a mainframe computer that is part of the nationwide network. 2) Local Area Networks : The LAN requirements of the individual LTER sites differ widely, and once the requirement for linkage with a nationwide network is met there is no need for all sites to have the same type of LAN . Rather , the Committee recommends that local communications needs be reviewed by each site individually and that a separate plan be prepared for each. The costs of improving computer communications at individual sites could range from a few thousand dollars to 50-60 thousand dollars, depending on the existing computer systems and the dispersal of investigators among buildings or between field sites and the home campus.

REMOTE SENSING

OVERVIEW.

One area of rapid technological advances that relates directly to the LTER network is the area of remotely sensed data. While one can argue that remote sensing covers a wide range of conventional technologies (e.g., aerial photograph interpretation), our concern here is with the more recently developed or currently under development technologies. These include a wide range of devices (radiometers, spectrometers, RADAR, microwave sounders, and LIDAR instruments). These devices are flown from aircraft, manned spacecraft and satellites. The data collection rates from some of these devices are enormous and represent 10's, 100's and, in some cases, more than 1000's times the density of data collected in even the largest ecological data collection efforts. The development of the ability to process and interpret these new, exotic and large data sets is both a major problem and an important intellectual challenge to ecologists.

Scientists in the LTER network need to be facile in the use of remotely sensed data to test theories of ecological processes and pattern, to extend the results from a particular LTER site to a regional context, and to determine attributes of ecosystems at different space and time scales. Several of the LTER sites are actively interested in remotely sensed data in the context of understanding how ecological and physical process interact to produce patterns. It seems apparent that the technologies most likely to extend the results from LTER studies to a larger spatial context will include remotely sensed data to some degree.

Along with the interest in remotely sensed data there is a second consideration that should be aired as a preamble to the committee recommendations. As was pointed out earlier in the section discussing GIS-systems, the geographic information systems that are most easily used in spatially explicit ecosystem or landscape modeling are raster-based. Remotely sensed data is typically handled as raster data and software and hardware systems for these data are raster-based. Thus, the acquisition of systems for processing remotely sensed data has the secondary effect of seeding the LTER network with GIS-systems that have desirable features for spatial ecological modeling. Usually software and hardware from systems used to process remotely sensed data are sold as a package.

Discussions with the LTER site leaders identified an interest and a concern about remotely sensed data and the utilization of these data. The discussions also identified the existence of a group of scientists in the network with a direct interest in this area of scientific research. It appeared that a LTER-network level group with a number of valuable institutional and professional contacts in the area of remote sensing was forming. It was clear at this first meeting that the interest in the research area was just developing and that the opportunity for comparison across sites in the future could be considerably enhanced by taking action to assure that the potential for future cross-site comparisons and LTER-network synthesis in the area of utilizing remote sensing not be confounded by local and relatively arbitrary decisions as to how to process the data and what GIS-package to use. The timing for a coordination across sites in the area of processing, displaying and modeling remotely sensed data seems suspicious.

Discussions in late January between the committee and experts in the area of remote sensing identified several important considerations:

1. Remotely sensed data from satellites (or aircraft) requires considerable processing to correct for geometric considerations (angles between the surface of the earth and the sensor), idiosyncrasies of the instrument, atmospheric effects that alter the quality of the data (clouds, haze), and many other features. This aspect of processing the primary data is highly technical, and requires technological specialists with particular abilities in processing data from the particular instrument. Depending on the sensor considered there may be a requirement for specialized computer configurations to handle the data processing. 2. Archival data for a number of the LTER sites exists and in some cases has been compiled. The historical remotely sensed data archive has not been compiled for all sites.

3. The sites in the LTER network have focused on two remotely sensed data processing "packages" and most of the sites that have attempted to obtain (or were investigating obtaining) such packages have decided on the ERDAS system.

4. There are considerable economies in the LTER network dealing with vendors of software and hardware as a network and not as individual sites. There are similar economies in dealing with some of the vendors of the remote data. These economies are inspired, in some part, by the commercial advantages of selling a larger volume to a single customer. However, the reputation of the LTER network and the interest on the part of the vendors in being "connected" to a conspicuous and major ecosystem research effort is also a part of their interest in the network. The vendors appear willing to reduce the prices of their wares and to provide several useful services (training sessions for LTER staff to learn to use the computer packages, development of software to fit LTER network needs as they develop).

RECOMMENDATIONS.

Subsequent discussions have produced the following general recommendations in the area of remote sensing:

1. The LTER network should probably not attempt the primary processing of remotely sensed data directly but should contract with a center specialized in this function. There are several centers that have the capability to perform this service with varying degrees of direct contact with the LTER network (for example the campuses of several of the LTER sites have remote sensing centers) but the principal issue is cost and service.

2. The LTER network should begin development of a capability in using remotely sensed data in spatial ecological research. The most likely way to initiate such work would be to install raster-based GIS remote-sensing systems at LTER sites with a strong scientific interest in this area. The network should probably use the same systems to the degree that this is possible.

3. The LTER network should contract to obtain network-wide archives of remotely-sensed data that could be used in the future. The French SPOT satellite would appear to be a likely candidate for such a archival collection. The archival data from remote sensing should be collected at ecologically appropriate times (e.g., the height of the growing season) and the determination of the number of images and the timing of the obtaining of the imagery is a topic that should be addressed by the LTER coordinating committee.

DATA BASE SYSTEMS

BACKGROUND.

The Committee discussed the status of data management and data base systems used by the LTER sites at the Long-Term Ecological Research Technologists Planning Meeting (Jan. 26-28, 1988). At the present time the LTER sites have the sole responsibility of maintaining the data bases at their sites which contain information of a spatial and temporal nature and deal with both the biological and physical environment. The sites have the responsibility of obtaining the data, maintaining the data base and providing access to other investigators. The National Science Foundation encourages the use of these databases by researchers at the individual LTER sites, across the LTER network and among the ecological sciences community.

The committee generally agreed that the present structure of the data base systems and the way they are implemented seem quite reasonable. The LTER data managers have developed a series of standardized formats for documenting and storing LTER data sets at each site and have guidelines for structuring data bases so that the data can be transferred to other sites. The committee also agreed that the present system in which each LTER site selects the best data base software for their computer system is appropriate.

RECOMMENDATIONS.

It is important to develop secure ways of archiving long-term data bases. This is emphasized since the potential value of some of the long term data bases increases with time and the investigators who collected the data may not be associated with the project in the future. The development of a formalized protocol for transferring data across sites is necessary if the LTER network is going to start meaningful cross-site comparison research. We feel that the above problems can be solved by asking the LTER data managers to share their standardized procedures for archiving data bases and transferring the data across sites. Protocols for this have been formulated in the past for some of the sites.

The establishment of a centralized data base for cross-site ecosystem analysis was also discussed. The development of a centralized data base which included general information such as plant production, weather, climatic and weather data, National Atmospheric Deposition data and soil data from all LTER sites would greatly enhance the ability of the LTER network to do meaningful cross-site comparison research. At the present time getting cross-site data bases is quite laborious and time consuming since it is necessary to contact individually each of the sites for a list of available data and potentially waiting a long time before all of the data sets are sent. It would also be useful for a centralized data base system to include a list of the type of data being collected at each site and a description of procedures used for collecting and storing the data.

The existence of a centralized data base system would greatly enhance the ability of the LTER network to work with other federal agencies such as EPA and NASA by having a centralized location for providing data from the network. The support staff associated with the centralized data base system could provide existing centralized data bases and facilitate the formation of new cross site data bases that would be needed by groups outside the LTER network. The centralized data base would also be useful in integrating the LTER network into the Global Geosciences program which is presently being developed. We anticipate that the centralized data base system would be managed in conjunction with the LTER intersite coordination committee.

CONCLUDING REMARKS FUTURE DIRECTIONS.

The recommendations that the committee has made in this report are largely tactical. It is important to allocate available resources wisely in such a way as to maximize the ability to solve current problems and to allow scientists in the LTER network to explore important research areas. In making the recommendations, we have attempted not to lose sight of future technological augmentation for the LTER network. The future of a scientific endeavor such as the LTER network is extremely exciting, particularly given the interest in global issues that is emerging at national and international levels. The recommendations in this document involve "seeding" the LTER network with improved capabilities in spatial data processing of several different sorts. We would expect these initial projects to create a considerable interest and to open up new lines of inquiry in the area of spatial modeling. We feel that in the near future an increased capability in using computer networks to tie the LTER network together is needed. Much of the cross-site synthesis will likely revolve around data synthesis and intensive interactions among scientists at different sites. The LTER network should not allow distance to hinder these interactions - the development of a user-transparent LAN/WAN capability is a logical step in the development of the network.

