Technology Development in the LTER Network

Status Report on Geographic Information Systems, Remote Sensing, Internet Connectivity, Archival Storage & Global Positioning Systems

David Foster & Emery Boose

Harvard Forest, Harvard University

Petersham, Massachusetts

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This report was prepared in response to a request from the National Science Foundation to analyze the status of the Long-Term Ecological Research (LTER) Network technical supplements and to assess future technical needs. It provides a history of technical supplements in 1989 and 1990, and a "snapshot view" of several important technologies across the Network as of September 1990. Since that time, use of Ingres as a relational database management system has become more widespread across the Network. In addition, upgrades of ERDAS (version 7.5), ARC/INFO (version 6.0), and GRASS (version 4.0) are commonly being utilized. Recommendations for an updated minimum standard installation are currently being prepared for later publication by the LTER Network Office.

RECOMMENDATIONS

Support from the National Science Foundation (NSF), over the last two years has produced dramatic technological improvements across the Long- Term Ecological Research Network. Major accomplishments include the establishment of competent geographic information systems (GIS) at every site; the acquisition of satellite data and aerial photography for every site; the acquisition of global positioning systems (GPS) units that can be shared across the Network; and the training of representatives from all sites in the use of these technologies.

The original recommendations of the Shugart Committee (1988), developed and augmented over time as described in this report, remain sound goals for technological funding of the LTER Network by NSF. This report recommends that the following areas be targeted for technological funding in the near future:

INTERNET CONNECTIVITY

The goal of complete Internet connectivity, following the steps outlined in the Connectivity Report (LTER Network Office Publication No. 7, Internet Connectivity in the Long-Term Ecological Research Network 1990), is of great importance. Internet connectivity is essential for many of the Network-wide activities discussed in this report, including real-time exchange of manuscripts and data and real-time access to distributed data bases or remotely-mounted satellite image files.

REMOTE SENSING

The sites that currently lack remote sensing capability (about six sites) should have the opportunity to acquire it. Acquisition of ERDAS or similar systems would permit these sites to take advantage of remote sensing data acquired by the Network. Network acquisition of remote sensing data, funded for 1991 only, should be supported on an annual basis, as recommended by the Gosz Committee (1989), to provide data for temporal as well as spatial analyses.

ARCHIVAL STORAGE

High-capacity data storage systems-in most cases optical disk systems--are rapidly becoming essential at all sites to handle the volume of data associated with large databases, GIS, and remote sensing. Optical disks provide a physical method for the exchange of large data sets.

GLOBAL POSITIONING SYSTEMS

Two more pairs of Pathfinder GPS units, to be located in the central and northeastern United States, would alleviate logistical problems and improve Network-wide accessibility to these units.

DATABASE SOFTWARE

The need to acquire new database software, especially software that supports structured query language (SOL), was discussed at the 1990 LTER Data Managers Workshop (LTER Network Office Publication No. 10, Proceedings of the 1990 LTER Data Management Workshop, Snowbird, Utah, 1990). Some sites will need to acquire SOL software in order to participate in Network projects such as the distributed climate database. In general, the Network would like to take advantage of the many ongoing improvements in database software design.

AUTOMATED DATA ENTRY

Hardware and software for the automated collection of field data in electronic format and direct transmission and entry into LTER computers would improve speed and accuracy of data collection.

The LTER Network should continue to study new computer-related technologies as they become available, as well as other technologies outlined in the Gosz Committee Report.

SUMMARY

Since its formation in 1979 the LTER Program has expanded to form a network of IS sites. During the course of this development a number of committees within LTER have recommended that NSF support the acquisition of common technological capabilities at the sites in order to enhance integrated studies and to improve information exchange. Major recommendations have covered the areas of GIS, remote sensing, connectivity, data storage and GPS. The National Science Foundation has responded to the recommendations by providing supplemental funding for technology acquisition.

This report assesses the progress made towards technology development in the above areas across the LTER Network. It concludes that dramatic improvements have been made at all sites during the past two years, improvements that have had a major impact on individual site research and the ability of LTER to operate as an integrated network.

or accomplishments include the establishment of competent GIS systems at every site, the acquisition of satellite data and aerial photography for every site, the acquisition of GPS units that can be shared across the Network, and the training of personnel in the use of these technologies. The report recommends that the LTER Network seek to complete the technology development proposed by the original working groups and to study additional areas of technology development for future consideration.

