Report to the National Science Foundation

from the

Second Workshop on the Development of a National Ecological Observatory Network (NEON)

held at the

San Diego Supercomputer Center

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Executive Summary

The second National Ecological Observatory Network (NEON) workshop (NEON Workshop II) attracted 25 participants with technical expertise in many areas of biology and computer science. All participants support the creation of NEON, a research infrastructure capable of supporting revolutionary advances in our understanding of ecological systems. The workshop focused on defining this infrastructure at two levels: that of the individual NEON observatory and that of the entire network. This document describes our vision of NEON, which includes the following major points:

- NEON will enable integration across disciplines, levels of biological organization, and scales of space and time (from the gene to the landscape). To achieve this integration, NEON observatories must be regional consortia of ecological and environmental research facilities.

- NEON will build an infrastructure, including data collections, that will allow researchers to ask questions that previously were impossible to tackle.

- The value of NEON will be enhanced by intellectual interactions among researchers from diverse disciplines ranging from field biology to companion natural, social and information sciences engaged in environmental research as they work together at NEON observatories. These interactions may be strengthened by defining a clear regional “center” for each observatory.

- Given the importance of spatial variation in characterizing ecological/environmental systems, NEON observatories will require spatially distributed arrays of sensors at a variety of scales.

- The resolving power of a NEON observatory will be a function of its "sensory network" of regional observation points. This singular fact motivates the essential need for each NEON observatory to be built on the existing resources of a consortium of field facilities.

- Important NEON facilities such as research museums, electron microscopy facilities, molecule specific mass spectographic laboratories, high volume gene sequencing capabilities, and high-end ports to the Internet are unique resources of and at universities that should be leveraged by and not duplicated at NEON field facilities.

- Fundamental change is taking place in the technologies available to support field biology. Measurements and technologies that once were available only in the laboratory are moving into the field. NEON must foster this technology transfer from the laboratory to the field.

- NEON infrastructure must include equipment and staff to make core field measurements and analyze field-collected samples. To compare these across the networkand over long time periods, NEON should develop and implement an appropriate methodology to archive and curate samples, data, and information.

- NEON's success requires development of a sophisticated informatics infrastructure that allows easy information exchange between the observatories, the network, and individual

researchers. Timely and broad community access to NEON data and information must be assured.

- Each NEON observatory will require a minimum operations and maintenance budget of $1.25 million per year.

- NEON network coordination should be achieved be establishing an institutional entity and appropriate governance system.

- NEON observatory consortia should foster human resource development and educational outreach.

It is worth re-emphasizing the findings of the first workshop, namely that "NEON represents an unprecedented opportunity for infrastructure to address environmental questions ranging over multiple levels of biological organization and over broad ecoregions. The network will provide infrastructure that cannot be afforded in current programs and will allow scientists to systematic, evolutionary and environmental problems on a scale not currently possible. … [and] represents a national resource available to all scientists with appropriate interests."

NEON is an exciting first step in fulfilling the vision outlined in the National Science Board's Taskforce on the Environment Report: Environmental Science and Engineering for the 21st Century - The Role of the National Science Foundation (NSB 99-133). NEON will contribute directly to "enhancing the disciplinary and interdisciplinary fundamental understanding of environmental systems and problems, improving the systematic acquisition of data, the analysis and synthesis of these data into useful information, and the dissemination of this information into understandable formats for multiple uses."

NEON also provides NSF with the opportunity to actively engage all of its directorates in a partnership in this exciting step in extending an environmental portfolio, thereby providing the community and the Nation with a model of Foundation-wide support for a vital national infrastructure aimed at understanding environmental systems.

Table of Contents

Vision

The purpose of the National Ecological Observatory Network (NEON) is to support field biological research across disciplines, levels of biological organization, and scales of space and time.

NEON will provide an integrated network of regional research platforms instrumenting the environment. Individual NEON observatories provide resources to focus on local to regional scales. Collectively, they form a resource to address national and continental scales. NEON observatories will provide infrastructure for the field biological research community through core data, instrumentation, and laboratory facilities.

An individual observatory will be comprised of a consortium whose members are likely to include field stations, marine laboratories, Long-Term Ecological Research (LTER) sites, other field research facilities, universities, community and tribal colleges, museums, nonprofit organizations, and state and federal agencies. Together, the consortium members constitute a local network capable of collecting, integrating, and archiving key ecological and environmental data. The core of each observatory consists of a field station, marine laboratory, LTER site, or other field research facility located in an environmentally or ecologically important area where the majority of instrumentation will reside. However, to achieve regional objectives and maximize efficiency of resource use, field instrumentation and selected laboratory tasks should be deployed at the facilities of other consortium members; for example, the responsibility to curate archival materials might be located at a museum.

