Long Term Agro-Ecosystem Research Network

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Executive Summary

Agriculture faces tremendous challenges in meeting multiple, diverse societal goals, including: 1) a safe and plentiful food supply; 2) climate change adaptation/mitigation; 3) supplying sources of bioenergy; 4) improving water/air/soil quality; and 5) maintaining biodiversity. The LTAR network enables long-term, trans-disciplinary science across farm resource regions to address these challenges. The goal of this research network is to ensure sustained crop and livestock production and ecosystem services from agro-ecosystems, and to forecast and verify the effects of environmental trends, public policies, and emerging technologies.

This shared research strategy (SRS) is a living document, founded on the basic goals of the LTAR network and designed to capitalize on the strengths of the initial 10 LTAR sites.[1] The LTAR SRS creates common geographically- and temporally-scalable databases that deliver knowledge and applications within the following four priority areas of concern:

1) *Agro-ecosystem productivity*;
2) *Climate variability and change*;
3) *Conservation and environmental quality*; *and*
4) Socio-economic viability and opportunities.

A key expectation of the LTAR Network is the application of research results to solve critical challenges facing agriculture. Because research based applications and their outcomes are impacted by continually-changing trends, demands, and innovations, the LTAR SRS exploits a mixture of data from on-going networked science, new cross-site

[1] The LTAR Shared Research Strategy (SRS) is a product of the LTAR Research Committee (J. Derner, K. Havstad, P. Heilman, D. Huggins, P. Kleinman, T. Moorman, E. Sadler, M. Sanderson, J. Steiner, T. Strickland, and M. Walbridge, Chair).

experiments, and long-term historical measurements (Figure ES-1). The ongoing integration of foundational science with long-term, multi-location experimental data underpins the provision of four key LTAR products: 1) new knowledge of processes and systems; 2) new technologies and management practices; 3) improved agro-ecological models; and 4) comprehensive, accessible data. Ultimately, LTAR will provide a wide array of clients, partners, and stakeholders with four basic outcomes:

1) Agroecosystem productivity is sustainably enhanced by the development and application of new technologies;
2) Mitigation of and adaptation of agroecosystems to climate change is improved by more accurate predictions of resource responses to system drivers;
3) Stronger linkages to other long-term research networks improves conservation and environmental quality in agricultural landscapes; and
4) The socio-economic viability of, and opportunities for, rural communities are enhanced through educational outreach by LTAR scientists and collaborators.

The LTAR's SRS is built upon a progressive approach that (1) focuses on priority research questions, (2) reviews measurement variables and protocols used by sites to confirm comparability and identify a core set of variables and protocols for the network to adopt, (3) develops shared data sets from across network sites, (4) initiates new monitoring and experimentation efforts in conjunction with other networks, and (5) conducts retrospective analyses of trends across LTAR sites and modeling studies to generalize locally-derived observations and forecast future outcomes.

Successful implementation of LTAR's SRS is based on the commitment to the SRS across all network sites, energetic leadership from each participant in the network, and the engagement of producers, partners and policymakers.

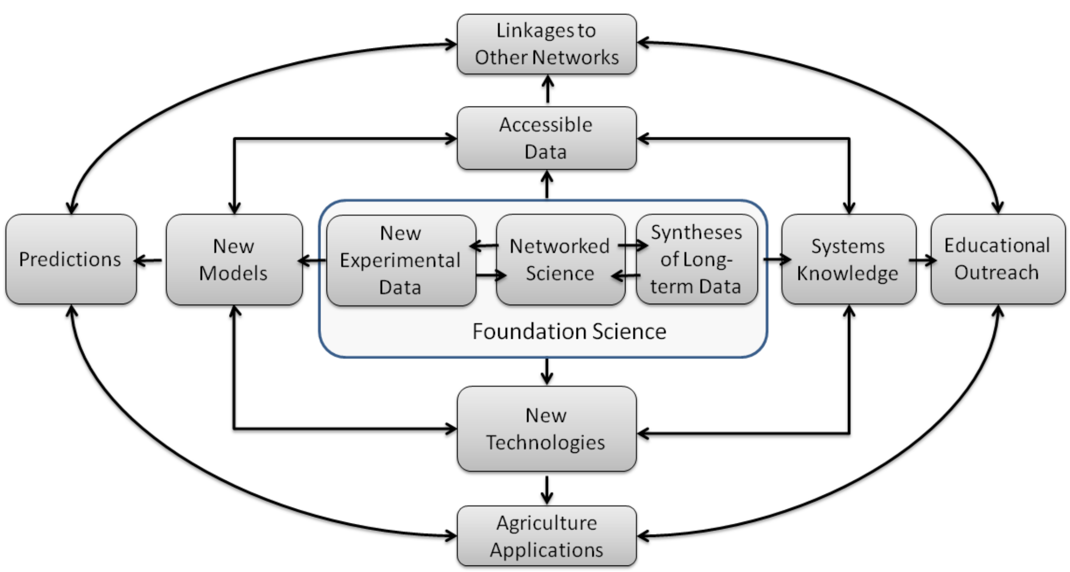

Figure ES-1. Overview of the foundation science activities of the LTAR network (figure center) resulting in key products (middle rectangle) that lead to an array of outcomes (outer ring).