INTRODUCTION

In September 1990 workshops on GIS, remote sensing, and GPS were held at the All Scientists Meeting of LTER in Estes Park, Colorado. As part of the GIS Working Group workshop, David R. Foster and Emery R. Boose (Harvard Forest LTER) polled all sites on GIS and remote sensing capabilities in order to assess the state of the Network, and to provide accountability to NSF on the effectiveness of the supplemental funding program in providing technology development and in promoting research, communication, and management activities. This document is an outcome of that workshop, with a broadened scope to include Internet connectivity, archival storage and GPS. Acknowledgement is given to James Brunt (Sevilleta LTER), William Michener-(North Inlet LTER), Rudolf Nottrott and John Vande Castle (LTER Network Office) for their cooperation and assistance in compiling this report.

HISTORY OF MSI & TECHNOLOGY SUPPLEMENTS

As background to the current analysis it is useful to review the development of the minimum standard installation (MSD and the funding initiatives for technology acquisition within the LTER Network. The following discussion highlights important stages in the emergence of a long-range technological plan in the LTER Network and reviews major workshop activities and funding opportunities.

The first formal planning for technological improvements is summarized in the report of the NSF advisory committee on scientific and technological planning for LTER projects, chaired by H.H. Shugart. On the basis of meetings with representatives of all LTER sites and with technical experts this committee made the following recommendations (Winter 1988) for priority NSF funding:

- **acquisition of GIS capability with compatible data formats across the LTER Network;**
- **development of a Network remote-sensing analysis capability; and**
- **augmentation of local- and wide-area computer networks (LAN and WAN) in the LTER system.**

More broadly, the Shugart Committee noted that the LTFR Network requires a minimum level of common technological capability and an ability to communicate rapidly in order to function as a coordinated group. The Committee concluded that GIS represents "the area offering the single most important technology advance for ecosystems studies in the LTER."

At the LTER Coordinating Committee meeting at Kellogg Biological Station in November 1988 representatives from all of the sites recommended that NSF enhance the development of common technologies in the Network through the funding of MSI supported by supplemental funding. An LTER Worksheet was drawn up describing the MSI as follows:

- **a GIS system-small multi-user computer with high-resolution color screen, digitizer, plotter, ARC/INFO software, half-time technical person;**
- **a LAN and a WAN network connecting at least some local computers, with access to a WAN such as NSFNet through a host**

computer;
- **a high-capacity data storage system-optical disk drive (either WORM or erasable).**

Two LTER working groups were established at the Kellogg meeting to further explore technological development, a GIS group chaired by David R. Foster and a general technology group led by James Gosz (Sevilleta LTER). The GIS working group report built on recommendations at the Kellogg meeting that supplemental funding be directed towards enhancement of GIS and LAN/WAN. Robert Robbins, the NSF representative in the GIS working group, distributed a questionnaire across the LTER Network that concluded: (1) capabilities and facility support in these areas across the Network were highly uneven and generally poor, and (2) the configurations of software and hardware at sites supporting these activities were diverse. The GIS working group endorsed the MSI specification, while recommending that specific hardware and software choices were less important than compatible data formats, and that all sites acquire both vector and raster GIS (compatible with ARC/INFO and ERDAS). 'Me group regarded the MSI as a highly competent system that would provide a standard to enhance research, management and communication activities across the LTER Network.

The Technology Working Group reviewed technologies not represented by the MSI. The group's report focused on four types of research that would drive the acquisition of new technology and that were thought to be important in terms of their relevance to LTER goals, urgency in implementation, expertise available, and cost. In order of importance, the four research areas identified include:

acquisition of satellite imagery for all sites;

biospheric/atmospheric interactions and measurements;

process modeling and spatial analyses,

and comparative experimental technologies.

A series of additional important technologies was also listed.

