Smart Forests for the 21st Century
A New Initiative to Develop EFR Cyber Infrastructure

The Issue – Rapid Environmental Change

The 21st century is emerging as a time of great environmental change, including a rapidly changing climate, continued inputs of atmospheric pollutants, and current and projected shifts in demographics and how the land is used. Together, these challenges threaten the health and sustainability of the nation's great natural resources. *The demand for information to understand and monitor these environmental changes and to expeditiously communicate this information among scientists, to policy makers, land managers, and the concerned public has never been greater.*

The Opportunity – New Advances in Cyber Infrastructure

Recent advances in environmental sensor technology, wireless communications, and software applications have enabled the development of low-cost, low-power multifunctional environmental sensors and sensor networks that can communicate environmental conditions to researchers, managers and the public in real time. This emerging technology generates information at unprecedented temporal and spatial scales, and offers *transformational opportunities* to better understand the physical, chemical and biological 'pulse' of both terrestrial and aquatic ecosystems. These real time 'windows on watersheds' also provide compelling new ways to engage the public, and provide novel tools for resource managers (see Box 1).

Box 1. Examples of Environmental Sensor Applications

Physical
- Climate (temperature, precipitation, rH, wind speed, etc.)
- Hydrology (stage height, soil moisture, ground water table, etc.)

Chemical
- Air pollution (O3, nitrous and sulfur oxides, etc), deposition
- Water Quality (pH, nitrates, dissolved carbon quality and quantity, etc.)
- Atmospheric CO2

Optical
- Phenology (canopy greenness and duration)
- Bird and animal movements

Acoustical
- Presence or absence of endangered species

Early Warning Systems
- Fire
- Floods
- Droughts

The EFR Network - Long Term History of Environmental Monitoring and Discovery

The US Forest Service operates a network of 80 Experimental Forests and Ranges (EFRs) across the continental U.S., Alaska, Hawaii, the Virgin Islands, and Puerto Rico. These sites are located along broad gradients of climate, vegetation, soils, and land-use that are representative of most National Forest System lands. EFRs have a long history of research and environmental monitoring. At some EFR sites, environmental records date back more than 100 years. These long-term data sets are critical for detecting patterns and trends in climate, forest and range health and productivity, and response to natural and human induced environmental change. Individually, these sites serve as *benchmarks* against which further change can be gauged. Together, they have the potential to serve as a *regionally distributed, long-term multi-site, multi-sensor platform for detection of short- and longer-term environmental change for forests and rangelands of the United States.*

The Need - Updated Cyber Infrastructure

In order to meet the information and discovery needs of the 21st century, the Forest Service must invest in new technology and cyber infrastructure within its network of EFR sites. Many EFRS still record basic information such as precipitation, temperature and streamflow using circa

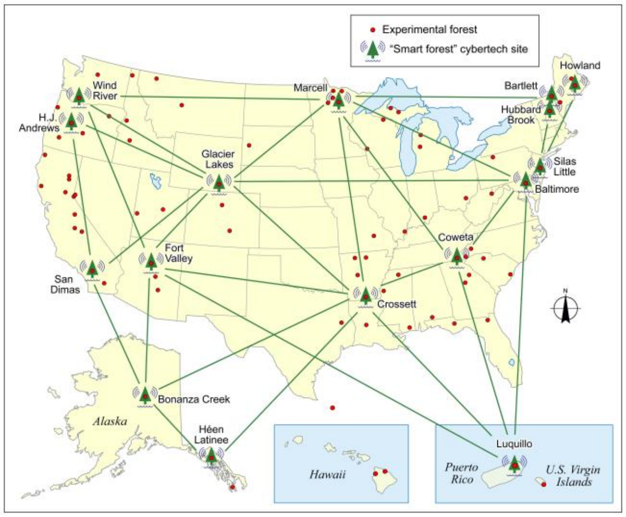
1950's mechanical devices attached to paper and pen charts; the charts are collected at weekly or monthly intervals by forestry technicians, transcribed by hand into electronic databases, and then analyzed, sometimes years later by scientists. These systems, although reliable, are labor intensive; delivery of data to end users is slow; they have limited capacity for expanded data collection in time and space; they cannot respond to environmental crises in real time; and, in many cases, are so obsolete that replacement parts are no longer available. At other sites, scientists and managers have begun to invest *ad hoc* in new technology. These are often one time purchases, address single aspects of a complete Wireless Sensor Network (WSN) system (e.g., electronic data collection but not transmission or real-time delivery to the internet), and funds are often not available or inadequate for replacements parts and/or training of competent staff. *A vision for a comprehensive redesign and standardization of environmental data collection and delivery at Forest Service EFR sites is critically needed.*

