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Scientist
Peter M. Groffman, Ph.D.

December 24, 2001

Dr. Robert B. Waide
LTER Network Office
Department of Biology
University of New Mexico
Albuquerque, NM 87131-1091

Dear Bob,

A group of us here at IES (Likens, Groffman, Pickett, Berkowitz, and Lovett) spent time a couple of weeks ago discussing the White paper on priority setting in the LTER network that was recently produced by members of the LTER Executive, Coordinating and Scientific Initiatives Committees. We believe that this is a strong and useful document for guiding the LTER program into the future. Below are some comments that we thought might be useful.

Particular strengths of the document included:

- An excellent review of history and trends in the LTER program.
- A strong statement of aims and mission (but see comments below). At IES, we take mission statements seriously and we appreciate the thoughtful use of mission, goals, objectives and aims in this document.
- The document does an excellent job of affirming the balance between site-specific and network-wide research foci. We feel strongly that this balance is both critical and central to the success of the LTER program.
- The goals for the future (Box 4) were excellent.

Some suggestions for improvement:

- There could be better separation between the mission statement and various statements of aims, objectives and goals. The presentation would be clearer if there were a short mission/vision statement subtended by specific objectives, aims and goals.

- The list of successes during the 1980's could be more impressive than what is stated. In general, it might be a good idea to separate administrative/structural accomplishments from scientific successes.

- An Executive Summary would be a valuable addition.

- It might be worthwhile to state that resources and partnerships will be necessary to ensure the success of K-12 Education programs in the LTER. Developing these programs is very challenging for many LTER projects, as many of our scientists have no training and expertise in this area. Ways to involve educators – academic and practicing – must be found and fostered.

- It might be worthwhile to state that there is a clear need to assist sites with developing the skills, tools and personnel necessary to deal with increasingly complex administrative challenges of the increasing complex LTER projects.

We were quite impressed with this document. We urge you to consider publishing and widely distributing a somewhat shorter version. It likely would be useful to a wide range of audiences both within and outside the LTER network.

Sincerely,

Dr. G. E. Likens

Dr. A. R. Berkowitz

Dr. P. M. Groffman

Dr. G. M. Lovett

Dr. S. T. A. Pickett

PMG/tlr

asked to rank a detailed list of site and network activities and to indicate how they would allocate their resources among these activities. The final writing was done by the Executive Committee.

3. THE US LTER NETWORK: OVERALL AIMS AND MISSION STATEMENT

As a result of this series of meetings and discussions, the US LTER Network has reaffirmed the following statement of its aims and mission : ***The central, organizing intellectual aim of the LTER program is to understand long-term patterns and processes of ecological systems at multiple spatial scales.*** To achieve this aim, the Mission of the LTER Network is implemented in six, interrelated ways (Box 2):

- ***Understanding*: Gaining ecological understanding of a diverse array of ecosystems at multiple spatial and temporal scales**

  The mission of the LTER network begins with research based at individual sites, each of which has a unique theme. This site-based focus has allowed for key scientific advances at each of the sites, while the common focus on long-term research in a diverse array of ecosystems and landscapes has facilitated broad comparisons and syntheses across sites. Together the network of sites covers a wide range of subjects at multiple temporal and spatial scales.

- ***Synthesis*: Using the network of sites to create general ecological knowledge through the synthesis of information gained from long-term research and development of theory**

  The products of LTER research extend beyond the accumulation of knowledge about diverse, individual ecosystem types. At a higher level, synthesis of this site-based knowledge across the network provides the broader scientific understanding from which new theory is derived and general applications can be developed.

- ***Information Dissemination*: Creating well designed, documented databases that are accessible to the broader scientific community**

  Long-term research demands long-term data. The creation, curation and dissemination of long-term databases is needed to assure that the data resources needed by researchers will continue to be available. These databases must include the additional information required to interpret data (i.e., metadata) as well as the data themselves. By adopting policies that promote the timely sharing of data (both inside and outside the LTER Network), the data can be used in a variety of ways not anticipated by the original collector such as regional, national and global syntheses, thus providing a resource for the broader scientific community.

- ***Legacies*: Creating a legacy of well designed and documented long-term observations, experiments, and archives of samples and specimens**

  Many ecological phenomena change at decadal to century and longer time scales, and it is essential to maintain experiments and observations across periods appropriate to the

questions addressed. The orderly transfer of experiments and interim results from one generation of scientists to the next requires a research design and setting that allows for multiple samplings (some unanticipated), long-term protection from competing uses, and meticulous documentation of experimental protocols. Also essential is a means to store protocols and observations in a manner that is secure and consistently accessible to the scientific community for use in syntheses and cross-site comparisons (both inside and outside the LTER Network).