On the basis of the strong consensus reached at the Kellogg meeting, the content of the two working group reports and a commitment within NSF to improve technological capabilities within LTER, two competitions for supplemental funding were held (February 1989 and 1990) with an emphasis on technology acquisition. The majority of proposals sought to develop site competency (MSD or additional strength in the areas of GIS and connectivity. Some remote sensing capabilities and other research support were also requested. The results of these two competitions, in terms of the implementation of the acquired equipment, are the focus of much of this report. Funding for technologies identified in the Gosz report has been largely restricted to Network-wide acquisition of remote sensing imagery, which is also addressed below.

During 1989 a series of workshops were funded by NSF, either through the LTER Network Office or direct grants, to introduce principal investigators (Pls) at the LTF-R sites to some of the major technologies. These included the Wide-Area Networking Workshop (Urbana, Illinois/April 1989); the GIS Training Workshop (Fort Collins, Colorado/September 1989); and the Remote Sensing Workshop (Durham, New Hampshire/November 1989). An additional series of mini-workshops was held at the 1990 LTER All Scientists Meeting at Estes Park, Colorado.

The Wide-Area Networking Workshop, with participants from all LTER sites, was a significant first step toward connecting all LTER researchers via electronic networks. LTER representatives demonstrated the use of networks, and speakers addressed various related topics, including: Internet resources, the evolution of NSFNet and the Internet, and Network security. Also discussed were links between LTER sites, links to supercomputers, and links to Internet resources relating to remote-sensing, centralized image processing and geo-referencing.

At the GIS Training Workshop organized by Ingrid Burke (Central Plains Experimental Range LTER), the primary emphasis was on introducing ecological applications of GIS, providing training in MSI GIS software and capabilities, and providing opportunities for intersite exchange and interaction. The workshop included a two-day introduction to GIS, a four-and-a-half-day training session in ARC/INFO, and a two-day training session in ERDAS. Two participants from each site attended.

The Remote Sensing Workshop organized by John Aber (Harvard Forest LTER) was held at the Complex Systems Research Center at the University of New Hampshire and was strongly complementary to the GIS/ERDAS training session. Participants from most of the LTER sites, as well as numerous remote sensing laboratories in the United States, provided reviews of the major types of remote sensing data, satellite systems and software development, and discussed specific case studies.

Leading up to and including most of the technological activities at the 1990 All Scientists Meeting, effort has been aimed at long-term planning of technology development, acquisition of systems, and training of LTER personnel in the specific technologies. With the exception of the 1990 Connectivity Report, there has been no attempt to summarize the extensive progress made in developing technological capabilities and acquiring the MSI across the Network. The following section provides such a review, including the Connectivity Report results.

CURRENT TECHNOLOGY & ACTIVITY

GEOGRAPHIC INFORMATION SYSTEMS

Survey. In preparation for the GIS Working Group workshop at the 1990 All Scientists Meeting, David R. Foster and Emery R. Boose conducted a survey of GIS and remote sensing capabilities across the LTER Network (18 sites, including the Network Office). The purpose of the survey was to identify the systems currently in use at each site: the computer platforms, the GIS or remote sensing software used on each platform, and the primary uses of each configuration. The survey did not try to describe the number of systems, the funding and ownership of each system, the personnel available at each site or, in most cases, other resources that may be available through LAN connections. Detailed results of the survey are given in Appendix I to this report.

A comparison of this survey with that conducted by Robert Robbins two years earlier shows a dramatic increase in GIS and remote sensing capability across the Network. In the December 1988 survey only about half of the sites had a working GIS. In the current survey all sites have GIS capability. Most show an impressive array of vector and raster GIS on a variety of computer platforms. More than half of the sites have remote sensing capability with ERDAS. In addition, the Network Office has acquired raster and vector GIS capability for support of GIS research activity across the LTER Network.

Some summary statistics from the survey are given on the following page. It is interesting to note that most sites are using a combination of Unix workstations and personal computers (PCs) for GIS and remote sensing. Apple Macintosh computers were mentioned at only two sites and in combination with workstations and PCs. The only vector software was ARC/INFO, while a wide range of raster GIS software was cited. Most sites that have ERDAS indicated that they use it both for image processing and as a raster GIS.