The committee has already recommended the creation of "nodes" in the network with specialized abilities in data processing, remote image processing and networking among sites. The future view of the computer technology for the LTER network would be for each site to have a capability in GIS, a remote sensing data processing capability, modeling and statistical analysis packages, and the ability both to contact scientists and use equipment at other sites in the network using computer networking. In the LTER network, "node" sites or service centers would process data, provide support and aid in specific analysis tasks that require a level of specialization, an unusual set of equipment, or other features that would proscribe the work at the individual LTER site.

Much of the computer equipment and the associated hardware to realize this future LTER network is available today. The existence of an interactive LTER network has provided a potential for a "dispersed-center" for ecosystem studies. The dispersed aspect of the LTER network provides a richness of understanding of a range of different ecosystems as well as a diversity of scientific talent at multiple institutions. The centered aspect of the LTER network will lie with the degree to which distance can overcome by the scientists involved. The technological augmentation of the network and associated increased abilities to transfer data, ideas and creative interactions among the LTER network is an important facet in the realization of this goal.

Report Appendix:

ARCTIC TUNDRA LTER

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OVERALL GOALS -

Our overall goals are: 1) to understand and separate the role of animal consumers vs. plant/ nutrient responses as controls over terrestrial and aquatic ecosystems in the tundra landscape; and 2) to advance understanding of how mineral nutrients move over the arctic landscape, from terrestrial to aquatic ecosystems.

We are pursuing these goals by conducting long-term experiments in adjacent but contrasting watersheds near the Toolik Lake Research Station on Alaska's North Slope. Both watersheds contain a variety of terrestrial ecosystem types common to the North Slope (e.g. tussock tundra, heath tundra, riverine willows). Both watersheds contain headwater and higher order streams, but differ in that the Toolik Lake watershed contains a large number of oligotrophic lakes, whereas the Kuparuk River watershed contains only a few small headwater lakes.

MAPPING AND COMPARISON

To meet our goals within this heterogenous landscape, we will require readily accessible, spatially explicit information on ecosystem structure and processes. This information will allow us, for example, to compare the abundances and distributions of various types of ecosystems in the two watersheds and to compare the relative contributions of various types of ecosystem to the processing of nutrients. A Geographic Information System (GIS) is necessary to meet these objectives. GIS's require large computer memory for both software and information storage. New technology has resulted in the development of 32-bit, 20 Mhz or faster) microcomputers capable of running large GIS ' s efficiently. This eliminates the need for large mainframe computers and, in addition, allows for rapid, on-site turnaround of information between field experiments and data analysis. A GIS also allows for combining remotely sensed data with data acquired from field studies.

MODELLING

Our study of the biogeochemistry of the tundra landscape is tied together in part by simulation models that incorporate information on ecological, climatic, hydrological, and geochemical processes. Because of interest in understanding these underlying processes, the models will be mechanistic (as opposed to statistical). To calibrate these models for our study sites, and to retain and evaluate the uncertainties associated with these calibrations, we intend to use Monte-Carlo procedures. Such procedures require a large computer memory and fast computing speed; needs that can again be met by 32-bit, high speed microcomputers. In addition, because our interests lie in spatial interactions among landscape units, our models will need to interact readily with GIS data bases.

SCALING UP AND EXTRAPOLATION

One of our long-term goals will be to evaluate the regional and global ramifications of the results of our LTER research. To do this, we will need to extrapolate our results to broader spatial and temporal scales. This will require access to remotely sensed data on the abundance and distributions of the various types of ecosystems throughout the tundra and a means for analyzing such data. These needs could be filled through the interaction between our models and a GIS for the tundra and at least a rudimentary capability for processing remotely sensed information into digital form so that it can be accessed by a GIS. Through this interaction, remotely sensed information of abundance and distribution of ecosystems would be entered into the GIS, the models would access this information and predict process rates over this broader spatial scale.

ANALYTICAL CAPABILITIES

To make the most use of large, spatially explicit data sets collected over the course of our long-term studies, we need sophisticated analytical capabilities that will allow for analyzing multivariate data sets, results of factorial field experiments, and time-series information. These capabilities can be met by statistical software that should be able to interact with both a GIS and our process models. The powerful statistical packages that we require to do these analyses are not available for micro-computers and will be all the more useful on the new family of fast, 32-bit microcomputers.

SUMMARY OF NEEDS

To maximize speed of data acquisition and analysis rill require two 32-bit microcomputers and peripherals: one to be used in Woods Hole where detailed modelling and GIS work will continue year-round, and a second for field use at Toolik Lake. A preliminary list of required equipment follows.

<u>Hardware</u>

-two 32-bit microcomputers with 20 Mhz for faster clock speed (one each at field station and lead institution)

-two large capacity hard disks and tape backups

-two high resolution monitors with graphics cards

-two printers

-two modems or similar communications devices

-one digitizer and large format digitizing table

-one large format pen-plotter

-one 9-track tape reader

<u>Software</u> (including site licenses to allow for multiple institutional use)

-GIS

-Statistical and analytical software packages (e.g. SAS, SPSS, BMDP, MATHLAB)

-Programs for converting remotely sensed data to GIS format

1/05/88

Virginia Coast Reserve

Long-Term Ecological Research Program

Scientific and Technological Initiatives

Statement of Problem. The investigators of the VCR/LTER Program have identified the development of enhanced capability in the processing of remotely-sensed imagery and geographical information management is our highest priority for technological innovation in computer applications. The Virginia Coast Reserve (VCR) is a vast, heterogeneous landscape. Our study site includes 1,000 square kilometers of barrier islands, salt marshes, mudflats, open bays and fringing mainland. We are concerned explicitly with the evolution, function and interrelationships of these diverse and highly dynamic landscape elements. We are thus implementing both fine-scale, site-specific process studies and macroscopic, spatially-extensive landscape analyses.

Our research thus requires a major commitment to remote sensing. Furthermore, the availability of an extensive archive of historic (1933+) remotely-sensed imagery opens the possibility for both "time lapse" studies of certain geomorphological and ecological processes (e.g., marsh accretion) and hypothesis testing based on "hindcast" information. Although the potential remote-sensing data base may be particularly extensive for the VCR, we suspect that our site is not unique in offering compelling research opportunities based on this type of information. The development of an enhanced capability to combine remotely-sensed data with geographical information management would thus seem to represent a promising area for technological innovation of value to the entire LTER network.

Remote Sensing/ Geographical Information Needs. We have identified four elements that would be essential to an initiative in remote sensing and geographical information management:

1) Establish a basic geographical information system (GIS) at each site.

2) Develop advanced GIS image-processing/networking capabilities.

3) Develop innovative remote sensing/GIS capabilities.

4) Continually monitor innovations in remote sensing.

A Draft Proposal. Such an effort could be implemented as follows:

1) Establish a basic Geographical information system (GIS) at each LTER site. A basic GIS such as the ERDAS-ARC/lNFO system would provide the capability to manipulate and manage spatiallyextensive information such as topographic and soils maps and to manipulate remotely-sensed imagery such as aerial photographs. When this information is placed on a common grid system, it is possible to monitor and analyze geomorphological and ecological processes on the landscape level. A basic GIS including microcomputer, video terminal, digitizing tablet, tape drive and software would cost $30,000 to $40,000 for each site.

2) Develop advanced GIS/image-processing capabilities. A central multi-user image-processing facility could be equipped to digitize SPOT, LANDSAT and other imagery and to produce GIS compatible data base: on request. Each site would have its own basic GIS for manipulating, managing and analyzing this information. The central facility, including additional computer capacity, scanning video cameras and tape drives, would cost in the range of $150,000 to establish.