- ***Training*: Developing a cadre of scientists who are equipped to conduct long-term, collaborative research to address complex ecological problems**

  One of the major lessons from the first 20 years of LTER has been that success both within sites and within the network requires a non-traditional approach to ecological research. This approach is characterized by a commitment to long-term measurements that may yield only a few useful initial results but that are essential to understanding long-term change, by a willingness to work as part of large teams that may have priorities that are different than one's own, by a desire to interact closely with others in order to share ideas and data, and by the need to develop a broad interdisciplinary perspective. Disseminating this approach through the involvement of graduate and undergraduate students, postdoctoral and international scientists, and K-12 educators, students, and the general public can ensure the success of long-term ecology in the future.

- ***Outreach*: Providing knowledge to the broader ecological community, general public, resource managers, and policy makers to address complex environmental challenges**

  Humanity faces increasingly numerous and serious environmental problems that range from local to global in extent, and that must be tackled by institutions at local to international scales. The LTER network and emerging ILTER networks provide the most comprehensive and diverse system of sites for ecological observations on the globe, and research of the LTER network has repeatedly demonstrated the ability of long-term ecological science to address these environmental challenges. Increasingly, LTER research is finding applications in the work of federal, state, and local agencies that manage environmental resources. The synoptic and detailed knowledge of individual LTER sites, and the opportunities for multidimensional comparisons among sites, also represent significant opportunities for other disciplines including social sciences, earth sciences, and basic biological sciences that must be pursued. Finally, knowledge from this breadth of views permits us to identify and anticipate new issues and challenges, test existing ideas about causation, and help provide the science that underpins the processes of open, participatory and forward-looking decision-making.

4. SITE-NETWORK INTERACTIONS FACILITATE THE LTER MISSION

Progress in achieving the LTER Mission begins with the work of individual scientists, students, and educators at the 24 LTER sites (Figure 1). It is their work at the site level that forms the foundation of knowledge, data, observational and experimental legacies, and training that will ensure a lasting impact of the overall LTER program. Data and knowledge gained from

intensive field experience are also key to development of syntheses of site-level information into models that allow prediction of long-term change and responses to human and other disturbances. Site-level synthesis activities often lead to new insights that feed back to affect the future course and evolution of site-level research.

The Network infrastructure also promotes and facilitates cross-site and regional analyses, leading to larger-scale syntheses and to development and testing of ecological theory (Figure 1). In this work the maintenance of a network data base and protocols for data searching and sorting are particularly important. All of these efforts add to the basic body of scientific knowledge of long-term, large-scale ecological phenomena and, because students are deeply involved both at the site level and in intersite and network-level syntheses, they help to increase the numbers of people with appropriate expertise in both research and environmental problem-solving.

Ultimately, both site and network-level activities feed back to the development of scientific capital, which includes well-trained scientists, a well-informed citizenry, and the basic data and understanding that underpin them (Figure 1). This accumulation of scientific capital also leads to new research and new applications of LTER research, including new forms of support for both research and education. Growth of scientific capital also includes interactions with new scientific disciplines, leading to expansion of the scope and applications of LTER research.

5. CORE RESEARCH TOPICS ENSURE BROAD SCOPE

A key feature of the LTER network is the relative independence of individual LTER sites with respect to the specific focus of their research, while at the same time all sites are required to maintain a broad-enough spectrum of research to allow intersite and network-level comparisons. The device used to ensure broad-spectrum research is the requirement that all sites perform at least some research in five "core" research areas (Box 3). Experience to date indicates that this compromise works well: The sites' freedom to develop their own lines of research has allowed each site to take maximum advantage of its own unique combinations of expertise and opportunity, and it has been a major factor in the high overall research productivity of the Network. The requirement that all sites maintain a wide range of research with minimum specification of topics, organisms, variables, and units of measurement has made possible several significant multisite comparisons and syntheses that could not have been anticipated with a more rigid, uniform research design for all sites.

The five core topic areas (Box 3) thus represent a compromise between the need to ensure research opportunities at the Network level while still promoting creative, independent, long-term research efforts at the individual sites. The overall purpose of the core topics is to ensure the development of a program of research with an appropriate balance of opportunities and effort at both the site and the Network levels, and that increases the total productivity of BOTH levels. The topic areas are NOT research objectives themselves, that are expected to be completed in the foreseeable future, but they do require that all sites collect data on a range of topics that are expected to be the subject of future LTER research. It is expected that as the intellectual scope of the LTER program evolves and grows it may be appropriate to revise the core areas occasionally, always with the aim of creating an appropriate balance between site- and network-level research.

Standardization of methods and units is a particularly important, continuing issue. Although additional multisite and network-level research could be done if we were to increase efforts to standardize and/or harmonize measurements, a monolithic design to the network as a whole (all sites identical) is not desired. As with the core areas, the present approach to standardization represents a balance between independence and initiative at the site level and the need for at least some means of cross-site and network level comparisons. Standardization efforts are continuing, however; in several cases thus far where particular comparisons are made at many LTER sites (such as comparisons of climate and soils), detailed "LTER standards" have been developed. Currently, the comprehensive understanding gained at LTER sites is attracting a wider range of monitoring and research from other institutions and agencies, who generally have well-developed standards. Agency programs are adding LTER sites to their monitoring efforts to capitalize on the system-level understanding at sites to help interpret their monitoring results.