Table 1. Summary of Computer Platforms and Software at LTER Sites

COMPUTERS		# sites	

Workstations + PCs		10	
Workstations only		4	
PCs only		4	
SOFTWARE		# sites	# planned
vector GIS	ARCINFO	16	
raster GIS	Map (various forms)	9	
	GRASS	4	2
	Eppl7	4	
	ldrisi	2	1
	Moss	I	
	Panacea	1	
remote sensing	ERDAS	11	2
	Las	1	
miscellaneous	In-house	5	

Research. Geographic information systems provide an excellent tool for describing spatial variability and patterning of ecological attributes and processes, and for examining long-term temporal variability in these factors. Interesting research applications of GIS are being developed at many sites, as indicated in the responses to the survey and in discussions at the 1990 All Scientists Meeting. Highlights of current GIS-related research at selected sites are provided below:

> *AND Modeling movement of sediment and coarse woody debris through streams. Analysis of landscape patterns of disturbance. Modeling of management scenarios for conifer forests in PNW.
>
> CPR Application of the Century model to Central Plains GIS data, to make long-term regional predictions about the potential effects of climate change.
>
> HBR Patterns of soil temperature and moisture and their responses to regional climatic change scenarios. Vegetation-environment interactions and their influence on patterns of soil nutrient retention and plant nutrient stress.

Relationships between variability in emissions of C, N, and S gases and the topographic, soil and vegetation parameters that regulate substrate availability and soil drainage.

HFR Analyzing landscape-level patterns of forest damage from Hurricane Hugo in the Luquillo Experimental Forest in terms of local topography and storm dynamics (damage estimated from aerial photographs). Studying spatial correlation between land-use practices and vegetation in central New England since settlement times.

JRN Modeling wind erosion and overland flow.

KBS Modeling spatial dynamics of insect movement in local and regional landscapes, including dynamics of beneficial insects at KBS, and population prediction and risk assessment of the gypsy moth across Michigan.

LUQ Studying correlation of topographic aspect with forest damage from hurricane Hugo (damage estimated from satellite images). Modeling habitat and migration of stream shrimp.

NET Acquisition of consistent Network-wide data sets for collaborative research.

NTL Regional, spatial hydrologic modeling. Effects of sensor scale on landscape parameters. Temporal/spatial analysis of variability in lake parameters. Assessing regional climate variation using ice phenology. Lake classification. Land-cover changes from pre-settlement to present.

NWT Studying effects of topography and snow distribution on vegetation.

SEV Studying correlation of lightening strikes and rainfall, and correlation of topography and location of trapped animals.

* - KEY:

AND = H.J. Andrews Experimental Forest; ARC = Arctic Tundra, BNZ = Bonanza Creek Experimental Forest, CDR = Cedar Creek Natural History Area; CPR = Central Plains Experimental Range; CWT = Coweeta Hydrological Laboratory; HBR = Hubbard Brook Experimental Forest; HFR = Harvard Forest; JRN = Jornada Experimental Range; KBS = Kellogg Biological Station; KNZ = Konza Prairie; LUQ = Luquillo Experimental Forest; NET = LTER Network Office; NIN = North Inlet; NTL = North Temperate Lakes, NWT = Niwot Ridge/Green Lakes Valley; SEV = Sevilleta; VCR = Virginia Coast Reserve

Site management. Several sites are now using GIS as a site management tool. A formidable problem for every LTER is that of managing the land base for potentially conflicting uses: e.g., research, education, nature reserves, resource management. Site managers must be able to rapidly locate and allocate appropriate sites for new activities, while assuring the viability of existing projects. Over time a large number of diverse activities makes this a complex cartographic chore. Geographic information systems provide a tool that can rapidly assist in maintaining records and making decisions, once the base data for the site have been digitized. It is likely that nearly all sites will be using GIS for site management in the next few years.

Data management. GIS provides an efficient means for recording, storing, and displaying cartographic information. In this sense, GIS can be regarded as a data management tool: it provides an alternative, for example, to hand-drawn paper maps for recording and displaying cartographic data. Many sites are finding that the extra work involved in digitizing and maintaining GIS files is justified by the ease of manipulation and display that GIS technology affords.