3) Develop innovative remote sensing/GIS capabilities. For example, interactive, real-time ground-truthing and monitoring would be very useful on the VCR/LTER site. We envision the development of a field-portable video system with a telemetric hook-up to a lab-based ERDAS data base. The staff of the central facility would be available to consult on such activities. 4) Continually monitor technological innovations in remote sensing. The USGS, NASA, NOAA, NORDA and other federal agencies are investing 10s of millions of dollars every year in developing new aircraft-, shuttle- and satellite-born sensors such as multispectral devices, NVDI, LIDAR, side-looking radar and synthetic-aperture radar. Many of these new technologies will have applications of interest to LTER activities. The central facility would mount a systematic effort to factor the technology of the 1990s into LTER planning.

A Related Point. There is another aspect of "remotely-sensed" information of interest to us. Each LTER site devotes a large fraction of its annual budget to collecting continuous, real-time information on a variety of site factors and processes. Much of this information is collected automatically and stored on cumbersome (e.g., paper- or mag-tape) or "opaque" (e.g., microchip) medium. Such information typically is unavailable for real-time analysis and interactive uses. We would like to see at least an appraisal of the possibilities for technological innovations in the area of real-time, on-line, interactive data acquisition and analysis.

6 January 1988

Technological Needs

Cedar Creek LTER Site

D.F. Grigal and G.D. Tilman

Our research focuses on the causes of spatial and temporal patterns in ecosystems, both at our Cedar Creek site and across the LTER network. This requires detailed analysis of observational and experimental data and the use of these data to test predictions of various models. To accomplish our research goals at Cedar Creek, we must analyze extremely large data sets in a variety of ways. Because all elements of an ecosystems are potentially linked to each other, either directly or indirectly, all data on all ecosystem elements and processes must be in a common data base. That data base must have an architecture that allows analyses of relationships among any possible combination of variables. In addition, some of the data are collected with a spatial orientation, such as by remote sensing. Thus, data analysis and modeling must also include a spatial orientation, as in geographic information systems (GIS).

The major technological problem that we have encountered at Cedar Creek has been in the management and analysis of data. Our project depends heavily on microcomputers and mainframes for data acquisition, storage, and analysis. Our existing observational and experimental data sets would have been impossible to collect and analyze without computers. Such extremely large, multi-investigator data sets are being generated both at Cedar Creek and at other LTER sites. These inter-related data sets are of direct interest to us in our research. They are, however, fast exceeding the compatibility of existing hardware and software. Although we have a workable system at our LTER site, it is clear that our future scientific accomplishments, and those of investigators at other LTER sites, will be hampered more by lack of good data management, data availability, data sharing, and data analysis capabilities than by any other single factor. Thus we see the major technological need of the LTER network to be an effective system of data management that is compatible among all sites. This system must encompass a number of essential elements that are listed in the following discussion. Please note that no order of priority is implied. All the elements listed below must interact equally to achieve our goal.

1. Local Network with a Central Data Base

We need a local network that will allow easy, rapid data sharing among scientists within the Cedar Creek LTER group. With development of interdisciplinary groups composed of individuals from a number of academic departments, the minor annoyances of data access become large obstacles. We need a central data base, with remote workstations tied to that data base. Workstations should be located in the laboratory/office areas of each investigator participating in the LTER project, as well as at the field site. In that way, all scientists could access the database when and how they liked.

2. Interactive Real-time Graphics

For statistical analysis, for spatial (GIS) manipulation and modeling, and for ecosystem-level modeling, these workstations must be equipped with high-quality, interactive , real-time graphics. At Minnesota, we have adequate amounts of "raw" computing power, including three supercomputers, for large simulations and/or data manipulation. However, our progress is inhibited by lack of statistical packages and hardware that allow real-time graphical analysis of large data bases. The ability to instantaneously view relationships among variables and to examine time-series of real or simulated data is essential in the iterative process of testing hypotheses and generating new hypotheses.

In summary, our major on-site hardware requirement is a system of linked workstations with high-quality, fast-response graphic capabilities. Our software requirements include data base, statistical, and GIS packages that effectively use the hardware capabilities.

3. Linked Network among Sites for Data Sharing

In order to carry out studies or comparisons among LTER sites, each of us must have access to the data bases of all other sites. One of the major limitations to such comparisons is the problem of rapid and efficient data exchange. Existence of an easily-accessible central data base, or a series of linked data bases, is essential. The hardware and software requirements for a local network at Cedar Creek (workstations with high quality graphics) are likely to be similar to the requirements for each of the other sites. As a consequence, the best way to achieve rapid and efficient access to data among sites might be to link the local networks at all sites into one system.

4. Uniform Software among Sites

A major obstacle for data sharing comes from incompatibilities in software for data management. We need a uniform system of data-base management, so that data can be readily exchanged. By this, we mean uniform software systems (programs) and uniform methods of structuring data among LTERs. Data-base standards should be established, but they must be flexible enough to simultaneously meet needs within and among sites.

5. Intersite Data Coordinator

To enhance the implementation of these standards, and to run the linked network, a national coordination effort with a team of one or more professionals is necessary. This team would aid transfer of data from individual LTER data bases to a common format.

As we see it, the LTER network has not just been set up to collect high-quality, long-term ecological data, but also to allow it to be as fully analyzed as possible. Unless the best technology is available to help all of us access and interpret that data, we will not receive the full benefit of the funds and effort expended on data collection.

The Central Plains LTER

The focus of the research at the Central Plains LTER that will most benefit from enhanced computer capabilities is the integration of simulation modeling and spatial analyses at a regional scale. We see two difficulties to be overcome in achieving our goal. The first is simply accessing these computing power necessary to adequately develop, run, and analyze spatially explicit simulation models. We believe that such models will approach the computational requirements of some of the Global Climate Models. The use of a supercomputer for such modeling may be required, although our experience with the Cyber 205 supercomputer has shown it to be a very poor environment for model development. We have also found the cost of using supercomputers to be a detriment to model development. Software that would help develop simulation models that are better structured for execution on supercomputers would be quite useful, although we are not aware of the existence of such software. A better environment for model development than a supercomputer might be a network of several mini- or supermicro-computers with software that would allow the execution of a single model to be distributed over the available machines.

The second difficulty to overcome in achieving our goal is to enhance our ability to perform analyses on spatial data. The technology to do spatial analyses clearly exists at several levels in terms of computer requirements and software capabilities. The recent funding of the Colorado State University/University of Colorado Facilities Center is a good start toward meeting our technological needs. However, because of limited funding the Center focuses on only one of the levels of sophistication in spatial analysis required by our current problems. The spatial analysis system of the Center addresses the most sophisticated of our current needs and is complex enough to require either working closely with programmers trained in its use or putting substantial effort into learning how to use the system. Access to the most features of the system is limited to a single user on each Micro-Vax workstation. What is lacking in our computing environment are some of the intermediate level tools that will enable our researchers to become directly involved with spatial analysis and model development. We believe that we can accelerate both the development of expertise in spatial analysis and its application by providing an intermediate level of spatial analysis technology to researchers. Software designed to work on high-end PC's or low-end super-microcomputer workstations would probably best meet our immediate needs.

Spatial analysis and modeling are facilitated by the use of graphics. However, we currently have only limited capability in the area of computer generated graphics. We believe that our research would benefit from the enhancement of our graphics systems. Quality graphics systems for PC's and access to hardware capable of producing good color reproductions would be very useful.

Our research would benefit from having better local networking capabilities. CSU is currently installing the first segment of a campus wide network referred to as the "campus backbone". However, a lack of funds is preventing CSU from providing service to all of the buildings on campus. The Natural Resource Ecology Laboratory will be installing a link to the backbone to meet the needs of the Facilities Center. However, the researchers with offices in the central part of campus are limited to accessing the NREL and CSU computer systems via asynchronous communication over phone lines.

Our networking capability with other sites is relatively good, in that we have access to BITNET, USENET, and soon (we are told) to ARPANET. However, our gateway to most of these networks is through the CSU Cyber, which poses a number of problems in trying to transfer files. It is often easier and faster to use either a commercial network for small files or one of the express mail services for large files than it is for us to use BITNET. Nevertheless, we believe that the cooperation required to adequately address regional scale questions would be facilitated by better remote networking capabilities.