To provide research resources at a variety of critical ecological scales, NEON observatories must be regional consortia of ecological and environmental research facilities. The resolving power of a NEON observatory will be a function of its "sensory network" of regional observation points. This singular fact motivates the essential need for each NEON observatory to be built on the existing resources of a consortium of field facilities. In addition, because most field research facilities are extensions of universities, the resource base of the universities will naturally support NEON observatories. For example, university-based research museums, electron microscopy facilities, molecule specific mass spectographic laboratories, high volume gene sequencing capabilities, and high-end ports to the Internet are unique resources of and at universities that should not be duplicated at NEON field facilities.

As a network, NEON should coordinate the regional observatories to facilitate synthesis of field research across national and continental scales. In addition to research projects conducted at NEON observatories, the field biological community will benefit from open access to real-time data collected throughout the network. Collecting a set of common data across the NEON network and thereby creating data collections will enable new avenues of research not previously possible. For example, researchers conducting a biotic survey of a particular taxonomic group will be able to use extensive habitat, soil, and atmospheric measurements to determine how these variables (or combinations of variables) affect changes in biodiversity. In addition, teaming scientists with disparate interests at one NEON observatory will create a dynamic and stimulating environment for developing new approaches to research that cross disciplinary boundaries.

Pivotal to the success of NEON will be the diverse group of researchers who will use the NEON infrastructure. These researchers will receive funding from NSF programs and other sources and use the NEON-provided infrastructure of staff, equipment, data, and archived samples to address specific research problems.

This report focuses on ensuring that the NEON infrastructure will be able to address the needs of the broadest possible group of field biological researchers. Although there may be overlap between the members of the NEON consortium and the group of researchers working at NEON observatories, the NEON infrastructure must benefit the widest possible audience.

The emergence of NEON will extend the frontiers of ecological inquiry in ways that have not been possible through existing funding mechanisms. Nonetheless, during the evolution of the NEON concept, there has been substantial discussion regarding how NEON observatories differ from existing field stations, marine laboratories, and LTER sites. Individual field stations and NEON observatories do have similarities: Both provide infrastructure for researchers operating in a field environment. However, unlike individual field stations, a NEON observatory will be tightly coupled into a national network and will have resources to implement cutting-edge technologies. NEON will also be unique in that each observatory will consist of a regional consortium of field research facilities. Like an LTER site, a NEON observatory will be responsible for information management and operation within a larger network.

Nonetheless, there are major differences. LTER sites are funded by research grants to specific principal investigators with specified research objectives. LTER sites are evaluated based on the productivity of their investigators in publishing research papers and only secondarily on providing data to the broader community. In contrast, a NEON observatory's role will be to provide infrastructure to the broadest field biological community regardless of specific research objectives. NEON, in its design, will be a coordinated research infrastructure, while LTERs are coordinated multi-investigator research projects. Evaluation of continued funding for a NEON observatory should depend on the excellence of its service to the community and the quality of science enabled by that service.

Infrastructure and Operations

NEON observatories are envisioned as regional providers of infrastructure that will permit scientists to operate across a range of spatial and temporal scales and across levels of biological organization. These observatories will include cutting-edge field and laboratory facilities. Each successful NEON proposer will need to balance the synergy of locating equipment at a single field site with the need to provide a regional perspective of the environment through the consortium members. Furthermore, the consortium needs to build on its existing research infrastructure to plan the application of NEON resources.

NEON must be willing to serve all fields of biology and companion natural, social and information sciences engaged in environmental research. NEON infrastructure should enable disciplinary, interdisciplinary, and multidisciplinary research. The workshop participants discussed likely facilities and equipment that would be placed in each NEON observatory.

General infrastructure common to all observatories would also include computing, teleconferencing, and wireless networking capabilities.

Equipment and Facilities

Participants in the workshop compiled a list of equipment and facilities relevant to a NEON observatory (Table 1). This list is not exhaustive but reflects the expertise of the scientists participating in the workshop.