6. PRIORITY-SETTING: BACKGROUND AND EVOLUTION OF PRIORITIES

The LTER program has evolved considerably over the past two decades although it has never wavered from its central, organizing intellectual aim: ***to understand long-term patterns and processes of ecological systems at multiple spatial scales***. Each decade of the program has seen major advances both scientifically and organizationally. Broadly speaking, the first decade of LTER (the 1980s) might be termed the Long-Term Research Decade, the second decade (the 1990s) might be called the Large-Scale Research Decade, and the program is currently in the first years of its third decade, the Decade of Synthesis. Major accomplishments and goals in the first two decades include the following:

Long-term Research Decade (1980s):

- **Recognition of long-term frequencies that affect system dynamics, system resets (e.g., fire, disturbance, climate cycles)**
- **Understanding of interactions among ecological processes that change at different rates (interaction of "slow" versus "fast" responses)**
- **Extended temporal analyses retrospectively (e.g. tree rings, paleo-studies) to understand and forecast behavior.**
- **Broadened the LTER view from a focus on ecosystems to an emphasis on ecological systems generally**
- **Development of networking/Network Office functions**
- **Development of data management/information management at sites**
- **"Magnet" role of LTER sites in attracting broad array of other scientific activities addressing behavior/interactions in ecological systems**
- **Expansion to 17 sites and Network Office**

Large-scale Research Decade (1990s):

- **Increased focus on spatial scaling of ecological patterns and processes and spatial-temporal interactions**

- **Role of land use and natural and anthropogenic legacies**
- **Broader representation of ecosystem types including human-dominated urban systems**
- **Collaboration with physical, social and economic sciences**
- **Cross-site comparisons testing generalizations**
- **Synthesis (often for science themes not directly addressed by core areas)**
- **Interaction/collaboration with non-LTER sites and programs including development of international interactions (ILTER)**
- **Development of LTER Network Information System and increased network-level data use and data exchange in cross-site and synthesis activities**
- **Increased use of LTER as an experiment to evaluate NSF initiatives (site augmentation, urban ecosystems, social science collaborations, schoolyard lter)**
- **Establishment of National Advisory Board**
- **Expansion to 24 sites; ~1200 scientists/students**

7. THE THIRD DECADE OF LTER: A DECADE OF SYNTHESIS

The LTER Network is now poised for a decade of synthesis, in which the data and knowledge gained over the past twenty years, plus current studies, are brought together to reach new levels of understanding of long term ecological patterns and processes. This synthesis is expected to lead to new research directions and new data gathering as well, driven by the new insights to be gained from the unique opportunities now available. Synthesis opportunities exist at the site level, at the network level, and through incorporation of new perspectives brought by other scientific disciplines to LTER. The range of topics is very broad, from intensive multidisciplinary analyses of patterns and processes in individual ecosystem types to comparisons among ecosystems across a wide range of climate, biodiversity, and interactions with human populations. To help maximize the impact of LTER research over the next decade, five key goals have been identified (Box 4).

Goal 1: Maintain the quality of science and integrity of core measurements at LTER sites.
Research at the 24 individual LTER sites is the foundation of the LTER program and will continue to be so over the next decade. Each LTER site has three principal, overlapping goals. These are:

1. To increase the understanding of ecological patterns and processes that characterize each site, through long-term research, experimentation, monitoring, and synthesis (i.e., by intensive analysis of the ecosystems and their biotic and abiotic components at each of the 24 sites).
2. To maintain a broad-based, multidisciplinary program of long-term ecological research at the site so as to ensure diverse opportunities for future (often unanticipated) multisite and network-level research (i.e., research in the Five Core Research Areas defined in Box 3).
3. To conduct long term ecological research on focused issues that are chosen by the investigators at the site.

Achieving these goals in the context of long-term ecological research requires each site to achieve a fine balance of its human and other resources, maintaining continuity of key long-term

measurements and experiments while always allowing for development of new ideas, new methods and measurements, and new disciplines that build on the existing research base. Management of this effort also requires consistent communication with the Network and with the Network Office, to ensure success in achieving Network goals. Major tasks include:

- Identifying core measurements, experiments, and research questions, and planning for their evolution and stewardship
    - Site: define what a core activity is for that site, define which are the core measurements, make a commitment to collect them, preserve samples, share with other PIs at the site ASAP.
    - Network: define core areas of research (Box 3), define network science themes,
    - Network Office: promote comparable measurements among sites, compile and distribute lists of core measurements collected by each site
- Continually adding to the core database to add basic understanding of the system. Build data in multiple dimensions as well as over time (in other words not all "core data" have to be long-term time series.) Basic descriptions of soils and of the genetics, population and community characteristics of flora and fauna, and organic matter and element distribution provide important context for interpretation and recognition of change.
    - Site: set aside funds for 2-3 year studies to complete studies in areas not included ("fill in the holes"); develop long-term plans for the components of the system that will be studied over the next 10 years. Core descriptions and measurements should not be archived and forgotten, but must be continually examined to guide the direction of future measurements
    - Network: share expertise among sites to help sites explore new planned research areas.
    - Network Office: provide support for Network activity, e.g. promoting database compatibility for core measurements at the sites.
- Continual improvements to data access and integration
    - Site: systematic review and use of data, make data available to other sites for cross-site comparisons. Develop data management system that allows for easy search and retrieval.
    - Network: encourage the sites to share data with other sites and non-LTER scientists, seek opportunities to increase core data comparability (e.g., after science synthesis efforts), share expertise in data management
    - Network Office: promote database management activities and do research to improve data quality and efficiencies of data management.
- Stay on cutting edge of technology to increase efficiency, improve reliability and consistency, observe new phenomena, and improve resolution of observations.
    - Site: research, test, and implement new technologies. Assure that quality is maintained at desired level, inter-calibration with old technology
    - Network: share experiences, provide expertise to other sites, provide sites with guidelines for minimum standard capabilities for various measurement categories.
    - Network Office: foster sharing of technology ideas (i.e., provide travel funds for sites to interact, website of ideas/what's new)
- Include fresh perspectives, expertise, collaborations and comparisons (e.g. increase breadth of standard ecological expertise)

  - Site: identify areas needing new perspectives and expertise and seek funds to support these efforts.
  - Network: serve as a source for some of the expertise and organize workshops around themes including techniques.
  - Network Office: provide funds for start up costs of efforts. Organize All-Scientist Meetings to include outside expertise.
- Legacies/archives.
  - Site: maintain quality and continuity of measurements, plan for studies to be passed from one generation to the next, and provide facilities to store samples and data.
  - Network: set minimum standards for archives, define possible investments in archiving infrastructure, and recommend types of samples to be archived.
  - Network Office: facilitate development of resources to store data and samples. Compile and distribute lists of archived data and samples that are related to core measurement programs, provide relationships to other archives.

Goal 2: Increase the pace of synthesis through activities such as site volumes, network-wide synthesis projects, multi-site synthesis projects, and database development

A wide range of synthesis activities are already under way within the LTER Network, with a wide range of products including a series of books about individual LTER sites, focused collections of papers, review articles, conceptual papers, quantitative multisite comparisons, and diverse modeling and scaling papers. A strong consensus has been reached within the LTER community that over the next decade these activities should be expanded and should become viewed as part of the normal course of operations at both the site level and the network level. There is also strong agreement that these are also important opportunities to include researchers and research results from outside the LTER network. The components of this synthesis effort should include:

- Site volumes: Two volumes have already been published (KNZ and NWT), and several others are nearing publication. These volumes are valuable because they provide in one place a synthesis and summary of what is known about a particular ecosystem or landscape, its environment, its plant, animal, and microbial components, and its interactions with neighboring systems and the globe. The volumes also describe interactions with human populations, and the responses of these systems to both human and natural change in environment at multiple time scales. In addition to summarizing knowledge about individual sites, the volumes are an important part of the foundation for multisite comparisons and other synthesis activities leading to general understanding of controls over ecological patterns and processes globally. *By the end of the decade, a complete set of volumes for all currently existing sites should be available, produced at a rate of 2-3 per year.*
- Network-wide syntheses:
  - **Focused Topic Meetings**. For several years LTER Network has used its fall Coordinating Committee meetings to explore scientific themes that are of interest throughout the sites. The topics for these meetings are chosen by the hosts of the CC meetings and have included "Biodiversity and Productivity", "Climate

Variability and Ecosystem Response", "Primary Production", and "Social Science and Long Term Ecological Research". Often the meetings have been followed up by smaller, focused meetings to allow further discussion, data preparation, or quantitative analyses of multiple data sets. Products are diverse and include major review articles (e.g., Waide et al. 1999), individual journal articles (e.g., Mittelbach et al. 2001), a book (Greenland et al. in prep), and collections of related papers based on presentations at the meeting (in prep). *The Network is committed to supporting one of these synthesis efforts every year, initiated at its fall Coordinating Committee meeting.*