Benefits of Enhanced Commuter Capabilities - Coweeta Site

Scientists working at the Coweeta LTER site are increasingly involved with computer applications in a variety of research areas. The microcomputer revolution of the last 5 years has resulted in an increasing variety of applications where microcomputers and sophisticated software are dedicated to routine measurements and analyses. Coweeta laboratories would benefit from computers fitted with analog to digital board interfaces, to both log data replacing worn-out strip-chart recorder in our laboratories and reduce operator time and errors from manual reading of strip charts. Existing software packages can replace current manual data reduction procedures. Compatibility between operating systems is now a minor issue the majority of our applications use MS-DOS compatible machines. The Apple Macintosh is an alternative favored by some PIs, but communication between the two systems is viable. Both types of systems communicate easily with mainframe computers via remote terminals.

Investigators on University Campuses (Georgia, Emory, VPI & SU, Michigan State) have good access to mainframe computers. At the Coweeta site itself, this is not so. Enhancement of computing facilities at the Coweeta Hydrologic Laboratory is a high priority goal for our project. The three areas which would benefit immediately from enhanced computing facilities at the Coweeta site are (1) modeling applications, (2) statistical analysis of long-term data sets, and (3) improvements in data management. Our emerging research projects in processing of remotely-sensed images and GIS-based data sets would clearly benefit as well.

A quick survey of Coweeta PIs yielded a selection of computer benefits which fall into three categories:

1. <u>Remote Sensing, Image Analysis and Geographic Information Systems.</u> We anticipate rapid development of research applications in this area. Coweeta investigators are keenly interested in remote sensing as a means of extrapolating research findings to landscape-scale areas. Dr. Peter Dress has been added to the roster of Coweeta PIs to bring his expertise in remote

sensing geographic information systems to bear on our research.

Software and hardware options for both remote sensing and graphic information systems are in a state of rapid development. The US Forest Service has an obvious interest in this area, and applications at Coweeta will necessarily meet their standards. The Coweeta LTER project must encompass compatibility between USFS, LTER network and possibly University of Georgia systems (Georgia's Institute of Ecology has not adopted a particular GIS as yet, but several exist among ecologists there). Dr. Dress has proposed a hardware/software package for the Coweeta project, which is listed in Appendix I.

Remote sensing using LANDSAT images is not a practical research procedure at the Coweeta site. Our experience has been that cloud cover is too probable for LANDSAT to be a reliable means of sensing a sequence of ecological events. Project Leader Swank has developed a joint program with NASA scientist Luvall which involves airplane overflights of the basin. This approach seems to us to be the most likely one at the moment. At present, computer equipment for analyzing the data resides with NASA.

2. <u>Image Analysis and Enhancement</u>. A large variety of research applications are beginning to benefit from image analysis systems. Coweeta Pls are beginning to utilize these were available, and develop them where they are not. This technology is undergoing a rapid expansion of software and dedicated hardware. This area is one which would benefit immediately from enhanced computer capabilities, since ongoing research projects can utilize image analysis now. We offer three different categories of current applications for image analysis.

One is the application of simple, home-grown image analysis systems. For example, Hargrove, Crossley and student are using simple computerized systems to measure herbivory on samples of foliage. This application mould benefit from enhanced software, Possibly using fractal analysis to resolve estimates of herbivory.

A second application uses sophisticated software (Biquant Image Analysis System) in conjunction with microcomputers. Wallace and associates will use this system to analyze stream invertebrate samples, deriving biomass/production data and avoiding much time-consuming measurement of individual specimens. Existing commercially-available software would benefit from further development and enhanced computer facilities.

The third category includes applications of full-blown image analysis systems. With these systems enhancement of images is a major feature, enabling enumeration and measurement of size classes for example derived from images obtained from various sources -- microscope, video recordings, 35mm slides, and so forth. Enhanced computer capabilities in this area would find application in such diverse areas as enumeration of soil microbes, measurements of root production and turnover (images derived from minirhizotrons), and analysis of seston distribution in samples from streams. Applications in this category include the most pressing needs for image analysis/image enhancement in our research programs.

3. On-line communications systems. Coweeta scientists in general have only little experience with networking and computer-based communications. We do not see much advantage (as yet) with linkage to the entire network of LTER sites. Of more immediate concern is linkage between Coweeta investigators at Athens, Emory, VPI and the Coweeta site itself. Simple postal communication between Athens and Coweeta can require 5 days to travel the 103 miles separating the sites. Back-and-forth travel by students and others is a major, pony-express system of communication with attendant perils of missed messages and everything short of indian attacks. Thus we view an electronic mail/electronic bulletin board system linking our investigators as a high priority application of enhanced computer capabilities. We have proceeded slowly because others have expressed interest also and we would want a high degree of compatibility. Others include the U S Forest Service, the Institute of Ecology, NSF, and the LTER network. Which will come first? Communications packages now in use allow us to transmit documents between some sites (Emory and UGA, for example) but these are done on a patch-together basis. Bit-Net has (so far) proved to be a clumsy, irritating, time-consuming vehicle for electronic communication.

Appendix I. Requirements for Remote Sensing/GIS Studies at Coweeta

Hardware:

IBM PS/2 Model 80 with 77 meg hard disk

X-Y digitizer X-Y plotter

Laser printer

Dot matrix printer

1024 x 1024 video grabber board

1024 x 1024 video RGB monitor

Scanning video camera

Software:

ERDAS PC/AT/PS Software

ARC/INFO PC/AT/PS Software

ADVANCED COMPUTER TECHNOLOGIES FOR THE

HUBBARD BROOK ECOSYSTEM STUDY

Traditional applications of computer technology, for data storage and manipulation, have been essential to the success of data-intensive ecological studies, including those at Hubbard Brook. In addition, the development and testing of models simulating ecological phenomena (e. g., JABOWA, BROOK, FORTNITE) have depended upon availability of state-of-the-art computational technology. Thus, we clearly recognize the enormous value to the Hubbard Brook Ecosystem Study (HBES) of continued development within this project of proficiency in new computer applications and availability of the required software and hardware. Currently, we recognize four principal technological advances which will contribute to our facility at studying and understanding ecological phenomena in the HBES: (1) access to supercomputer facilities for simulation modeling; (2) development of more efficient data acquisition systems for monitoring meteorology, hydrology and chemistry of HBEF; (3) expanded availability and use of computer networks within the HBES and among LTER and other ecological research sites; and (4) development of geographic information systems (GIS) within the HBES and other LTER sites. In the following paragraphs, we briefly describe our needs in the three former areas and then describe in some detail our proposed application of GIS.

Some large simulation models currently are being developed or applied to the Hubbard Brook watersheds, including the Integrated Lake-Watershed Identification Study (ILWAS) model and an expanded version of the FORET model. To model extended time intervals the latter require very long execution times on mainframe computers. We expect to utilize supercomputer facilities (e.g., Cornell University) to facilitate these operations. Dr. D. Weinstein already is using the Cornell supercomputer for FORET runs and is planning to apply a refined version of this model to address questions of spatial patterns of vegetation succession and nutrient availability over long time scales at HBEF. The ILWAS model simulates the chemical processing of acid precipitation in forested watersheds and may be ideally suited to addressing several questions concerning element flux in the Hubbard Brook basin. Drs. C.T. Driscoll and C.A.. Federer hope to adapt this model to the HBEF and probably will seek access to the Cornell supercomputing facility for this purpose.

On-site data acquisition systems at HBEF have been limited by the lack of line power to the site. We hope to bring line power to the base of the experimental watersheds and to automate sampling of streamwater and hydrologic and meteorologic instrumentation in the next few years as funds become available. Current technologies are adequate to match our data acquisition needs, but we expect to apply the most efficient systems available at the time this automation is initiated. Currently, we rely on a variety of battery-powered data loggers, automatic samplers and meteorologic equipment.

Although computer networks (especially BITNET) are routinely used within the HBES, more widespread utilization would be desirable both for communication and data transport within the project and to other intensive research sites. Unfortunately, two of our principal institutions are not directly linked to BITNET, though indirect access would be possible. A better development of networking within the HBES and the LTER program is seen as a valuable step for technological advancement.