At the same time, the use of a GIS adds considerably to the data management tasks at each LTER site. Geographic information systems and remote sensing data pose several problems not found with ordinary non-spatial tabular data: e.g., the overlay files tend to be quite large, it is easy to make numerous derivative overlays without clearly documenting the derivation, errors can be very difficult to locate, overlays require considerable documentation and, in most GIS systems, the documentation does not reside in the overlay file.

Initial discussion of these and related issues concerning the data management aspect of GIS has been undertaken by the LTER Data Managers. At its 1990 meeting, the group proposed a GIS/remote sensing/data management symposium that would consider standards for scale, classification, and documentation. Development of Network-wide standards, where feasible, could facilitate intersite research in the future. As each site's data management efforts are extended to include GIS and remote sensing data, the result should be better data management and exchange across the Network.

Recommendations for data and information exchange. At the 1990 All Scientists Meeting there was general agreement that no single available GIS system meets all the needs of LTER scientists. Nearly all commercial GIS systems have been developed for cartographic and not scientific applications, and typically lack functions such as spatial statistics that are essential for scientific research. Also, no current system combines all the advantages of vector and raster GIS. As a result, most sites currently use more than one GIS system, and many sites (at least five) have developed their own in-house software to implement special functions or to provide an interface to spatial models.

It became clear at the All Scientists Meeting that the LTER Network could benefit from dissemination of information about new software and new techniques developed at individual sites. In many cases, such sharing of information could reduce duplicated effort. The LTER electronic bulletin board was suggested as a possible forum for this interchange. Sharing of actual GIS data typically involves transfer of or remote access to very large files. This can be accomplished in real-time by researchers who have Internet connectivity. Optical disks provide a means for physical exchange of the same data.

Remote Sensing

Survey. More than half of the LTER sites indicated that they have software for remote sensing data analysis, with many sites running multiple systems. Of these, 11 sites are currently using ERDAS on workstations and/or PCs, while two more sites are planning to acquire ERDAS, and one site is using Las. Two sites mentioned that they also have access to more extensive facilities at a university remote sensing laboratory-the same is probably true for other sites as well.

There is a strong interest across the LTER Network in improving remote sensing capabilities, both as a means of scaling up ecosystem analysis and as a complement to the growing expertise in GIS. Representatives from all sites received training in ERDAS at the GIS training workshop in Fort Collins, Colorado and most sites were represented at the remote sensing workshop at the University of New Hampshire.

Network data acquisition. The expense and complexity of acquiring the data, and the restrictions on data sharing imposed by proprietary data copyrights, are important obstacles to research based on remote sensing. However, the scientific advantages of remote sensing, especially for regional and intersite studies and for the assessment of global change, are great. The acquisition of satellite imagery for all LTER sites was the number one recommendation of the Gosz Committee; it also received unanimous support at the remote sensing workshop, where details of possible acquisitions were discussed.

In September 1990, NSF funded a proposal by the LTER Network Office to acquire the following data for each LTER site:

> one Landsat-5 Thematic Mapper full scene, 30-m resolution, seven spectral bands, less than 30 percent cloud cover;
>
> one SPOT-HRV panchromatic scene, 10-m resolution, less than 10 percent cloud cover, clear coverage for site;
>
> regional AVHRR data from NOAA and USGS sources, 1-km resolution;
>
> current HAP (high-altitude photography) from USGS in film format; and
>
> retroactive search for all data available from the SPOT and Landsat archives.

The data will be purchased and archived by the LTER Network Office under the direction of John Vande Castle, and distributed to sites on computer tape, optical disk, or by Network link depending on the individual site's capabilities. The data files are quite large: each Landsat scene is about 300 megabytes, each SPOT scene is about 50 megabytes, and each AVHRR scene 60 to 130 megabytes. A shared license agreement has been negotiated with the private companies involved, so that any or all site data may be used by any site.

This collective database will be the basis for a wide array of collaborative research across the LTER Network. The digital satellite data and aerial photography will function as an historical record and common means of comparison for each LTER site. And the acquisition will act as a "test case" for future acquisitions, including those from EOS era space platforms.