The Solution - "*Smart Forest*" Initiative

The EFR "Smart Forest" initiative offers a strategy to update and modernize cyber infrastructure for the collection and delivery of environmental data at EFR sites across the country. EFR "Smart Forests" will provide an integrated technological platform to monitor and respond to environmental change at the local to continental scales. The basic features of this initiative will include:

- Improve and/or standardize cyber technology for collection of and wireless transmittal to the internet of a foundational set of environmental measurements at, initially, a core set of 'Smart Forest' sites. These sites will be strategically distributed across major geographic, climatic and vegetation gradients.
- Identify, evaluate, and deploy solutions to provide real-time access to environmental sensor data from core sites to a *single point of entry* web site.
- Apply emerging visualization and outreach tools to engage researchers, resource managers, educators and the public with 'Smart Forest' data.

Considerable groundwork for this initiative has been laid and real-time data access and viewing are available at a growing number of EFR sites (see Figure 1). Examples of current applications include: continuous monitoring of climate variables, stream flow, water quality, groundwater table, sap flow, and trace gas flux; installation of webcams to improve quality and frequency of phenological measurements and observations of animal behavior; and installation and use of radio collars for tracking wildlife movements across the landscape.



As the processing powers of sensors and computers continue to improve at an exponential pace, as energy requirements and costs continue to come down, and as the world becomes increasingly globalized and connected, WSNs will assume an increasingly common role in our everyday lives, as much or more so than the present day personal computers and cellular telephones. It is critical for the Forest Service to make a sound and strategic investment in this technology now in order to create the "smart forests" of the future.

Appendix I: Foundational Principals for 'Smart Forests'

Our guiding vision is to build a network of research sites that are equipped with a synergistic technological platform, combining high frequency, real-time sensor-based measurements with traditional ecological field-scale studies, designed to monitor and respond rapidly to environmental change at the local to regional scales.

Implementation of the 'Smart Forest' Initiative will require the formation of a planning committee to include a multidisciplinary team of scientists, resource managers, information managers, hardware and software engineers, education and outreach specialists, and administrators. The keys to its success will be modularity and flexibility. By modular, we mean developing a basic unit and its communications hardware and software that can be deployed at multiple locations within a site or across sites, and which can accommodate an expandable suite of sensors of different types. By flexible, we recognize that the basic unit will need to be adapted to individual sites, reflecting potential implementation barriers (such as complex terrain, remote access, harsh conditions, and the availability of power and/or trained personnel), as well as different resource and management needs. Developing this technology with the limited resources available to individual EFR sites is daunting, and only yields site specific applications and insights. Developing this technology with the resources available to the U.S. Forest Service, providing this to individual EFR sites, and developing new 'middleware' to stream data from multiple sites to a single point of access, where is can be made available to a range of end users, and used to develop synthesis products in real time is an exciting and attainable goal. Below, we outline several features that should be considered in the development of the 'Smart Forests' initiative.

I. Key Components and Considerations

For this initiative to succeed and gain wide acceptance, the following issues must be addressed.