- **All Scientist Meetings**. In the first 20 years of LTER, there were four All Scientist meetings. These meetings were remarkably successful at stimulating diverse cross-site research and synthesis activities by students and scientists at all levels. In addition to centrally-planned plenary sessions, most of the meeting time was available to any individual or group for discussions on topics and in formats of their choosing. After the fourth meeting at Snowbird in 2000, funds were made available for follow-up workshops on over 20 different topics; these activities are currently in progress. A consensus exists that these meetings were valuable in stimulating synthesis at all levels, particularly among students and other non-PI participants. *Additional support will be needed, but the goal is to hold All Scientist meetings every three years over the next decade (in 2003, 2006, and 2009), including support for follow-up activities that lead to publications or other synthesis activities such as the design of new multisite comparisons or new and novel, integrated multidisciplinary research.*
- **Books and special journal issues**. At irregular intervals the Network will continue to produce special volumes such as the recently-published volume on standard methods of soil ecological research at LTER sites (Robertson et al. 1998), and special journal issues such as the special issue of BioScience on LTER research that was published in 1990 (Callahan, Franklin, Magnuson, and Swanson articles). Articles for a second LTER issue of BioScience are now nearing completion (Hobbie), and a book on primary production methods is in the planning stages. *Within the next decade the goal is to produce at least two books and two special journal issues on LTER research, aimed at the general scientific reader.*
- **Committee on Scientific Initiatives.** The Committee on Scientific Initiatives (COSI) is a standing committee of the LTER Network, charged with identifying and helping to develop new opportunities for LTER in research, education, and outreach. *Over the next decade, COSI should meet annually to develop synthesis recommendations and research priorities.*

- Multisite syntheses and working groups. Over the past decade there has been a large increase in the number of smaller groups of investigators interested in bringing together ideas and data on a wide range of topics that are best addressed at LTER sites or using long-term data and experiments. Often these include investigators from outside the LTER network; frequently these are instigated by those outside the network who see an opportunity created by LTER research. Many of these groups were formed at the last All Scientists meeting in 2000, with follow up support from the Network. *Over the next decade the goal is to regularize this activity including support for small meetings and*

planning sessions. About 6-8 of these groups per year should be supported (=20-25 following each triennial All Scientist meeting).

- Support for individual investigators, students, and postdocs. Over the past 20 years, occasional investigators, students, and postdoctoral fellows have developed individual synthesis activities within the LTER network as part of their sabbatical leaves, with support from NCEAS, and from a variety of other sources. *Again, these activities should be regularized over the next decade, so that at any time at least one senior investigator, 2-3 postdoctoral fellows, and 2-4 graduate students can participate in synthesis activities as their primary effort. By the end of the decade, a separate program of support for student participation in synthesis efforts and cross-site research should be established.*
- Database development and informatics. Virtually all of these synthesis efforts require the bringing together of diverse, long-term data sets, with associated problems of compatibility, coding, transformation, sorting, and searching. *There is thus a particular need to establish within the next decade a program of logistical support for LTER-related synthesis efforts, with a focus on database development and informatics techniques optimized for ecological research.*

Goal 3: Increase experimental and comparative cross-site research

The creation of the LTER network has also created important opportunities for new research, particularly cross-site research focused on explaining the variation in ecological processes and patterns within the major biomes and among contrasting ecosystem types. The wealth of knowledge about each LTER site, particularly their long-term records of observation of multiple interacting variables, provides essential context for interpretation and analysis of similarities and differences among sites. Key questions, such as the relative sensitivity of different systems, populations, or processes to a particular kind of environmental change, can be answered more clearly in the context of this extensive background of information.

Cross-site research includes both experimental manipulations and comparative, long-term observations. The feature that distinguishes cross-site research from the more qualitative comparisons and multisite syntheses described under Goal 2 above is that cross-site research is designed from the beginning for comparative purposes. Detailed decisions about units of measurement, definitions of variables, and experimental treatments are not necessarily the same as would be made when only a single site is involved. In practice, implementation of cross-site research may be as simple as adding a new set of complementary measurements at one site, to match those already made at another; on the other hand it may involve carefully developed compromises in the selection of an experimental treatment, reflecting contrasting initial conditions and investigator perspectives.

Cross-site research is already growing within the LTER network, frequently including both LTER and non-LTER sites and investigators. Support for this research has come from *ad hoc* collaborations, from independently-funded, focused projects, and from two special NSF competitions for cross-site research. The growth in demand for this kind of research, however, has been much greater than the increase in available mechanisms. Over the next decade,

individual LTER sites, the Network as a whole, and the Network Office can act to increase Cross-site research in several ways:

- Site level. A few simple steps would go a long way, including:
  - Identify priorities and include plans for cross-site research in routine planning at site level, including renewal proposals
  - Increase use of standard methods and measurements where appropriate. This must be done without constraining the sites' current ability to design a broad, multidisciplinary research program that optimizes research productivity *at each site*, consistent with the five core LTER research areas (Box 4).
  - Use annual supplemental funds for cross-site research
- Network level.
  - Agree on common measures (units) for comparison in cross-site research.
  - Use occasional Coordinating Committee meetings to plan explicit cross-site research with "standard" experiments and measures.
  - Develop "Center Expertise" within LTER Network for measures not taken at all appropriate sites and coordinate sampling/analysis (requires new funding).
  - Promote collaborations with other networks on cross-site issues.
- Network Office
  - Develop cross-site planning workshops and training for consistent sampling.
  - Provide personnel for cross-site data analysis
  - Provide technical support for analysis and interpretation of long-term data sets
  - Co-fund sabbaticals for cross-site analysis.
  - Provide student fellowships for cross-site analysis
  - Fund cross-site "calibration" studies to get various measures into comparable units for cross-site analysis.