Some components on the list may be inappropriate for a particular observatory; for example minirhizotrons would be inappropriate in a lake, just as profiling buoys would be inappropriate in a desert. Equipment and facilities were categorized into field, laboratory and network. The Field and Laboratory categories included items that might be at each observatory. The Network category focused on equipment and capabilities that might be too expensive to provide at each observatory but from which the network would benefit. In addition to listing equipment and facilities, we also included costs, personnel requirements, and the expected lifetime of equipment where such information was available.

Table 1: Infrastructure Needs of NEON Observatories.

The Network column focuses on equipment that might be provided at the network level. The Laboratory column is subdivided into laboratory equipment, information management and archives, and facilities. Field equipment is subdivided based on whether the equipment will be dispersed on a landscape grid or at a single site. The end of that column lists potential consortium members who might participate in the deployment of field facilities.

Network	Laboratory	Field

• **C^{14}**
  ◦ accelerator/ conventional facility
  ◦ molecule-specific mass spec (CHNSO)
  ◦ could include thermal ionization mass spectrometer to allow isotopic studies of heavier elements (Sr, Pb, Cu, etc.)
• Techniques Development
  ◦ radar systems for soil/root systems
  ◦ cutting-edge remote-sensing/ GIS techniques
	Laboratory
	• Genomics
	  ◦ basic molecular biology lab (extraction and electrophoresis setups, photodocumentation, fume hoods, sinks, etc.)
	  ◦ thermocyclers, robocyclers
	  ◦ 1 automated sequencer (with service contract)
	  ◦ microarray blotters & readers
	  ◦ personnel: 1 MS- level FTE
	• Biogeochemistry
	  ◦ CHN analyzer (combustion/gas chromatography)
	  ◦ autoanalyzer (NH_4^+, NO_2^-, NO_3^-, PO_4^-)
	  ◦ AAS/ICP
	  ◦ ion chromatograph
	  ◦ inductively coupled plasma spectrometer
	  ◦ soluble organic carbon analyzer
	  ◦ gas chromatograph (soil trace
		Grid (NET Elements)
		• BON
		  ◦ see earlier workshops
		  ◦ team of collectors
		  ◦ "smart" vouchering and archiving equipment
		• Hydrology
		  ◦ rain gauges
		  ◦ Time-domain Reflectometer (TDR) (soil water content)
		  ◦ neutron probe (soil moisture)
		  ◦ sap flux
		  ◦ stream flow gauges
		  ◦ data loggers
		  ◦ ground water wells
		• Meteorology
		  ◦ temp/humidity
		  ◦ rain gauges
		  ◦ IR sensor for surface temperature*
		  ◦ radiation sensors*
		  ◦ data loggers

Network	Laboratory	Field

• small organism telemetry
• Information Technology Lab
  • 2 FTE minimum
• Scanning Electron Microscope Lab
• Aircraft/satellite Imagery
  • hyperspectral sensors
  • near real-time GPS-referenced aircraft imagery
  • eddy covariance CO2-H2O flux
  • sampling flask
  • energy balance
  • radiation
• High-level Molecular Biology Laboratory
  • genomic & CDNA library construction and screening
  • microchip array analyses
  • high-throughput sequencing or genotyping
  • development of new techniques
  • personnel: 1-2 Ph.D, 2-3 techs
	gases)
	• infrared gas analyzer (soil respiration, photosynthesis)
	• NO_x analyzer (NO, NO_2 fluxes from soils)
	• centrifuge
	• ancillary equipment: plant & soil grinders, drying ovens, muffle furnace, water deionizer, freezers for sample storage
	• equipment lifetime: 10 years
	• Isotope
	  • 2 continuous-flow isotope ratio mass spectrometers, one for natural abundance, one for enriched samples
	  • peripherals for organic δ^{13}C, δ^{15}N, δ^{18}O, and δD; water δ^{18}O, δD, trace gasses δ^{13}C, δ^{15}N, and δ^{18}O
	  • equipment lifetime: 10 years
	• Microscopy
	  • compound scopes ($10-150K each)
	  • stereomicroscopes ($1-$90K each)
	  • camera lucida
	  • all should include electronic image capture for remote use via network
	• Electronic Instrumentation, Including
	  • telemetry
	    • receivers & tracking antennas
	    • wide array of transmitters
	  • instrumentation for atmospheric calibration of satellite data
	  • GPS
	    • $80-100K for GPS equipment, computers, software
	    • personnel: 1 FTE
	    • replacement 5-10 years
	• RS/GIS Computer
	  • minimum one workstation per analyst
	  • printers, input devices, software (Imagine, IDL, ENVI, ARC/INFO, Splus)
	  • minimum $30K computers
		• sonic anomometer*
		• heat flux plates
		• Substrate
		  • tensiometers
		  • lysimeters
		  • soil or water temperature
		  • soil or water respiration
		  • minirhizontrons
		  • coring device suitable for 1.5 m depth
		  • truck mounted coring device for sampling to depths of up to 10 m
		• Ecological Characterization**
		  • land cover, land use, and habitat classifications
		  • canopy analyzer
		  • H_2O/CO_2 porometer
		  • pressure chamber
		  • buoys for vertical profiling (current velocity, turbulence, energy flux, water temperature, O_2, CO_2, pH, chlorophyll, color, turbidity, nutrients, sonar)
		  • remote platform fuel cells
		  • lake-level sensors
		  • electrofishing boat
		  • sonar equipment with multiple sensors for aquatic organisms
		• Biodiversity Characterization**
		• Regional Land Use Characterization**
		