Internet Connectivity

The LTER Connectivity Committee chaired by James Brunt (Sevilleta LTER) was established by NSF in July 1989 and charged with assessing the current connectivity of LTER sites to the Internet and with making specific recommendations (with cost estimates) to the LTER Coordinating Committee and to NSF. During the fall of 1989, the Committee formally visited five LTER sites, informally visited four others, and delivered its report (LTER Publication No. 7 *Internet Connectivity in Long-Term Ecological Research Network*) in February 1990. The Committee's findings and recommendations are summarized below.

Computer networking technology can now virtually eliminate the physical and temporal barriers to scientific collaboration. The NSF Network (NSFNet) and associated mid-level networks, referred to as the Internet, provide a common and stable thread with which LTER investigators are being joined. This "network of networks" is predicated on communications software standards, the Internet protocol suite, that enable a wide array of heterogeneous computers to exchange or share data and information. Increased levels of connectivity are responsible for new intersite activities, such as a distributed climate database and an on-line dataset catalog, as well as greatly increased use of electronic mail through the LTERnet mail forwarding system. Future use of the Internet for remote file sharing and direct transmission of imagery (including real-time remote display) offer increased potential for collaborative research within LTER.

Despite the advantages of Internet connectivity, and despite the fact that nearly 90 percent of the universities that administer LTER grants have connections to the Internet, the Committee found that the majority of LTER computers, all of the field laboratories, and many Pls remain isolated from Internet capabilities. In many cases there is a missing link between an LTER computer and the Internet access point on campus; in some cases (e.g., field sites) the nearest Internet access point must be reached via telephone or radio. Detailed information for each LTER site as of fall 1989 is presented in the Connectivity Report.

The Connectivity Committee strongly recommended that the LTER Network pursue complete Internet connectivity through the addition of equipment, personnel, and education directed at networking. Three steps were recommended for each site:

> (1) Develop a basic LAN infrastructure with connections to the Internet at the main location of each LTER site to provide at least minimal access to Internet services.
>
> (2) Upgrade LAN facilities at main locations to provide complete Internet connectivity and provide electronic mail (E-mail) service to remote sites.
>
> (3) Establish full Internet connectivity and LAN infrastructure at large field sites.

Other recommendations included funding for technical personnel in networking, acquisition of at least one multiuser Unix (or variant) computer at each site to provide E-mail and network services, workshops involving advanced uses of computer networks in ecological sciences and technical instruction (e.g., a Unix system administration workshop), and production of a networking manual to assist sites in developing their networks.

Archival Storage

The need for a high-capacity data storage system to accompany a GIS was recognized in the original MSI specification, which included an optical disk drive (either WORM or erasable). In the past two years that need has increased with the development of large on-line databases, especially with the LTER Network acquisition of remote sensing data for each site. Through data storage systems were not covered in the current survey, it is our impression that few sites have used supplemental funds to acquire these systems, in part because other technologies such as GIS have over- shadowed data storage, and in part because industry standards are still evolving for optical disks. A recent survey of protocols for the archiving of LTER core data sets (Barbara Benson, LTER Databits newsletter, Fall 1990) shows that all 10 sites responding to the survey are using magnetic and not optical media for data storage, though several sites have plans to acquire optical technology.

With the emerging ANSI standards, optical disk technology appears to be one of the most promising solutions to the problem of affordable, reliable, high-capacity data storage. With the increased use of large databases, GIS and remote sensing, many LTER sites will soon be forced to purchase some kind of high-capacity storage system-in most cases, an optical disk system.

Global Positioning Systems

The Global Positioning System (GPS) was developed by the U.S. Department of Defense to provide accurate geo-positional data for any point on the earth's surface. The GPS utilizes computers and a constellation of 21 NAVSTAR satellites orbiting at an altitude of 10,900 nautical miles to triangulate positions on earth. Though not part of the original MSI specification, GPS technology has great potential for complementing the MSI: it can be used for surveying and for geo-referencing GIS and remote sensing data.