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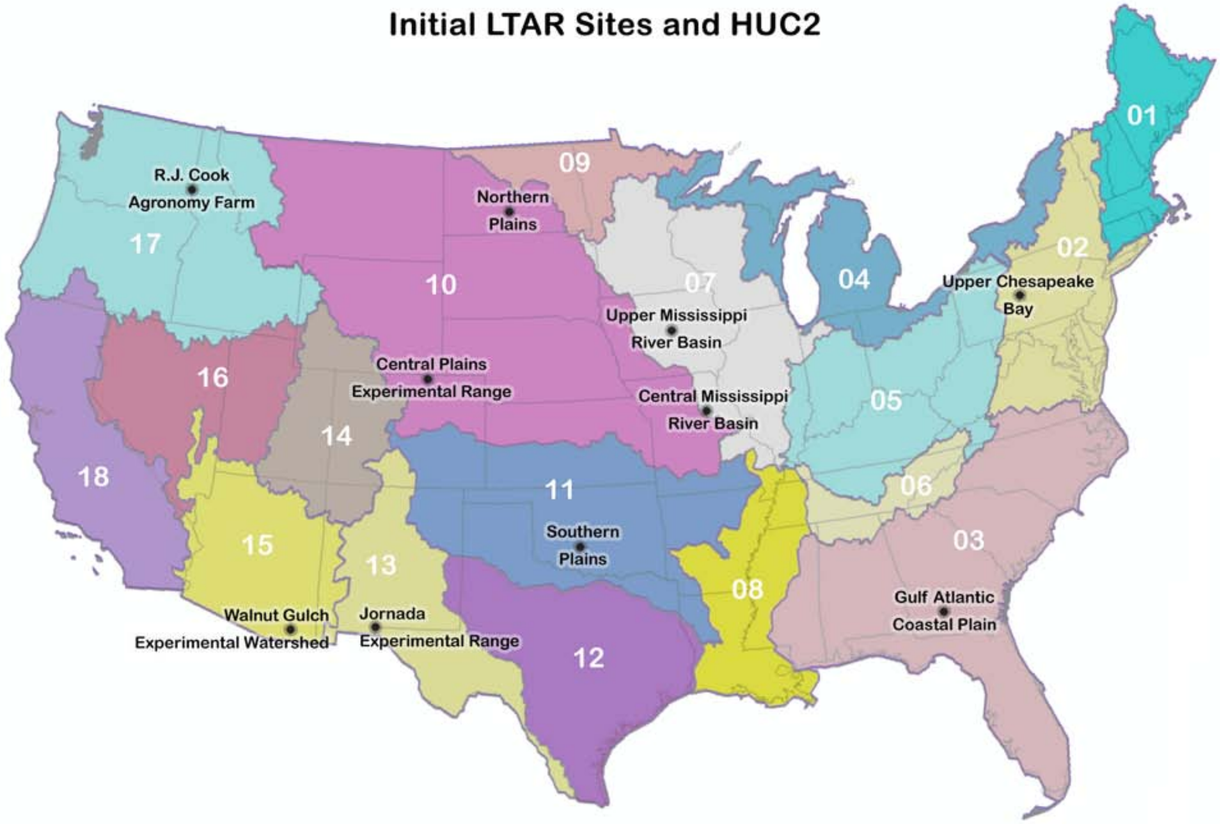
Introduction

Challenges to agriculture have never been greater. The American Society of Agronomy's Grand Challenge for the 21st Century (ASA, 2011) is "to double global food, feed, fiber, and fuel production on existing farmland … with production systems that enable food security; use resources more efficiently; enhance soil, water, and air quality, biodiversity, and ecosystem health; and are economically viable and socially responsible." Long-term research is essential to understanding how agriculture has and will adapt to changes in technologies, consumer demands (food, fuel, fiber and other ecosystem services), policy, resource availability and environmental stresses (Walbridge and Shafer, 2011). Existing networks, such as the National Ecological Observatory Network (NEON), Long-Term Ecological Research (LTER) network and the U.S. Forest Service's Experimental Forests and Ranges (EF&R), reflect the established recognition of the need for coordination and consistency in land management research programs.