		*= at flux tower site.
		** = responsibility of core NEON site.

Network	Laboratory	Field

	• replacement: 3-6 years
	    • software $80K (annual software costs $8-10K)
	    • personnel: 1 to 2 FTEs
	• Networking/communication (Wireless)
	    • connection to Internet
	        • connection $20-60K
	        • operating costs $1.5-5K per month (distance-dependent)
	        • personnel: 0.2-0.5 FTEs
	    • LAN and wireless
	        • $100K installation
	        • personnel: 1/2 -1 FTEs
	        • replacement: 6-10 years
	• Growth and Culture Facilities
	    • growth chamber(s)
	    • microbial culture
	    • greenhouse(s)
	    • animal maintenance	

	Information Management & Archives
	• Data & Information
	    • remote sensing data & metadata
	    • on-demand spatial and remote sensing data
	    • minimum $50K computers
	        • replacement: 3-6 years
	    • software: $25K - w/ DBMS
	    • personnel: 2 FTEs (minimum)
	    • mass storage: $5-50K
	• Bulk Samples
	    • cabinets
	    • braced shelving
	    • freezers
	    • fireproof/hazmat storage for ETOH, formaline
	    • small wet lab for specimen preparation, implant radio transmitters
	• Images (digital)
	    • $50K for digital video manipulation system
	    • Terabyte+ data storage
	        • $75K (disk)
	• Microsamples
	    • regular and ultracold freezers (4^{o}, 2x -20^{o} & 2x -80^{o})
	• Vouchers
	    • insect-proof cabinets
		Point
		• Flux Tower
		    • sensor grid within the flux tower footprint
		    • temperature humidity
		    • eddy correlation aneometry
		    • solar & terrestrial radiation
		        • over representative vegetation surface
		        • APAR, UVB, PAR, IPAR
		        • LAI
		    • sun photometer
		    • sky cover meter
		    • gas analyzers (CO_2, NMHC, NO_x etc.)
		• Substrate/below-ground Observatory (minirhizotron, soil temp and moisture profilers, lysimeter, probes.)
		• Other:
		    • rain-out shelters for manipulation of rainfall
		    • FACE system for CO_2 studies
		    • open top chamber system (CO_2 or atmospheric pollutants

Network	Laboratory	Field
	• braced shelving • freeze driers • small environmental chamber for dermestid beetle colony used for specimen preparation	

	Facilities
	• Accommodations
	• Meeting Space
	  • includes access to analytical facilities
	  • range of sizes to meet different needs - large group to seminar
	  • equipped with state-of-art projectors and other A/V equipment
	• Computational Facilities
	  • computers for analyses
	  • computers for e-mail, WWW access, etc., for visitors and public education
	  • connections to virtual libraries
	• Network Collaboration Infrastructure
		Consortium
		• Field Stations
		• LTERs
		• Marine Labs
		• Museums
		  • K-12 links through NEON kiosk displays
		• Community & Tribal Colleges
		• State and Federal Agencies
		
		• All partners must be linked via high-speed networks to allow
		  • data exchange
		  • teleconferencing
		  • remote instrument sharing
		  • educational activities

Core Measurements

The infrastructure required for NEON extends beyond the equipment listed in Table 1 to include streams of core data and archived samples that set a common context for research at NEON observatories. Although there was strong consensus among workshop participants that such core measurements were a critical feature of NEON, we did not attempt to tabulate specific core measurements. The mechanisms for developing a list of core measurements should be addressed by NEON workshop III and NSF program officers prior to the release of the NEON program announcement and through cooperative agreements with the network once it is established.