Finally, in cooperation with scientists at the Cornell Laboratory for Environmental Applications of Remote Sensing, we propose the development of an intensive geographic information system (GIS) for the HBES. A GIS is an integrated process of mapping, analyzing, and managing environmental data. The GIS model integrates cartographic features with their respective attributes. A feature is the fundamental unit of interest of spatial or non-spatial character, and is graphically represented by either points, lines, or polygons. To permit the graphical overlay and analysis of features at multiple spatial scales, the position in space of a feature is referenced to the grid of a standard map projection system. Sets of attributes form the non-graphIc descriptors of features; both features and attributes are stored, retrieved, manipulated, analyzed, and output using a relational database structure.

Spatial data in a HBES GIS would be structured both as grid cells (raster-based) and as directed line segments (vector-based). Raster data structures facilitate the analysis of multiple map overlays and modeling of surfaces. Vector data structures facilitate data archiving and plotting of high quality interpretive maps. The function of the GIS will be to create digital files from mapped features, and to quantitatively describe these features with respect to their position within a frame of reference, to their spatial interrelationships to other features (topology), and to their characteristics.

The development and integration of GIS technology in the HBES LTER will serve to characterize the nature and spatial patterns of watershed disturbance and the nature and spatial distribution of landform, vegetation, soils, and topographic variables. We expect several important scientific and managerial benefits from the development of a HBES GIS. First and simplest would be an efficient cartographic system for location of study sites and management of site resources. Second, we hope to utilize GIS capabilities to integrate our small-scale, plot measurements of ecosystem structure and function to the watershed scale for comparison with our frequent watershed estimates of water and element fluxes. Extended scaling to the whole Hubbard Brook basin, White Mountain National Forest and the northeastern region of the U.S. may also be possible if related GIS development occurs. Eventual application to global geochemical estimates under the IGBP would be an ultimate goal of such efforts, and linkages to satellite and other remotely-sensed images a valuable tool. Finally, we would expect to be involved in LTER-based, cross-system comparisons of landscape interactions. Development of new concepts and understanding of the interaction of geomorphic and ecological processes and of the general nature of landscapes as a unit of study should result from these comparisons.

Data layers and attributes of the GIS at the HBES LTER site would include, but not be limited to, soil map units and tables of characteristics; surficial geology; bedrock geology; hydrologic variables; relief variables of elevation, slope gradient, and slope azimuth; vegetation data including age-class since disturbance of patches, productivity, community types; and finally landform characteristics. Files would be organized on a watershed basis with the ability to aggregate files for characterizing the entire Hubbard Brook site. Each data layer would be digitized using standard protocols and referenced to a mutually agreed upon ground coordinate system. Given the areal extent of the experimental watersheds at HBEF, we propose to grid polygon files to a 5 x 5 m square cell. This would permit aggregation from forest gap to watershed levels of resolution without severely taxing data manipulation, storage and retrieval, and analysis and output operations of most mini- and microcomputer-based systems. This cell size corresponds well to existing and proposed satellite data for linking watershed processes to the landscape and regional hierarchical levels, as well as to actual scales of permanent plot grids currently existing in the HBEF. Data volumes per geographic data layer covering the entire HBEF would be approximately 0.3 to 0.5 mb well within the range of most microcomputer-based systems.

JORNADA - MAJOR RESEARCH ISSUES RELATED TO COMPUTER USE

The long-term studies of the Jornada LTER center on model of desertification, based on changes in levels of resource distribution and use in space and time. The overall hypothesis being tested is that man has altered a previous, relatively uniform distribution of resources, especially water, leading to changes in community composition and biogeochemical processes that establish and maintain the desertified state of the landscape. Our approach involves three levels of simulation models. Process level models are being developed to elucidate pathways and controls of carbon, nitrogen and water fluxes. These process models are being integrated into ecosystem level models, with less detail, to simulate specific sites within the major plant community types. A landscape level model incorporating explicit flow path relationships between sites, such as imports and exports of water and nutrients is our ultimate modeling objective. This will require integration of the landscape level model with a dynamic GIS to allow us to incorporate landscape dynamics and explore their relationships to ecosystem patterns and processes. Remotely sensed data is an integral part of the GIS and will become even more important as we attempt to extend our findings and results to other areas that are current or potential areas of desertification.

Our research obviously relies heavily on computing capabilities in numerous ways. These include; data management, modeling, geographic information systems, processing of remotely sensed data, statistical analysis, text and graph preparation, and communication. We currently have access to adequate computing facilities to meet the needs of our research program. There is, however, one area where improvement of our capabilities would be immediately beneficial. Our computing hardware is literally spread across the continent. We use computers located in San Diego, California, Las Cruces, New Mexico and Durham, North Carolina. At the present time we are limited to ASCI file communication by BITNET or phone modem communication. The ability to access the various computers being used in the project by a "long-haul" network would greatly enhance the efficiency of our work. This is also true for intersite activities. In the longer-term the development of parallel computing capabilities could greatly enhance our ability to achieve our research objectives. Our modeling efforts and those of other LTER projects involve the integration of models that operate at a variety of spatial and temporal scales. These models represent a hierarchical conceptualization of the systems being studied. Integration of these models into a single simulation requires some type of simplification or averaging of the transfers (input and outputs) across different levels in the hierarchy or the use of extensive amounts of computer time. In addition "bottom-up" process-based models often become inaccurate as their results are extrapolated over larger spatial areas and longer time periods. This problem can be addressed by using "top-down" models to constrain the output of models at lower levels. Parallel computing could allow models at different levels to be run simultaneously in such a way that process based models are controlled or constrained by higher level models. In theory, at least, a parallel computing approach could greatly facilitate our ability to scale-up "patch" models to landscape and global scales. The utilization of this newly developed technology would require considerable development of new approaches to ecosystem modeling and could probably only be achieved through a cooperative effort of many of the LTER programs.

Technological Needs

Agricultural Ecology LTER Site (KBS)

<u>Overall Goals</u>

The Kellogg Biological Station LTER Project is centered on agricultural ecosystems with research foci on ecological constraints to agronomic productivity and on the impact of agriculture in the larger landscape. Our global hypotheses is that agronomic management based on ecological concepts can effectively substitute for reliance on chemical subsidies in production-level agronomic systems.

<u>Computer Resources and Needs</u>

Researchers at KBS enjoy ready access to a VAX 11/780 computer that provides database, statistical, programming, and communications support in a completely networked environment. Included in the network are several dozen terminals, personal computers, supermicro workstations (VAX Stations), and remotely-queried dataloggers. A small image analysis facility is currently under construction. A high speed link to campus provides access to various departmental computers on campus and the campus mainframes via MSUNet. Access to other institutions is provided via Bitnet, directly linked to the local VAX Mail system, and via the MSU-based MERIT network, the newly designated host system for NSFNET.

The major technological needs at KBS fall into 4 categories: GIS systems, graphical analysis, modelling environments, and data management enhancements. Additionally, we see an LTER-wide need for better communication that could be met by a formal commitment to electronic mail by each site.

1. GIS Systems. At present KBS has no GIS software as part of the networked environment. Several GIS packages are in use by different investigators on stand-alone microcomputers, and a major package (ARC/INFO) is available through a campus mainframe, but there is no central KBS facility readily available to LTER researchers. Such a facility would serve to standardize GIS activities at the site as well as provide the access needed to truly exploit this powerful medium. Our need then is both for software (compatible with existing KBS databases and with databases at other sites) and for hardware (specifically a graphics workstation including digitizer dedicated to GIS development and general user access).

2. Graphical Analysis. Associated with GIS needs is a need for a high-quality graphics workstation. This station could be used both for GIS queries as well as for non-GIS-statistical analysis. Despite the availability of microcomputer based graphics packages at the station there remains a very serious need for a centralized facility with scientific capabilities.

3. Modelling Environments. Model-building and running tend to be extremely CPU-intensive tasks. As such, they can be very difficult tasks to undertake efficiently on either microcomputers or multiware mainframes such as the KBS VAX. Efficient programming requires access to a supermicro workstation networked to the larger system. Such a system could provide a modeler with his or her own CPU, with supporting services (database access, tape drives, etc.) provided by other network nodes. At present we have a need for at least one such workstation.

4. Data Management Enhancement:. We see two need for further data management capabilities at KBS. The first is for software development for allowing us to include in the database information that no current database system now efficiently handles. Such information includes methods documentation and data management history. The second need is for dedicated workstations to handle this software development and to provide rapid access to the database in both text and graphical formats.