In the spring of 1990, the National Science Foundation funded a proposal organized by William

Michener (North Inlet LTFR) to purchase GPS units for use across the LTER Network. The following equipment has been purchased:

> Four pairs of Trimble Navigation Pathfinder GPS units. When used as a pair, with one unit at a known location, these units provide 2- to 5-m accuracy, good enough for U.S. Geological Survey 1:24000 map accuracy standards. These units are rugged, portable, and relatively maintenance free. Pathfinder software has postprocessing, display, plotting, and GIS interface capability. Training for these units was conducted at the 1990 All Scientists Meeting.
>
> One Trimble Navigation 4000 SST unit. This survey-grade unit provides spatial resolution down to centimeters. It is less portable and much more difficult to use than the Pathfinder units. The unit is currently being tested.

Plans call for four sites to serve as regional centers for the Pathfinder units (H.J. Andrews Experimental Forest, Cedar Creek Natural History Area, Sevilleta, North Inlet). Regional centers will provide distribution and support for the LTER sites in their region. The high-precision unit will be based at NIN, and will probably require a traveling team of experts for its use.

APPENDIX 1. LTER GIS/Remote Sensing Survey 9/90

Site	Computer	Software	Primary uses
*AND	Sun N28O	ARC/INFO 5.0.1	landscape modeling, site inventory
	Sun 3/60	ARC/INFO 5.0.1	landscape modeling, site inventory
	Sun 4/110	ARC/INFO 5.0.1	landscape modeling, site inventory
	Sun 3/60	ERDAS 7.3	image processing, interface between image data & ARC/INFO
	Sun 3/6O	GRASS	supplemental raster GIS
	DG MV 15000	Moss	supplemental raster GIS, access to National Forest data
	Sun 4/110	In-house	ARC/INFO interfacing menus, Sun Xwindows interface for GRASS, programs to supplement GIS
	*Sun sparc	*ARC/INFO	landscape modeling, site inventory
ARC	Sun sparc	ARC/INFO	vector GIS
BNZ	Sun 4/390	ARC/INFO	vector GIS
CDR	Sun 386i	ARC/INFO 4.0.2	vector GIS [St. Paul]
	PC 286	Eppl7 2.0	raster GIS [St. Paul]
	Sun 386i	*GRASS	raster GIS [St. Paul]

	*Sun sparc-1	*ARC/INFO 5.1	vector GIS (St. Paul]
	PC	ARC/INFO	vector GIS [Minneapolis]
CPR	Dec work	ARC/INFO	vector GIS
	Sun 386i	ARC/INFO	vector GIS
	Sun 386i	GRASS	raster GIS
	PC	ARC/INFO	vector GIS
	PC 286	ERDAS	image processing & raster GIS
CWT	Sun sparc-1	ARC/INFO	vector GIS
	*Sun 4/10	*ARC?INFO	vector GIS
	*Sun 4/10	*ERDAS	image processing, raster GIS
HBR	Tektronix 43xx	ARC/INFO 4.0	vector GIS [Cornell]
	PC 286	ERDAS 7.4	image processing [Cornell]
	PC 286	OSU map	raster GIS [Cornell]
	*PC 386	*ARC/INFO	vector GIS [Hubbard Brook]
HFR	PC 386	Map	raster GIS analysis & modeling
	PC 286	Panacea	raster digitizing & editing
	PC 386	In-house	additional GIS functions, spatial statistics, spatial models, graphics, file conversion
	PC 386	*Mapbox	raster GIS
	PC 386	*Idrisi	raster GIS
	PC 386	*ERDAS	image processing
JRN	Sun 4/1 0	ARCD/NFO 5	vector GIS [Las Cruces]
	Sun 4/10	ERDAS 7.3	image processing [Las Cruces]
	PC 386	Geoeas	mapping [Las Cruces]
	VVax 11/750	ARC/INFO	vector GIS [San Diego]
	VVax 6000	ARC/INFO	vector GIS [San Diego]