- *Clear articulation of initial scientific and societal needs and questions for which baseline ecological data are required.* An initial set of needs and questions that can only be addressed by a multi-site, multi-sensor cyber technology platform delivering data to end-users in real time must be identified, coupled with clear and timely deliverables.
- *Identification of specific data needed to address these questions.* Careful consideration must be given to specific data needs to address the questions identified above. Scientists, modelers, resource managers, educators and members of the public should be consulted to verify that the appropriate set of measurements are identified.
- *Determination of spatial and temporal resolution needed to address these questions now and in the coming decades*. New techniques for processing and storing 'Big Data' are being advanced daily, and these aspects of cyber infrastructure are no longer major barriers to deployment of these systems. Data collections should be predicated on research, modeling, management and outreach needs.
- *Evaluation of hardware and software needed to collect these data*. Considerable effort has already been spent to identify and evaluate hardware and software needed for this initiative, both by Forest Service scientists as well as scientists within other agencies (e.g., NOAA, USGS, NSRC). A review of these efforts should be a starting point for the

Smart Forests Initiative. The question of whether to use identical hardware and software at all sites (NEON model) or allow individual sites to develop their own systems but mandate common data quality and delivery objectives (LTER model) must be addressed.

- *Determination of how to deliver data most effectively and efficiently from the field to the repository for storage and subsequent analysis.* A range of options now exist for real time data delivery, including cell phones, satellite, radio telemetry, meteor bursts, and regular manual downloads. This is an area where site factors, such as terrain and access, will determine technologic solutions.
- *Designing a system with maximum flexibility for expansion in time and space as new environmental concerns emerge and novel environmental sensors are developed.*

II. Principles for Managing this Initiative:

Although the vision for the EFR "Smart Forest" initiative is expansive, it is also necessary to maintain focus and manageability. The following principals will thus help guide this initiative:

- The initiative is aimed to serve the entire EFR network. However, it may not be possible or desirable to implement the approach at each EFR, at least initially. A selection approach will be adopted to strategically determine which EFRs should be part of the initial implementation of the effort. This will be rooted in the information objectives of the overall effort.
- The fundamental purpose of this initiative is to develop credible scientific data and analyses to inform land and resource management decisions. Strategic partnerships will be developed with other federal, state, and private agencies where possible to share the cost and benefits associated with this initiative.
- The basic intention for this initiative is to provide for data integrity and access. Data collection protocols, accuracy and precision will be the highest priority to enable pooling of the data and cross-site analyses involving the entire network.
- A fundamental shift in scientific data sharing and 'ownership' will be required to make this initiative a success. It will be important to develop and foster a culture of a collegiality and collaboration that involves all 80 EFRs and any partner agencies and facilities.
- It must be recognized that this is an investment in the future and requires a relatively significant short-term investment followed by a long term commitment to maintain the system.

III. Strategic Investment Requirements

The success of this initiative will depend on careful planning, a sound and robust investment strategy, and a commitment to adopting and maintaining this technology as part of our mission statement and how we 'do business' at these Smart Forest sites. Achieving the objectives of this initiative will require investments in ***all*** of the following:

- *People*. Skilled technicians, trained in the deployment and use of the equipment, will be needed. These technicians need not be site specific but may service several sites in a Station or Region.
- *Network Office*. Direction from a central network office will be critical to effectively manage this initiative on a national scale. Trained staff to provide support for data oversight, delivery and synthesis will be important to maximize the benefits of this continental scale observational platform and to provide support for individual nodes of the national network.
- *Equipment*. Selected, state-of-the-art equipment will replace the outdated, inefficient equipment that is currently in use. Careful planning is required to determine what best fits both the individual requirements of each site as well as the needs of the network.
- *Data Management*. The entire EFR network is currently being evaluated to determine data management requirements that optimize archiving, storage, and retrieval of the large and growing body of data. This initiative needs to be imbedded in that larger overall strategy. Innovative and effective means are needed to deliver the data from the field to the end user.