5. LTER-wide Communications. Communication among various working groups within the LTER network could be substantially enhanced by providing all investigators ready access to an established electronic mail system. We would like to see sites tied into BITNET because it is readily available at no cost to most sites, it ties directly into our local electronic mail system, and there are a number of sites already part of the system. At many sites however such access is constrained by hardware needs, and we would like to see resources made available to bring these sites on-line directly.

Summary of Needs

Our technological needs at KBS can be summarized in the following specific terms:

1) a workstation for GIS development complete with digitizer and software;

2) a graphical analysis workstation with capabilities including but not limited to GIS access;

3) a programming/modeling workstation to provide sufficient power for efficient programming;

4) personnel for modifying existing database software to provide more complete documentation; the workstation needed for this could be shared with item (3) above; and

5) a means for accessing other LTER sites and investigators via electronic mail.

MAJOR RESEARCH ISSUES OF KONZA PRAIRIE

Konza Prairie has benefited from three distinct programs: 1. The Konza Prairie LTER research (1980-present), 2. The NASA-FIFE research (1987-present), and 3. The Fire and Grazing Ecosystem study conducted by Colorado State University (Parton, Schimel et al.; 1982-present). Because of these studies, Konza Prairie has a large and expanding database focused on the five core areas of the LTER effort, and a unique and immense data set focusing on the role of the landscape in influencing surface climatic variables. The FIFE (First ISLSCP Field Experiment, ISLCSP = International Satellite Land Surface Climatology Project) study focused national and international attention on Konza Prairie as a prototype experiment for measuring canopy-atmosphere interactions. Thanks to Bill Parton and others, we have the CENTURY model (e.g., see Soil Sci. Soc. Am. J. 51: 1173), a plant and soil ecosystem model that has the capability to use both the LTER and FIFE data sets to help us try to put together and interpret this magnificent volume of information.

The major research issues at Konza Prairie have been provided for us by an international group of ecologists and biophysicists. The first of these issues has been the major focus of the

Konza LTER effort, the study of long-term effects of fire and grazing on population, community and ecosystem processes of the tallgrass prairie. Recently, our group has become particularly interested in the interaction of climatic and landscape variables on these processes. The second major issue is one currently being added to our LTER effort. This research concerns the interaction of the biota with the atmosphere, including carbon dioxide, water and trace gas fluxes. This research clearly demands that we have an adequate geographic information system and image processing capabilities, as well as systems capable of handling and processing massive amounts of data from such equipment as the Fourier-transformed infrared radiometers, or high resolution spectrophotometers.

We recognize our deficiencies in research expertise at KSU. We need more personnel involved with modeling and canopy-trace gas analyses. We do, however, have plans to resolve these limitations. We plan to hire more LTER personnel in these areas and/or have new faculty positions added in these areas. Also, we continue to attract investigators from other institutions to our site because of its research potential. Given our database and interests, we fully expect Konza Prairie to be in the first group of sites chosen as Biosphere Observatories for the International Geosphere Biosphere Program. Of course, Konza Prairie is a mesic grassland, a warm tallgrass prairie site with a near 50-50 balance of C3 and C4 grasses. Vegetation composition and net primary productivity of our site should be particularly sensitive to temperature and CO_2 changes, which, combined with our present database, provides ample justification for the selection of Konza as an observatory.

Our immediate technological needs have been formulated by evaluating current trends in data processing, along with the specific equipment requirements necessary to participate in the NASA-FIFE program. We anticipate taking over the management and operation of the FIFE database after the Land Processes Branch of NASA chooses to no longer maintain the system. We therefore are leaning towards ORACLE, a SQL Dbase system. As mass storage costs decrease and the speed of micros increase (i.e., optical disks and 386 machines) we see more work done on desk-top systems. We currently envision our long-term hardware needs as follows:

32 bit (or greater) multitasking machine with large (100+ megabyte hard disks),

Image processing board: 1024 x 1024 x 32 bit wide,

Tape drive: able to read various densities (1600-6250),

Mass storage - optical disk (write many - read many), as these become available,

Plotter: large flat bed - 36" x 48", and

High resolution color printer

LARGE RIVER LTER

SUMMARY OF RESEARCH ISSUES

WHICH WOULD BENEFIT FROM ENHANCED COMPUTER CAPABILITIES

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Preface

The Large River LTER site is interested in intersite collaboration and in coupling of remote sensing techniques, geographic information systems, and ecosystem simulation models to scale up from site-specific data and models to regional and global scales, and to scale down from existing global-scale physical models to the regional and site level. Most of these activities would be enhanced by acquisition of specific equipment, software, and expertise which are currently available. These needs are touched upon briefly below, under each research issue, and presumably will be discussed in detail at the forthcoming meeting of technical experts.

However, there are technological and conceptual limits on those research activities which might be pushed back with assistance from the National Science Foundation, perhaps by joint involvement of the Divisions of Biotic Systems and Resources, Advanced Scientific Computing, and Computer and Computation Research. These limits include such obvious things as the rate-limiting step of hand-digitizing maps for input to GIS (which could be overcome with better optical scanners), the large storage requirements for GIS, and the processing power and speed required for most ecosystem simulation models, as they are extended over larger areas.

Not so obvious is the limitation imposed by the prevailing concept of computers as general purpose machines, with applications to specific scientific tasks achieved through software, rather than as machines which could be built for special purposes (Hut, P. and G. J. Sussman. 1987. Advanced computing for science. Scientific American 257(4):145-153). Software for 3-dimensional hydraulic modeling (an essential component of models for lateral exchange of sediment, nutrients, and organic matter between floodplain and river channels) takes years to write and months to transfer from one operating system to another. Hardware can be easier to design and build than software, and the resulting specialized computers can be simple and physically small, according to Hut and Sussman. They describe a machine developed by 3 theoretical physicists, 2 computer scientists, and a technician, which calculated the orbits of the planets in the solar system over a 200-million-year period. The machine was not much bigger than an IBM PC AT and was 60 times faster than a VAX 11/780 with a floating-point accelerator.

It may be useful to include a representative from the appropriate computer science division of NSF at the meeting of LTER technical experts, and to consider the development of specialized computers for 3-dimensional hydraulic modeling (including surface and ground water), near-surface air movements, ecosystem simulation modeling, or other purposes suggested by the LTER site representatives at the 7-8 January 1888 meeting.

Hierarchical Analysis

Large floodplain rivers are spatially complex along both an upstream-downstream axis and a lateral axis extending from the main channels across the floodplain. We are interested in aggregating properties at the level of patches (floodplain forest, floodplain pool, emergent macrophyte bed, submergent macrophyte bed) to describe and explain processes and structure at successively higher levels. Properties of the Mississippi River which may have global significance (e.g., rate of delivery of water, sediment and nutrients from the land to the sea) depend on lower level properties which exhibit thresholds and lag effects and which are strongly influenced by variations in the annual pattern of flood and low flow.

Remote sensing and GIS are useful in defining patches and determining the extent and duration of annual floods. Hydraulic and biological models are used to simulate patch dynamics, interpatch exchanges, and long-term effects of alternative flood regimes, but require more computer power (access to general purpose supercomputers or the specialized computers described in the preface) for 2- and 3-dimensional analysis and expansion to larger geographic areas. Networking would be useful to exchange and analyze data collected on large systems (Mississippi River) by a variety of agencies (USGS, River LTER), and to make comparisons between systems (Mississippi River, Ogeechee River, streams and rivers associated with other LTER sites).

Patch Analysis

We are investigating determinants of patch information and maintenance. Overlay analysis, using GIS, is useful in associating patches with physical determinants (erosional vs. depositional areas, sediment characteristics) and biological determinants (location of patches dominated by consumption adjacent to patches dominated by primary production). 2- and 3 dimensional hydraulic models, coupled with carbon flow models, are needed to determine whether production and export rates from producing patches are sufficient to account for secondary production in the consumptive patches.

Local vs. Basin Control

The basin provides the water which creates the manual flood, and may "top up" the supply of nutrients stored in the sediments of the floodplain, but we hypothesize that high secondary productivity (macroinvertebrates, fish) depends on local primary production, not on long-distance transport of organic matter via tributaries. In order to test this hypothesis, we need to measure primary production in both aquatic and floodplain areas. Remote sensing from aircraft (using 3-band video recorders), rapid and highly automated image analysis techniques, and GIS would all be helpful.