- Several additional steps should be taken that are outside the control of LTER Scientists. Perhaps the most important of these is for NSF to continue to hold periodic "Cross-site" competitions. Second, much more could be done, by both scientists and funding agencies, to advertise the availability of LTER sites for cross-site research funded by other programs within NSF, and by other agencies.

Goal 4: Facilitate multidisciplinary and interdisciplinary research with disciplines not now well-represented in LTER efforts (e.g., physical, social, economic, and computer sciences and relevant subdisciplines of biology such as genomics, evolutionary biology and systematics, and microbiology).

Long-term, large scale ecological research requires a multidisciplinary approach, and this is reflected in the diverse groups of investigators with complementary skills that can be found working at all LTER sites. As the research at each site and across the network matures, however, new opportunities and new questions continuously arise that require new expertise to address effectively. At the same time, scientists from a wide range of disciplines outside the traditional ecological fields increasingly see links to the research done at LTER sites. Clear opportunities exist for interaction with physical/earth scientists, with environmental engineers, and with social and economic scientists that would greatly expand the range of application of LTER research.

Within biology, clear opportunities exist for expanded interactions with evolutionary biologists, molecular biologists, microbiologists, and in the realm of biodiversity and systematics.

Over the next decade, the LTER network plans to expand the range of its interdisciplinary and multidisciplinary collaborations in three general ways: (a) by increasing its efforts to foster a positive environment for multidisciplinary research, (b) by enlarging its vision of multidisciplinary research, and (c) by lowering the barriers to multidisciplinary research that are often perceived by those outside the program. Specific steps should include the following:

Site Level:

- use site resources to promote research by new disciplines
- encourage social, physical, and other scientists to submit requests for funding.
- have researchers come together to develop shared questions.
- Increase allocation of time & energy to "big picture" thinking (synthesis is improved by interactions among multiple disciplines).
- Hold multidisciplinary workshops to inform peers. It is especially important to communicate with collaborators from disciplines that do not traditionally emphasize collaborative research or that have not had the opportunity for long-term research.
- encourage submission of NSF-IGERT proposals.

Network Level:

- Work to prioritize areas of importance and needs for new disciplinary involvement
- Periodic reexamination of five core areas (Box 4) to ensure continued relevance with respect to LTER priorities and disciplines in the context of understanding ecological systems.
- Periodic reexamination of core data sets. Attention needs to be given to what core data should be collected across all sites both to ensure comparison studies, but also to encourage as-yet-unknown possible collaborations.

Network Office Level:

- recruit scientists by providing seed money. Intellectual engagement can initiate a dialog, but carrying forth with direct collaboration and/or the collection of initial data involves real costs that may not easily be covered by site budgets.
- The network office can fulfill a valuable role in encouraging the collaboration within the network, but in particular fostering inputs from outside the network, including other agency programs.
- interaction at other conferences. The All Scientist meeting has traditionally been tied to the Ecological Society of America meetings, which do not typically draw a wide cross-section of disciplines. In order to increase the visibility and recruitment potential of allied disciplines, other venues should be sought, e.g., AAAS or AGU.
- encourage submission of IGERTs.

- History & importance of the LTER. Incoming collaborators need to be introduced to the specific merits and modes of operation of the LTER network.
- Specific efforts should be directed to drawing together the widely scattered documents and oral history associated with LTER. This repository of information about the origins and direction of the LTER can serve to benchmark the trajectory of research and emphasize the distinct importance of the approach.

Goal 5 : Extending the use of LTER knowledge in education, policy-making, management and public understanding at the site level, the Network level, and by the Network Office

The ultimate goal of long-term ecological research is to develop an understanding of ecological systems that is both useful and relevant. To achieve this goal requires outreach to a number of both scientific and non-scientific groups using a variety of mechanisms for communication. Outreach activities are diverse but include (A) development of external relationships with other agencies and research and policy organizations, and (B) development of a wide range of educational programs such as the current "Schoolyard LTER.".