Appendix II: First 'Smart Forests'

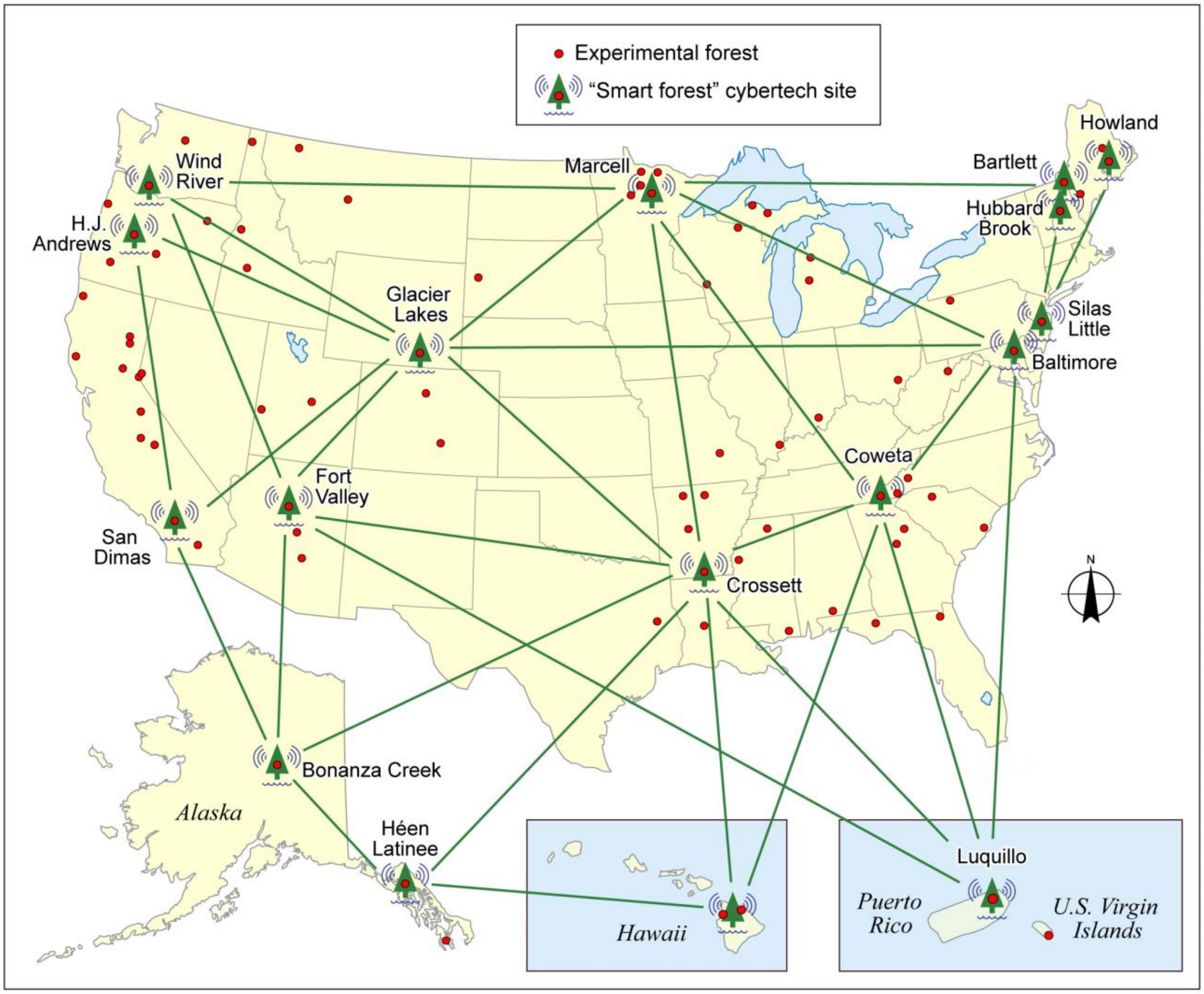
As discussed previously, it will not be feasible, affordable or desirable to deploy cyber technology in all EFRs at the outset of implementation. Here we suggest a set of *First Forests* (Table 1, Figure 2). Selection criteria include the following:

- Location: EFRs selected for the initial set of Smart Forests are distributed across the geographic and climatic gradients of the entire EFR network, with First Smart Forests in all nine Forest Service Regions and Stations.
- Vegetation Types: First Smart Forests include a variety of forest and range types.
- Existing Cyber Infrastructure and Trained Personnel: For expediency and economy, most of the First Smart Forests were chosen to have robust existing cyber infrastructure and trained personnel. One (Helen Latinee) was selected to demonstrate feasibility to build a Smart Forest with little existing cyber infrastructure, no trained personnel, and a remote location.
- Historical Record: The initial Smart Forests effort will focus on climate and hydrology. Therefore, those sites with long term meterological and hydrological records were given priority (e.g., Fort Valley and Crossett).

Table 1. Suggested Initial EFRs for Smart Forest initiative.

EFR	State	Region	Station	Cyber Infrastructure	Climate Tower Network	EFR Climate Synthesis	Other Feature
Baltimore	MD	R9	NRS	***	x	x	LTER
Bartlett	NH	R9	NRS	***	x		NEON
Bonanza Creek	AK	R6	PNW				LTER
Coweeta	NC	R8	SRS	***	x	x	LTER
Crossett	AR	R8	SRS			x	
Fort Valley	AZ	R3	RMRS			x	long record
GLEES	WY	R2	RMRS	***	x	x	
Hawaii	HI	R5	PSW	***			remote, RAWS[1]
Héen Latinee	AK	R6	PNW	none			remote
HJ Andrews	OR	R6	PNW	***		x	LTER
Howland	ME	R9	NRS	***	x		Ameriflux
Hubbard Brook	NH	R9	NRS	***		x	LTER, SCAN, USGS
Luquillo	PR	R12	IITF			x	LTER
Marcell	MN	R9	NRS	***	x	x	
San Dimas	CA	R5	PSW			x	long record
Silas Little	NJ	R9	NRS	***	x		
Wind River	OR	R6	PNW	***	x		

[1]RAWS = Remote Automated Weather Station, Operated by National Interagency Fire Center



Experimental forest
"Smart forest" cybertech site
Howland
Bartlett
Hubbard Brook
Wind River
H.J. Andrews
Marcell
Glacier Lakes
Silas Little
Baltimore
Coweta
Fort Valley
San Dimas
Crossett
Bonanza Creek
Alaska
Héen Latinee
Hawaii
Luquillo
Puerto Rico
U.S. Virgin Islands
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Appendix III: Initial Infrastructure and Measurements

We expect to convene a panel of experts to provide input to the First Smart Forests design and implementation. Here we propose an overview of what we anticipate to be key components of this initiative.

Given that physical measurements are the most developed and given the need for climate data at the local and continental scale, especially for extreme weather events, we will focus the First Smart Forests efforts on (1) developing the cyber infrastructure 'back bone' for each First Smart Forest site, (2) deploying a vertical array of sensors to measure and monitor a suite of climate variables, (3) transmitting these data to a base station, (4) transferring data from the base station to a single point of access in near real time (defined here as within 24 hours of data collection), and (5) developing interactive visualization, graphical, and downloading capabilities. Considerable effort will be devoted to both quality assurance and quality control, from routine sensor calibrations through automated streaming QC and gap filling alogrithms, to human screening of final data products.

The cyber backbone for each site will consist of:

- individual sensors
- power source (ac, dc, solar, other)
- data loggers for data collection and storage
- telemetry system to transmit data to base station
- base station connected to the internet

We expect to tailor this infrastructure to meet individual site needs without compromising our ability to pool the data from all sites. The systems will be designed for maximum flexibility to accommodate additional sensors as funding or technology becomes available. Many of the sites listed in Table 1 have existing infrastructure and only need support for upgrades, replacement parts, and ongoing maintenance.

We propose the following vertical suite of core measurements for each site (to be collected at 30 minute intervals).