Use of Historical Data to Verify Simulation Models

Maps and hydrographic records are available over a 103-period for the Upper Mississippi River. It is possible to reconstruct the flooding pattern of the pristine river, prior to damming and leveeing of the floodplain, and to simulate some of the properties of the floodplain-river system. Existing simulation models could be started with parameters derived from the historical data, to see if they reliably predict physical and biological features at later times, up to and including the present. Another test would be to input present conditions, and run the models backwards to see how well the output agrees with historical conditions. Once the models were verified with the 103-year record, they could be used with greater confidence to reconstruct the characteristics of the system before the coming of the white man and to make projections over hundreds of years into the future. Trends and effects of natural and man-induced perturbations could be determined. GIS and access to supercomputers or specialized computers certainly would help.

Implementation Issues Which Should be Considered by the Technical Experts

l. New hardware and software requires training of existing staff or hiring of new staff, and these needs and costs should be taken into account. It is important that the tools be made as easy as possible to use, and that technical support bc provided. Existing networking systems are a special problem. Can individual scientists become networkers , or will they need interpreters and operators?

2. Is it more efficient to provide LTER access to a general purpose supercomputer or to build

specialized computers? (See preface.)

3. Is it better to build up computer, GIS, and remote sensing capabilities at every site, or to establish a few centers and make them accessible to all sites via a network? Accessibility is a major problem with the center approach.

Scientific and Technological Planning

Niwot Ridge

University of Colorado (CU) LTER

N.R. French

January 7, 1988

Long-Term Research Directions

The CULTER program is developing in two directions: 1) toward a landscape ecology evaluation which focuses on geographic variation, image processing and pattern analysis; 2) and continuing along an analytical approach in examination of decomposition processes and of chemical-physical, and mineralogical properties of soil in relation to nutrient cycling and disturbance. The pattern of soil movement on slopes has been determined, and vertical movement within soil profiles is under investigation. Property of surface horizons are greatly influenced by eolian dust accumulation, which is being measured. Eolian dust contains wind-blown calcite which tends to offset acid deposition by raising the pH of surface soils. Organic carbon (fulvic acids, short chain aliphatic acids and oxidation products of carbohydrates) are also important in the buffering capacity of alpine soils. The role of dissolved organic carbon on metal chelation has also been studied. The chemical equilibrium of aluminum in alpine soils is highly dependent on concentrations of fulvic acids, H_4SiO_4, and pH. Spatial and temporal variations of 15 constituents of soil solutions are being determined along 3 geochemical catenas. Biological N-fixation rates and dentrification rates are under investigation. Our plan is to continue these measurements on an alpine tundra hillslope after a surface disturbance treatment has imposed on the system.

Our perspective of the alpine landscape is expanding by utilization of image processing technology to compare pattern at different scales. We are comparing satellite images of our site obtained by Multispectral Scanner and Thematic Mapper sensors with color infrared aerial photographs which have been three-color digitized. These will be compared with a digitized version of the Niwot Ridge vegetation map. The immediate objective is analysis of area-perimeter relationships for determination of fractal characteristics of the alpine landscape. These data will initiate the formation of a data base for our soon-to-be-acquired Image

Processing Workstation as part of the Joint Facility for Regional Ecosystem Analysis. This facility is a cooperative effort between INSTAAR and CSES at the University of Colorado, and NREL at Colorado State University. It will serve two LTER sites, the Niwot Ridge tundra site and CPER shortgrass prairie site.

Integration, Synthesis and Modeling

In the current year, we intend to develop a plan for synthesis of information and data on alpine ecosystems, drawing upon the rich data base developed over 30 years of investigations on Niwot Ridge and the Front Range. The objective of integration and synthesis will be to clarify our concepts of ecosystem processes, while our development of a GIS data base will clarify our concepts of ecosystem pattern. The alpine geosystem model provides us with a framework for identification of key subsystem processes and integrations, which will be the focus of efforts to develop detailed mechanistic models for testing our concepts and understanding of ecosystem processes. The Precipitation Runoff Modeling System, which has been used successfully to model streamflow from the upper Green Lakes Valley, has been improved by evaluation of snow depletion curves for the different Hydrological Response Units of the area. The performance of this model will be further improved when our GIS data base can include snow cover monitoring results.

Scientific and Technological Needs

Two important future needs can be identified by the current direction of our research effort. As we conduct detailed measurements on small sample sites, we foresee the necessity to identify all similar sites in the area or on a regional scale so that results can be extrapolated and integrated on a landscape scale. Similarly, as we work with landscape images from remote sensing, there is a need to identify types and patterns at a finer scale of resolution - the mesoscale. We need a remote sensing multispectral scanner that is small and portable, and that will produce data in digital form that can go directly to GIS system. Presently, available radiometers do not have the spectral latitude of multispectral scanners, and the other alternative of photographic representation requires unsatisfactory manipulation to get digitize data. We need a digitizing video monitor with multispectral sensing ability.

Research Benefiting from Enhanced Computer Capabilities

North Inlet LTER Site

Several major research areas have been identified that would benefit directly from access to enhanced computational facilities. Specifically, the highest priority technological requirement is related to mapping and analysis of spatially oriented data. Four research projects which are currently underway would benefit directly from access to this technology:

1) *Spartina* production studies. The relationship between Spartina production and salinity and nutrient regimes is currently being examined. Remotely sensed data have been used successfully to pinpoint high salinity and lower salinity vegetational complexes within North Inlet. In addition, *Spartina* production has been monitored in different habitats (differing in relation to tidal inundation duration and frequency) since the inception of LTER. Recently, the *Spartina* study has been expanded in scope to examine spatial patterns in productivity. Other estuarine systems differing in salinity and nutrient regimes have been added. The ultimate goal of this research is to incorporate the data into a GIS along with elevation data and hydrodynamic models. Remotely sensed data may be used to hindcast productivity changes over time. Resulting spatial models may be useful in assessing the potential impacts of sea level rise or alteration of salinity regimes.

2) Oyster research. Research is currently underway to examine oyster population processes at the supra-organism level Intertidal reef. Specifically,

- Recruitment patterns within and among oyster reefs along two estuarine transects [1 area being in a relatively pristine state (the North Inlet LTER site) and the other site having experienced a recent disturbance event the Wando River which is receiving higher salinity water as a result of the Cooper River rediversion] are being examined.

- The ability of oysters to recolonize disturbance patches of varying size and intensity along the two estuarine transects is also being examined.

This information will be incorporated into a large spatial database for further analysis. The 'Wando River' database is currently in development and contains such factors as reef size, reef matrix depth, biomass estimates, geographic distances (i.e., from ocean, channel, bank, etc.) for each of the 2,115 reefs located therein. North Inlet oyster reefs are currently being aerially surveyed and mapped.

Analysis of this large database will initially focus on robust exploratory methods and proceed to more complex levels including traditional multivariate techniques.

The ultimate goal of this research is to:

- determine the scales of estuarine ecological processes

- relate oyster reef growth to hydrodynamic processes and examine the potential impacts of sea level rise to estuarine natural resources

- further our understanding of supra-organismal responses to disturbance and relate this to traditional recreational and commercial harvest techniques

Initial map and database development as well as exploratory analyses will be performed in a micro to mainframe environment employing existing software (GIMMS, SAS). The final database continuing multilayered thematic data for 1,000's of oyster reefs in South Carolina is ideally suited for inclusion in a GIS for spatial analysis.

3) Waccamaw River study. A model is being developed to examine the effect of point and non-point source nutrient loading in the Waccamaw River. All major point sources have been determined and vegetation maps completed. Hydrodynamic modelling is currently underway. These data sets are ideally suited for inclusion in a GIS to statistically analyses spatial patterns. The ultimate goal of this research is to develop a landscape model which can interact with remotely sensed data for validation and fine-tuning. LANDSAT data would serve as the data input to the model.

4) Impact of salinity on wetland processing. A large study has recently been initiated to examine wetland processing along a salinity gradient. Objectives are to assess point and non-point source inputs and the role that riverine systems play in modifying those inputs along a salinity gradient. The resulting physical, chemical, and biological datasets represent a broad spatial coverage and are amenable to statistical analysis of spatial patterns. The ultimate goal is to develop spatial models of estuarine nutrient processing and assess impacts of habitat alteration.