A.) Relationships with other agencies and research organizations

- At the Site Level, all LTER sites already cooperate formally or informally with local government, with the owners of the land on which the sites are located (state, federal, local, university, or private), and with local citizens and citizens' groups. LTER scientists frequently advise these interest groups on environmental and other issues related to their knowledge of the local and regional ecology. One goal for the future is to recognize and support this effort more directly, by providing consistent funding support for local outreach activities.
- At the Network level, LTER already has a Memorandum of Understanding with the US Forest Service allowing formal collaboration. Five LTER sites (Hubbard Brook, Luquillo, Andrews, Baltimore, and Bonanza Creek) are located at least in part on Forest Service land and strong collaborations with Forest Service Personnel have developed. An important next step is to develop similar relationships with other agencies such as the BLM, USDA-ARS, the National Park Service, and the US Fish and Wildlife Service where long-term research projects already exist and where several additional current LTER sites are located.
- At both the Site and the Network levels, we must build relationships with long-term monitoring and research programs such as those of EPA, NOAA, and USGS. We must also start speaking the same language as the agencies, or at least learn how LTER research designs and protocols complement or parallel others. For example, when EPA talks about monitoring environmental health, they qualify sites according to a "tier" system in which different sites have different levels of expertise and involvement. Development of standard protocols is uneven within the LTER network, with the exception of some climate and soils research, where some standards have been developed. Benefits to LTER would include building LTER science through

increasing infrastructure and resources, and the collaborations would increase applications of LTER science.

- The Network Office can help significantly by coordinating these efforts, specifically including:
  - Development of a comprehensive list of agencies cooperating with LTER sites and the nature of the cooperation.
  - Organization of an annual presentation of LTER results and activities, to be held in Washington DC for the purpose of informing the federal agencies about LTER. The first of these is already scheduled for February, 2002, at NSF.
  - Support (through cooperative agreements or other means) for agency staff to spend sabbatical or leave at the Network Office or to work with individual sites or groups of sites on common interests.

B.) Build relationships to benefit formal and informal education at all levels. All sites have strong graduate and undergraduate training programs, including participation in the NSF REU site and supplement programs. A recent network-wide addition to educational programs is the Schoolyard LTER activity (SLTER), supported by annual supplemental funds. Most sites have additional education or outreach programs as well. In the future, K-12 education and informal education in particular should be strengthened by building stronger, more predictable relationships with NSF educational programs and with those of other agencies. This would reduce current stresses on LTER sites and would benefit cooperating organizations by providing infrastructure, funding and access to LTER science. Many organizations have been active in involving K-12 students in science and the transition to using SLTER may be fairly simple. Developing such relationships would also provide a basis for continuity when supplement funding structures change. Examples include:

-GK-12 grants (SGS)
-EPA's EMPACT local site funding program (HBR)
-USDA's ARS (JRN)
-GLOBE (BNZ)
-Local school programs (JRN,)

K-12 partnerships have in general been productive avenues for educational outreach, and most sites have expressed interest in building these partnerships further. Other avenues have also been successful, but schoolyard ecology seems to be a particularly effective network-wide opportunity to extend LTER science to the larger community. In some cases these take the form of K-12 field trips to sites and follow-up classroom visits by LTER scientists, with further involvement aided by LTER-sponsored internet connections and minor research equipment. Often these are formalized relationships with specific schools and programs. In other cases the target audience is teachers rather than students. And in a few cases external funding is being used to provide larger, more formal K-12 outreach. In one of these cases a site is part of a GK-12 grant, in another case a site has a major EHR award to partner with secondary science teachers.

Site Level

- Develop local K-12 linkages
- Share successful strategies with other sites
- Pursue external funding as appropriate to build on existing programs

Network Level

- Share success stories among sites
- Help to develop assessment activities

Network Office

- Provide summary of existing K-12 outreach efforts
- Sponsor workshops to coordinate and develop successful programs
- Help to identify external funding sources or agency partnerships

BOX 1. STAGES IN DEVELOPMENT OF THIS DOCUMENT

- August 2000 — LTER Coordinating Committee, LTER All Scientists Meeting, Snowbird, Utah
- November 2000 — LTER Executive Committee Scientific Initiatives Committee Fort Collins, Colorado
- December 2000 — Survey of Site and Network Priorities
- January 2001 — LTER Executive Committee LTER Site Lead Principal Investigators Sevilleta NWR, New Mexico
- February 2001 — LTER Executive Committee LTER National Advisory Board NSF, Arlington, VA
- April, 2001 — LTER Executive Committee LTER Coordinating Committee Tempe, AZ

BOX 2. THE MISSION OF THE US LTER NETWORK

The central, organizing intellectual aim of the LTER program is to understand long-term patterns and processes of ecological systems at multiple spatial scales. **To achieve this aim, the Mission of the LTER Network is implemented in six, interrelated ways:**

Understanding**: Gaining ecological understanding of a diverse array of ecosystems at multiple spatial and temporal scales**

Synthesis**: Using the network of sites to create general ecological knowledge through the synthesis of information gained from long-term research and development of theory**