1. Aboveground Climate: We propose the standard suite of measurements following NOAA protocols:
    - Air temperature (mean, minimum and maximum for interval)
    - Relative humidity
    - Wind speed
    - Wind direction
    - Total precipitation
    - Solar radiation

2. Belowground Climate We anchor the soil climate measurements at an upper 2 cm depth and a lower 50 cm depth. The middle two depths are arrayed according to site specific rooting depth
   - Soil temperature (5 cm, mid rooting zone, bottom of rooting zone, 50 cm)
   - Soil moisture (5 cm, mid rooting zone, bottom of rooting zone, 50 cm)
3. Hydrology – Sites with existing hydrology programs will additionally measure:
   - Stage height
   - Stream temperature
4. Webcam – Two web cams will be installed at each site: one for high frequency phenological measurements and one for capture of charismatic species or vistas for outreach and education purposes.

Identical sensors will be used for all measurements at all sites, facilitating quality assurance controls, intersite comparisons and network level technical and scientific information sharing. We will adapt NEON’s plug-n-play model, where each sensor has a unique identifier, recognizable anywhere in the Smart Forests network system.

Appendix IV – Initial and Continuing Costs

It is not the purpose of this document to provide a detailed budget for this initiative at this time. However, it is possible to provide preliminary insights on costs based on current efforts at EFRs across the country. These are shown in Table 2. For sites with no known cyber infrastructure, start-up costs are estimated at $25,000 per site for the suite of measurements in Section III, For sites with existing Forest Service Tower Network (FSTN) or similar quality cyber infrastructure, start-up cost is pro-rated to $5000 per site for belowground climate and/or hydrological sensors. Maintenance costs will vary, depending on the complexity of the site sensor network, with less maintenance associated with a single weather station, and more with networks of weather and stream gaging stations. Here we use an average of 0.5 person days per week (~$4160/yr), and $3,000 per site per year for equipment maintenance and upgrades.

Table 2. Preliminary cost estimates for First Smart Forests Initiative

EFR	State	Region	Station	Cyber Infrastructure	Climate Tower Network	EFR Climate Synthesis	Other Feature	FSTN Infrastructure Costs	Maintenance Costs/yr	Maintenance Costs/5 yrs
Baltimore	MD	R9	NRS	***	x	x	LTER	$5,000	$7,160	$35,800
Bartlett	NH	R9	NRS	***	x		NEON	$5,000	$7,160	$35,800
Bonanza Creek	AK	R6	PNW				LTER	$25,000	$7,160	$35,800
Coweeta	NC	R8	SRS	***	x	x	LTER	$5,000	$7,160	$35,800
Crossett	AR	R8	SRS			x		$25,000	$7,160	$35,800
Fort Valley	AZ	R3	RMRS			x	Longest Record	$25,000	$7,160	$35,800
GLEES	WY	R2	RMRS	***	x	x		$5,000	$7,160	$35,800
Hawaii	HI	R5	PSW	***			remote, RAWS[1]	$5,000	$7,160	$35,800
Héen Latinee	AK	R6	PNW	none			remote	$25,000	$7,160	$35,800
HJ Andrews	OR	R6	PNW	***		x	LTER	$5,000	$7,160	$35,800
Howland	ME	R9	NRS	***	x		Ameriflux	$5,000	$7,160	$35,800
Hubbard Brook	NH	R9	NRS	***		x	LTER, SCAN, USGS	$5,000	$7,160	$35,800
Luquillo	PR	R12	IITF			x	LTER	$5,000	$7,160	$35,800
Marcell	MN	R9	NRS	***	x	x		$25,000	$7,160	$35,800
San Dimas	CA	R5	PSW			x	Long record	$5,000	$7,160	$35,800
Silas Little	NJ	R9	NRS	***	x			$25,000	$7,160	$35,800
Wind River	OR	R6	PNW	***	x			$25,000	$7,160	$35,800
Total per column								$225,000	$121,720	$608,600
grand total 5 year cost										$833,600