Core measurements should address the needs common to the broadest possible user community. Moreover, to the maximum degree possible, core measurements should be held in common across observatories. In general, the core measurements made at each observatory will not be the types of measurements an individual researcher would make (those can be accomplished through other means), but rather the common measurements that set the physical and biological context in which intensive studies operate.

A long-term archive of biological and physical samples is a necessary form of infrastructure development at NEON observatories. Each NEON observatory will need to provide curatorial and archival capabilities (through a museum in its consortium) that will lead to the accrual of a collection of physical and biological samples that can form the basis of future studies using advanced genetic and isotopic analyses.

We can envision that core measurements at each NEON observatory could focus on the biosphere, atmosphere, hydrological system, and soil, and on the fluxes of mass and energy between these components of the NEON observatory environment. As such, core measurements should include, but not be limited to, meteorological and watershed observations, biodiversity and ecological characterizations, and soil physical, chemical, and ecological properties, and the fluxes associated with atmospheric wet and dry deposition, gas and energy transfers from the biosphere, waters, and soils to the atmosphere, and the horizontal transports through biological and hydrospheric flow paths. A NEON site will be responsible for maintaining these measurements for the NEON user community.

To best serve the community, the core measurements made by NEON observatories need to be made available online without delay. Non-core measurements taken by individual researchers at NEON observatories also need to be made available, but here some delays compatible with preparation of publications may be acceptable.

Operations and Maintenance

Staff

Identification of staffing needs for NEON observatory operations was addressed during workshop discussions. The following list of staff members was identified as a model for an individual observatory:

- Observatory Director/Project Manager (Ph.D.-level)
- Site Coordinator/Budget Administrator (B.S.+ level)
- Data/Information Manager(s) (See NEON Informatics Section for more details on possible informatics staffing models.)
    - Data focus
    - System support
- General Lab Tech(s)
- Stable Isotope Tech
- Biogeochemistry Tech
- Curatorial Assistant
- GIS Tech(s)
- Field Tech(s)
- Equipment Engineer/Electronics Tech (B.S.+ level)

Operations

The annual operating budget for an observatory such as that outlined above is likely to exceed $1 million per year. This budget, at a minimum, will include salaries for the staff listed above, equipment service contracts, consumables, and institutional overhead. We recommend that a minimum expenditure of $1.25 million annually be allocated per observatory, subject to adjustments over time for inflation (particularly in the area of observatory staff salaries). We also recommend that a more thorough evaluation of the operating budget versus the budget available for research be made in the subsequent management-related workshop (NEON III).

Operation of complex and delicate laboratory equipment at remote field locations poses greater challenges than at universities and other large, centralized research institutions. These include higher costs for repairs and maintenance due to increased travel time for repair personnel and lack of local sources for parts, decreased access to "hands on" technical support for computer and network problems and higher operational costs. Electrical power and telecommunications links are typically less reliable (and more expensive) in remote locations. It may also be more difficult to attract skilled personnel to areas that lack cultural and educational resources. Moreover, access to skilled part-time labor derived from graduate students and part-time technicians, that is so important in university environments, is often lacking in remote locations. Housing and food for large laboratory staffs could overwhelm the residential and dining facilities of field stations, potentially crowding out field-based researchers. For these reasons individual NEON consortia will need to balance their proposed resource allocation plans to maximize the science that can be achieved.

NEON observatories will support individual site research and network-wide activities. Proposed research will be evaluated in the context of site longevity (30 years expected) such that ongoing and potential future research is not compromised by the research activities themselves. This view recognizes that the sites hosting a NEON observatory are a finite resource subject to degradation by research activities and subject to overuse. An observatory may be able to minimize these impacts by distributing research activities across consortium members. Accordingly, each NEON site needs to develop a plan for conservation and preservation of the observatory environment. We encourage participants in the NEON III Workshop to revisit this issue.

Topics of Special Importance to NEON

Informatics

Investment in NEON informatics is of paramount importance to the success of the NEON network and the individual observatories as a community resource. The scope of the needed informatics activities is broad, including observatory-specific and network-wide activities, activities targeted at supporting specific research projects, and development activities addressing difficult problems that have not yet been solved in information technology.