	Sun sparc	ARC/INFO	vector GIS [San Diego]
	Sun sparc	ERDAS	image processing [San Diego]
	PC 386	ARCANFO	vector GIS [San Diego]
	PC 386	ERDAS	image processing [San Diego]
	Mac II	Map 11	raster GIS [San Diego]
	Mae II	ldrisi	raster GIS [San Diego]
	*IBM power st.	*Spans	raster GIS [San Diego]
KBS	Vax 31 00	ARC/INFO 5.0	vector GIS
	PC 386	ARC/INFO	vector GIS
	PC 386	ERDAS	image analysis & raster GIS, modeling
	PC 386	Live-Link	integration of vector & raster GIS
	PC 386	In-house	data conversion to ARC/INFO format, ERDAS data entry & conversion, integration with video images
	PC 386	Cmap	digitizing
KNZ	Sun 411 1 0	ARC/INFO 5.1	vector GIS
	PC 386	ARC/INFO	vector GIS
	PC 386	ERDAS 7.4	image processing & raster GIS
	PC 386	Live-Link	integration of vector & raster GIS
	PC 386	Map	education, small research projects
	PC 286	Pmap	education
	PC 286	OSU Map	education
	PC 286	ldrisi	education
LUQ	PC 386	ERDAS 7.4	image processing & raster GIS
NET	Sun sparc-2	ARC/INFO-Ingres	vector GIS
	Sun sparc-2	ERDAS 7.4	image processing & raster GIS

	Sun spare-2	Live-link	integration of vector & raster GIS
	Sun spare-2	GRASS 3.1	raster GIS
	PC 386	Map	raster GIS
	PC 386	Eppl7 2	raster GIS
NIN	Sun sparc-1	ARC/INFO	vector GIS
	Sun 330	ERDAS	image processing & raster GIS
	Sun 330	In-house	programs to supplement ERDAS
	PC 386	ARC/INFO	digitizing & editing, GIS documentation
	PC 386	ERDAS	image processing & raster GIS
	PC	OSU Map	raster GIS
	PC	Eppl7	raster GIS
NTL	PC 386	ARC/INFO 3.3	digitizing, vector GIS, modeling
	PC 386	ERDAS 7.4	digitizing, image processing, raster GIS, modeling
	PC 386	Live-Link	integration of vector & raster GIS
	PC 386	Eppl7 2	raster GIS
	PC 386	In-house/ERDAS	raster GIS analysis & modeling
	PC 386	In-house	image processing & analysis, modeling, expert systems
	PC 286	Map	raster GIS & modeling
NWT	Microvax 3200	ARC/INFO 4.0/5.0	digitizing, mapping, analysis, training
	Microvax 3200	Las 4.0	image analysis, education & research
	Dec st. 31 00	Las 4.0	image analysis, education & research
	Dec st. 3100	PV wave	image analysis & 3-D display
	PC 386	Pmap	raster GIS analysis, linking to spatial models
	Dec st. 3100	*GRASS	raster GIS

	PC	*ARC/INFO	vector GIS
	Mac SE, 11	*Map 11	raster GIS training & analysis
SEV	PC 386	ARC/INFO 3.3	vector GIS
	*Dec st. 5WO	*ArcOracle	vector GIS
VCR	Sun sparc	ARC/INFO	vector GIS
	Sun sparc	ERDAS 7.4	image processing & raster GIS
	Sun sparc	GRASS	raster GIS
	PC 386	ERDAS 7.4	scanning, reading tapes

=> access to additional facilities ad University Remote Sensing Lab

=> network access [from Minn.] to Vax running ARC/INFO [in Duluth]

=> access to additional facilities at Environmental Remote Sensing Center

=> subcontract some work to NASA Technical Applications Center

=> working with computer engineering & Los Alamos on GRASS

*Key:

AND = H.J. Andrews Experimental Forest; ARC = Arctic Tundra, BNZ = Bonanza Creek Experimental Forest, CDR = Cedar Creek Natural History Area; CPR = Central Plains Experimental Range; CWT = Coweeta Hydrological Laboratory; HBR = Hubbard Brook Experimental Forest; HFR = Harvard Forest; JRN = Jornada Experimental Range; KBS = Kellogg Biological Station; KNZ = Konza Prairie; LUQ = Luquillo Experimental Forest; NET = LTER Network Office; NIN = North Inlet; NTL = North Temperate Lakes, NWT = Niwot Ridge/Green Lakes Valley; SEV = Sevilleta; VCR = Virginia Coast Reserve