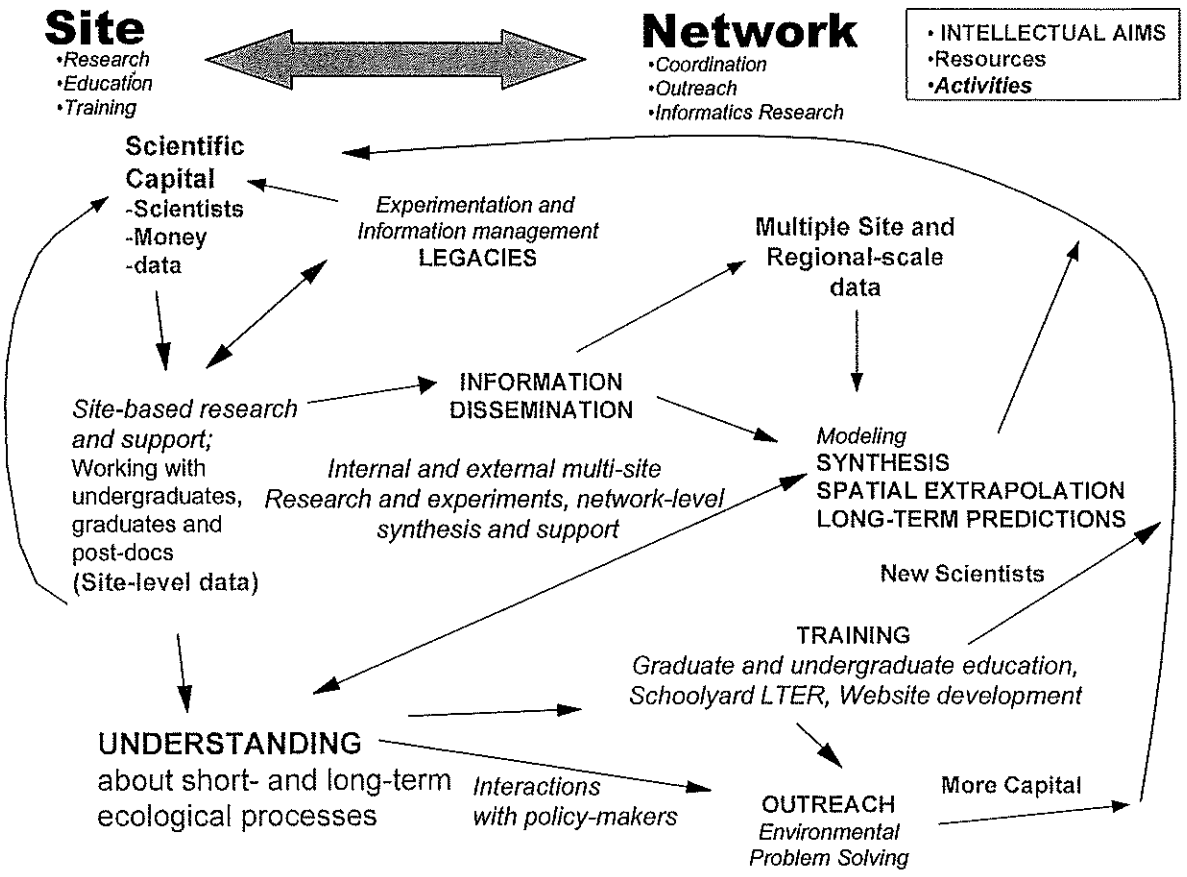
Information Dissemination**: Creating well designed, documented databases that are accessible to the broader scientific community**

Legacies**: Creating a legacy of well-designed and documented long-term observations, experiments, and archives of samples and specimens**

Training**: Developing a cadre of scientists who are equipped to conduct long-term, collaborative research to address complex ecological problems**

Outreach**: Providing knowledge to the broader ecological community, general public, resource managers, and policy makers to address complex environmental challenges**

Figure 1. Flow diagram of LTER site-network interactions



BOX 3. FIVE CORE RESEARCH AREAS AT ALL LTER SITES

- Pattern and control of primary production
- Spatial and temporal distribution of populations selected to represent trophic structures
- Pattern and control of organic matter accumulation and decomposition in surface layers and sediments
- Patterns of inorganic inputs and movements of nutrients through soils, groundwater and surface waters
- Patterns and frequency of disturbances

BOX 4: GOALS FOR THE THIRD DECADE OF LTER

1. **Maintain the quality of science and integrity of core measurements at all LTER sites**
2. **Increase the pace of synthesis through activities such as site volumes, network-wide synthesis projects, multi-site synthesis projects, and database development**
3. **Increase experimental and comparative cross-site research**
4. **Facilitate/increase multidisciplinary/interdisciplinary research and synthesis efforts with other disciplines (e.g., physical, social, economic, computer sciences)**
5. **Extend use of LTER knowledge in education, policy-making, management and public understanding**