With respect to the mission of an ecological observatory, it is obvious that the collection and management of information are critical and pervasive activities, and the success of NEON will depend heavily on its ability to manage information, from data collection, through analysis, dissemination, and long-term archiving. This is an extremely challenging undertaking, and the proposers of a NEON observatory and NEON network must make serious investments in this area.

Network-wide interoperability in information infrastructure is needed. Automation in data acquisition and an integrated approach to the design, development, and maintenance of the NEON information infrastructure will facilitate this goal. A network perspective and a design and development approach that emphasizes modularity and standardized interfaces should be adapted to maximize system flexibility and efficiency. To centralize planning and information infrastructure development, the observatories must actively participate in all aspects of the process. This coordination will provide benefits in terms of economies of scale and quicker technology dissemination and advanced technology development, without compromising the observatories' flexibility.

Balancing the autonomy of the individual observatories with network-level standardization will be a challenging task, but it must be addressed at the inception of the NEON network so that individual observatories implement compatible infrastructures. Exploring issues of inter-site compatibility and agreeing on common standards and procedures will reduce the complexities of information management in NEON greatly while enabling individual observatories to retain the flexibility to respond to unique site characteristics.

Below, we present a functional breakdown of the informatics activities, followed by a list of infrastructure elements needed to support NEON informatics functions. The following section identifies the development activities needed to implement the infrastructure. The final section addresses some of the organizational and planning issues necessary to design, develop and maintain the informatics infrastructure.

For NEON to be successful, the informatics infrastructure will need to address the full range of data and information management activities, including the following:

- Data Acquisition—Acquiring data through sensors, field measurements, and other methods.

- Quality Management—Documenting and managing the quality of input data and the curation of data collections.

- Storage and Archiving—Implementing secure local storage and long-term archiving and caching of data.

- Dissemination and Access—Making the data available to NEON researchers and the larger research community, including the provision to control access to data as appropriate (see "Data Policy," below) and support for information discovery and data set management.

- Integration and Aggregation—Making data compatible with collections and tools, e.g., co-registration, and preparation of new data products by federating multiple data sets.

- Analysis, Synthesis, and Modeling—Supporting the investigation and application of the collected data, including standard analysis tools and custom NEON-specific applications. Examples of similar custom tools for other domains include the Biodiversity Species Workbench and the Biology Workbench.

To accomplish the necessary NEON functions, the information infrastructure will require a broad suite of integrated technological components, including sensors, communications devices, networks, and computing platforms. This infrastructure will need to support informatics activities that are NEON-wide as well as specific to individual observatories. It should also capitalize on existing resources from organizations such as PACI, NCEAS, LTER, the Natural History Museums, and others.

The overall system should be robust and extensible, which is best accomplished by modular design and well defined interfaces between components. For example, although there will be a variety of different field sensors, there should be a standard protocol for the interfaces. Under this approach, NEON observatories will have the flexibility of installing site-specific sensors while taking advantage of a network-wide collection of protocols interfacing sensors with the information management system. Many issues that deserve further consideration, including persistent archives, mirroring, reliability, standards, data formats, etc. The major components of the informatics infrastructure are the following:

- Hardware—Compute servers, workstations.
- Network—Wireless in the field, vBNS-speed linkage between observatories and other resources.
- Software—We recommend commercial off the shelf (COTS) software when possible and custom software development when necessary. Even so, COTS software will require some effort to interface to other elements of the infrastructure. Very few software packages/tools are truly plug-and-play as advertised.

Implementation of the NEON information infrastructure will require a systematic cycle of activities. This will be a continuous cycle, and there will always be ongoing development activities. Such development will be necessary to ensure that the system remains operational and capable of supporting its mission. Over the planned life of NEON, the established information infrastructure will require updating through a systematic cycle of activities that consist of

1. Requirements assessment.
2. Design.
3. Systems integration.
4. Prototype development.
5. Deployment.
6. Evaluation and feedback.
7. Maintenance and upgrades.

The scale and complexity of the NEON informatics infrastructure will require a substantial investment in organization and planning. There was some disagreement among workshop participants on the degree to which informatics issues could be resolved using centralized vs. distributed approaches. One view was that, since many software components will be common across NEON observatories, it is desirable to develop these at one location and then disseminate them. Alternatively, a central facility might guide implementations of the best practices generated within NEON, thus serving as a dissemination site for adoption of new technology by NEON observatories. The central site would need to provide interoperability mechanisms for authentication, remote data access, collection building, and information discovery. Workshops addressing these topics will be needed prior to initial awards and in concert with the initial three NEON sites. There will be some need for informatics research to address open issues; however, this may be accomplished best through independent research awards.