Three additional technological shortcomings have been identified:

1) Database software. An adequate database software package for the microcomputer environment has not yet been identified. Ideally, this package would run in both a MAC and IBM environment, be both design and user-friendly, and have sufficient links to other software packages. Such a package would, for example, allow a visiting scientist to easily query site climatic data and generate statistics and graphics. [Note: One limitation may be the amount of RAM on our micro's. We currently have 1 Mb or less on each machine and have experienced problems running larger datasets on certain software.]

2) Networking. Currently the MACs and IBMs are not on a network. This capability would considerably ease the burden of transferring data from one machine to another, thereby enhancing productivity.

3) Image storage and retrieval. Thousands of pages of data, field notes, maps, etc. are currently xeroxed and stored in flame proof cabinets. Although this material is infrequently accessed, it is nevertheless important to maintain. We have neither the personnel time nor the money to digitize all records. A reasonable alternative may be to optically scan important old (as well as new) records and store the data as an image in a searchable database. In this manner, old records will be efficiently maintained and cataloged without requiring considerable effort for entry and verification.

NORTH TEMPERATE LAKES LTER

Background for Scientific and Technological Planning Meeting

JAN 7-8, 1988 at NSF in Washington, D.C.

SCIENTIFIC OPPORTUNITIES AND CHALLENGES

1. New concepts and methods for intersite comparisons and intersite testing of ecological theory. We are interested in developing ideas such as the intersite and interyear analysis of variation within and among LTER sites that we have begun through intersite support in fall 1987. This will require one-on-one interaction with persons at other sites, sharing of site data, computer analysis or modeling workshops and joint publication.

2 . Develop and test approaches to extrapolate from our LTER lake site to the northern highland lake district and to lakes in general. Our site can be used to calibrate such projections and extrapolations. One approach will be to develop regional features such as regional connectedness and regional species richness of lakes Instead of the features of individual lakes such as area, pH and specific biota which is traditional in lake typological analyses. A second approach will be to apply island biogeographic and niche theory in conjunction with multivariate community analyses to predict the structure and function of lakes at increasing distances from our LTER site.

3. Use mechanistic analytical models for the dynamics of the structure and function of lake ecosystems and landscapes to develop scenarios of future states and rates and test them against future measurements. Initially we will use the output of global climate models to drive the temperature dependent functions in state-of-the-art models of lake thermal structure and fish growth and consumption. We also would like to try some with water budgets, water levels and lake solute chemistry, carbon storage in and CO_2 release from peatlands, and food web structure and flows. We would like to evolve a similar system for testing Ideas on the accumulation of contaminants in lake systems and will as the opportunities develop.

4. Analysis and interpretation of spatial heterogeneity (patchiness) and pattern in lake landscapes and within lakes using state-of-the-art sensing and processing tools. Landscape patterns of bog evolution since deglaciation would be studied with satellite remote sensing and image processing capabilities of the Remote Sensing Center at UW-Madison, within lake patterns will use acoustic remote sensing, towed florimeters and other instrument packages, and areal photography at littoral zones. Our acoustical technology provides high density data of backscattering from organisms in the water column. With several frequencies of underwater sound the system is analogous to the multispectral satellite remote sensing except that acoustic remote sensing paints an analyzabIe picture of the entire water column across the

lake instead of across the surface of the landscape . The analysis procedures of multispectral remote sensing from space will be applied to these water column data based initially with the acoustic data but in the future with yoyo towing of instrument packages now technically feasible from oceanographic vessels. We also have made areal photographic surveys of the littoral zones of our lakes and wish to use the tools of remote sensing to analyze and interpret spatial heterogeneity of shallow water habitats.

Most important enhancements for our site:

1. Database management software which provides easy access to the data sets. We have found that using SIR as a database management system places the database manager between the researcher and the data. The long term data must reside on a machine capable of manipulating large data sets quickly.

2. The capacity for manipulation and analysis of subsets of the database by researchers who do not want or have the time to expend a major effort on hardware or software specific training. Menu driven access and analysis capabilities would be ideal.

3. The capacity to easily transfer files to among LTER sites and offices and field stations at our site. We want to exchange figures, tables, data and text electronically in usable form,

4. GIS systems hopefully will be available from U.Wisc.-Madison's Environmental Remote Sensing Center and perhaps the Technological Applications Center in New Mexico.

John J, Magnuson, Jan. 5, 1988.

BONANZA CREEK EXPERIMENTAL FOREST (Taiga)

"Successional Process in Taiga Forests"

This study focuses our attention on population and ecosystem level questions within the framework of succession. It capitalizes on a substantial existing base of information and understanding of these phenomena in taiga ecosystems to address hypothesized controls of system development, which previously have not been examined in a comprehensive manner in the North American taiga. Results of this research will greatly improve understanding of the links between resource (moisture, light, nutrients) supply and plant growth, as influenced by herbivores and soil microbial activity.

Specifically, we will examine current theory concerning the influence of substrate quality (i.e. structural carbon, and secondary plant chemicals and inorganic nutrients) on decomposer activity and element supply (especially nitrogen) for plant use. Moreover, the importance of changing resource supply, especially inorganic nutrients, to plant growth, and chemical composition of material flowing to the decomposition process will be considered within a successional context. Examination of herbivore-mediated changes in plant communities, and especially their impact on plant carbon/nutrient balance, and consequently their influence on litter quality is an additional important link in understanding ecosystem processes in a successional framework. These aspects of taiga forest development will be considered on a short and long term observational and experimental basis.

Interior Alaska is an ideal location for carrying out long term ecological research of this nature. Development of a forest industry is just beginning, and any manipulation of forest ecosystems is very rudimentary. Consequently, any findings relative to successional controls may be translated into workable management strategies before major human disturbance. Perhaps, by capitalizing on the results of incisive, long term ecological research, serious errors in ecosystem stewardship, which occur so frequently worldwide, may be averted in interior Alaska.

This study will provide a northern base for long term global programs such as IGBP and links with other global ecosystems. The inclusion of a boreal site in the IGBP is important, because (1) the boreal forest is the northern-most extreme of forested ecosystems and thus provides a valuable contrast to temperate and tropical forests; (2) the boreal forest is the most widespread of any forest ecosystem; (3) the boreal forest should be highly sensitive to CO_2 related climatic change, because such changes are predicted to be magnified in polar regions and the large pool of soil organic carbon could create a positive feedback in the global CO_2 trend; and (4) the boreal forest of Alaska is one of the few areas still relatively unaffected by acid rain and human disturbance, providing an important comparison with plant-soil processes in temperate ecosystems.

Increased technological capabilities would greatly enhance our ability to (1) analyze and catalog our existing data base, (2) collect environmental field data in a manner that can easily be transferred to the primary data analysis computers, (3) summarize and add to existing data bases current data which is presently being collected at our LTER site, (4) communicate and transfer data between existing LTER sites and possibly between IGBP sites, (5) facilitate the use of "real world" data in the computer simulation program, and (6) extend our information base from our intensively studied research sites to a very broad picture of taiga ecosystem function through the use of both geographic information systems and satellite resource analysis.

Computer requirements to accomplish these tasks would include either a dedicated minicomputer with a number of intelligent work stations or a small network of 80386 and 80286 based desktop computers.

Peripheral pieces of hardware should include printers (both laser and a fast dot-matrix), a plotter, an array processor that can be dedicated to image processing and the necessary interface devices that would allow transfer of automatically logged field data using various storage mechanisms (tape or chip) and the primary data computer.

One very necessary set of equipment that would greatly improve data collection and analysis at the taiga site is a complete set of data logging devices that can be used to automatically collect a wide array of environmental information automatically on both long tern control and treatment sites. To a large extent our ability to collect complimentary sets of data on all replicated sites is limited by our access to data logging equipment. The increase in our capability to collect the necessary sets of complimentary environmental data is our highest short tenn priority.

Specific types of software that would be required include the following:

l. Statistical analysis package (SAS-pc or equivalent).

2. Communications software to allow transfer of data logged field information directly into the primary computer.

3. Communications software for both data and text transfer between LTER sites.

4. Computer language compilers Fortran, C, LISP, etc.

5. Geographic information systems.

6. Programs specific to analysis of satellite imagery.