The development of a comprehensive informatics infrastructure for NEON will require a significant investment in personnel, including PI-level participation. We recognize the need for the following staff:

- Assistant Directors for Informatics: These individuals will design and oversee the implementation and operation of observatory and network information systems. One will manage the centralized infrastructure development. One at each observatory will oversee informatics activities.

- Development Engineers: These will be the infrastructure implementers. They may be concentrated at a center for informatics development and may not be needed at all observatories.

- Information Managers – These will serve as the interfaces between the scientists and technology. They will address such issues as metadata collection and quality management. They have some scientific domain knowledge and computing skills. They will be needed at all individual observatories.

- Systems administrators: These will deal with operational issues, such as equipment installation, upgrades, backups, establishing accounts, etc. Some functions may be performed on a network-wide basis; however, each site should have someone to handle these tasks.

Success of NEON as a community resource will depend on its ability to make data available to the broader scientific community. To enable that, NEON needs to develop a “Data and

Information Policy." Such a policy will govern the collection, use, and dissemination of data at all observatories. Workshop participants agreed that data collected at NEON sites should be made available to the general research community at the time of data collection (although we did see a need for provisions that allow quality management and data processing before distribution). Some workshop participants described the success that that the gene sequencing community has achieved in requiring public access to gene sequence data prior to scientific publication and the lack of negative consequences of such a policy. We encourage NEON to build on those successes by making available data collected at NEON observatories, both as part of core data measurement and NEON-affiliated research projects.

Network Coordination

The purpose of network coordination is to facilitate the use of NEON by the broader, multidisciplinary scientific community and ensure that the NEON information base is supportive of national- and continental-scale research. The network as a whole should facilitate cross-site research and cross-site coordination of informatics, establish close ties to other agencies (federal, state, and private) that do research on environmental issues, and develop mechanisms that allow observatories to maximize their resources and achieve economies of scales. To make this a reality, we envision development of an institutional entity with responsibilities in the areas of coordination and sharing of common resources across NEON.

Specifics of the governance of the network will be discussed at NEON Workshop III, but we propose a general outline here. We suggest that the network be governed by a coordinating committee consisting of representatives from each observatory, members of the scientific community who use these observatories for research, and experts in bioinformatics, genomics, wireless technology, and information and archival management. Membership on the committee should be rotated to ensure that fresh ideas and perspectives are built network governance.

The charge to this committee may include, but is not limited to

- Coordination with existing organizations and programs such asPACI, TIGR, NLANR and NCEAS, and federal agencies such as USGS, EPA, USDA-FS, USDA/ARS, USDA/NRCS, NASA, NPS, and Smithsonian bureaus.
- Establishment, implementation, and periodic evaluation of standards for bioinformatics and core measurements.
- Coordination of periodic network conferences to review new developments in science and technology (from research done at the observatories and related efforts elsewhere) and network infrastructure.
- Coordination of information, technology, and management.
- Evaluation of efforts in education and outreach.
- Maintenance of a common framework for network collaboration and communication.

- Evaluation of the success of the network.

Given the constraints of the operational budget for each observatory, it is crucial that the central network plan for common tools and their management. For example, centralized software engineering efforts will reduce costs for each observatory and enable cross-site availability and analysis of metadata. Other centrally coordinated items might be a high-throughput sequencing facility, aircraft for remote sensing and atmospheric sampling, and a housing site for conducting workshops (e.g., to train observatory staff and brainstorm effective incorporation of new technologies). A detailed list of centrally coordinated or network operated functions are presented in the "Network" column of Table 1.

Educational Outreach

In keeping with NSF's dual evaluation criteria—scientific merit and societal and national significance—NEON presents an unprecedented opportunity to include underrepresented communities and citizen scientists via outreach activities. NEON proposers should consider educational outreach an integral part of observatory proposals. To be considered for inclusion in NEON, site should address their ability to contribute to the education and outreach component. We encourage inclusion of formal and informal educational institutions as consortium members.

Various target audiences can be served through science outreach programs and citizen science projects. Science outreach programming might include on-site seminar series or tours, teacher training workshops, school field trips, electronic field trips for more distant populations, Web site access to on-site projects and data, and site-specific electronic field guides and keys. Citizen science—drawing non-scientists into the process of science occurring at NEON sites—can include involvement in monitoring at the primary site and the consortium sites.

The "field" nature of the observatories and their proximity to under-served populations will make these sites attractive to these populations. For example, rural school districts will have the opportunity to introduce their students to scientists and scientific research at NEON observatories. Through NEON, it also will be possible to reach out to communities such as ranching, forestry, and agriculture that use natural resources but that traditionally have been antagonistic to environmental initiatives.

NEON sites will also serve as a valuable platform for professional science training by involving undergraduate and graduate students in research projects and undergraduate and graduate field courses. NEON should consider how to get involved with scientific technician training programs offered at some four-year colleges.

NEON sites also will serve the traditional educational community of K-12 students and teachers. NEON is ideally situated to tap into this and other resources of personnel mentioned above for on-site data monitoring and management. The large data sets generated by NEON sites will be made available electronically to a scientific research audience and informal and formal scientific education audiences who can then become involved in data analysis and processing.

Information Technological Frontiers Symposium

This workshop included a stimulating day of presentations on technology advances of relevance to NEON. The workshop participants found the presentations to be informative and useful. A list of the speakers and their topics is included below. Slides and full audio and video of their presentations is available from the San Diego Supercomputer Center at: http://www.sdsc.edu/NEON

Introduction to Information Technological Frontiers Symposium - Peter Arzberger

I. Data acquisition

Hans-Werner Braun: Ubiquity Issues for a Distributed Internet Environment
Dave Hughes: The Low-cost, Low-power, Wireless End of Things

Darrell Long: Real-time Environmental Information Network and Analysis System

Robert A. Morris: Engineering Desiderata for Biodiversity Software

II. Advances in informatics

Cherri Pancake: Why NEON Will Need to Address the Usability of Ecological Data

John Quackenbush: Querying and Visualizing Fully Sequenced Microbial Genomes

Paul Kanciruk: Project Mercury—A Web-based Metadata Search and Data Retrieval System (*available as slides only*)

III. Integrated data management and analyses

Shankar Subramaniam: The Biology WorkBench—A Seamless Database and Analysis Environment on the World Wide Web

David Stockwell: Biodiversity Species Workbench

Reagan Moore: Information-based Computing and Knowledge Discovery

IV. Scientific visualization and modeling

John Helly: Acquiring and Visualizing Ecological Data

Larry Smarr: Frontiers of Visualization of Ecological Systems

Dennis Ojima: Regional Carbon Modeling—Integrated Modeling across Scales

Topics for NEON Workshop III

We recommend that NEON Workshop III attempt to do the following:

Governance:

- Develop a model of governance for NEON and the types of institutional entities that might advance NEON network coordination. In particular address start-up and steady-state models.
- The regional consortium nature of NEON observatories and the model for both the sharing existing field research resources and the distribution of new, NSF NEON observatory resources is the key question that must be resolved if NEON is to become the exceptional national resource its promise holds. The scientific community and NSF planners need to close this gap before the final design of NEON is determined**.**

Data and Information:

- Develop mechanisms for identifying core measurements and ensuring development of network information and data management standards.
  - This could include discussion to determine how to ensure strong commitment and involvement from supercomputer centers or centralized computer centers for the information technology aspects of the NEON infrastructure.
  - In addition, this discussion should address the need for strong guidance at the inception in data coordination and sharing to realize the vision of NEON.
- Outline general features of a data policy that addresses how NEON will manage, archive, and disseminate data while maintaining sensitivity to publication considerations. Distinguish between core data and data generated by researchers using the infrastructure.

Operations:

- Review the operational needs of NEON observatories relative to a $1.25 M/year operating budget. Identify areas where cost recovery (e.g., fees for service) might be required to meet operational expenses. Such a review should consider the effects of inflation over a 30-year period and its impact on operating budgets. In particular, an independent assessment of the costs of running and maintaining a NEON observatory should be conducted, based on the components identified in this report (i.e., staff salaries, networking expenses, operating and administrative costs (e.g., telephones, copying, maintaining equipment), and facilities costs (e.g., electricity, physical upkeep, heating/cooling). What is possible for the estimated costs of $1.25M/year of total operating costs? What are the real costs?
- Develop cost estimates for the coordination aspects of the network.

Assessment:

- Identify measures for a successful NEON site, the network, and the coordination body.

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