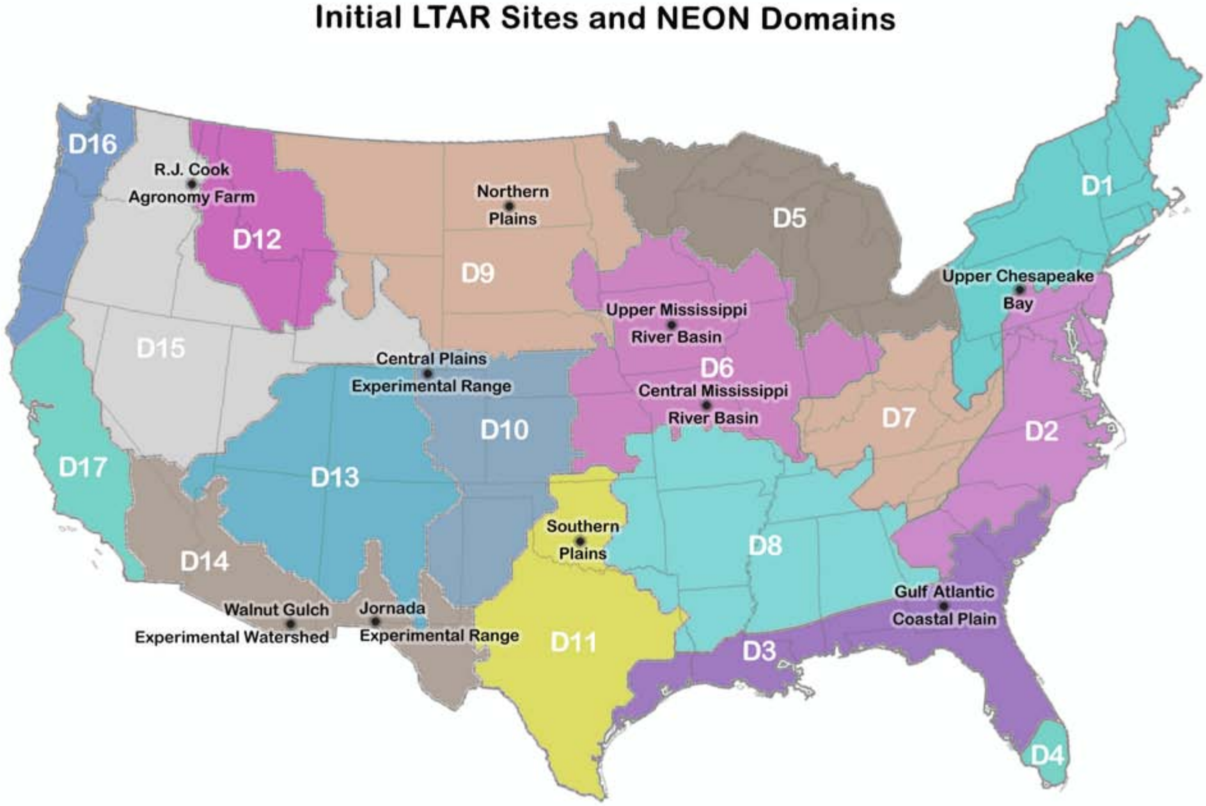
The Long Term Agro-Ecosystem Research (LTAR) network was initiated **to sustain a land-based infrastructure for research, education, and outreach that enables understanding and forecasting of our capacity to provide agricultural commodities and other agro-ecosystem goods and services under changing conditions** (Walbridge and Shafer, 2011). The 10 initial LTAR sites meet multiple criteria, including: a track record of productivity, a data record with length, breadth, depth, and overall quality, an existing long-term research facility with support for continued operation for the next 30-50 years, and a history of partnerships to enhance research, education and outreach (Figure 1; Table 1). LTAR network sites were selected in part for their representation of the 10 major US agro- ecosystems, the 21 HUC 2 watersheds within the lower 48 US states, and to complement existing monitoring or research networks by filling geographic gaps and providing unique long-term datasets or data collection opportunities not possible at existing sites.

The LTAR network is based on a scientific foundation that exploits a mixture of data resulting from coordinated experiments and relevant long-term, historical datasets that are a unique strength of the LTAR. **This document describes the basic principles of a Shared Research Strategy (SRS) and the changes we are employing to create a research network out of the 10 initial LTAR sites.** As a living document, the shared research strategy will be revised as the LTAR Network expands in response to scientific progress or to collaborations developed in the future.

Initial LTAR Sites and HUC2



Initial LTAR Sites and NEON Domains



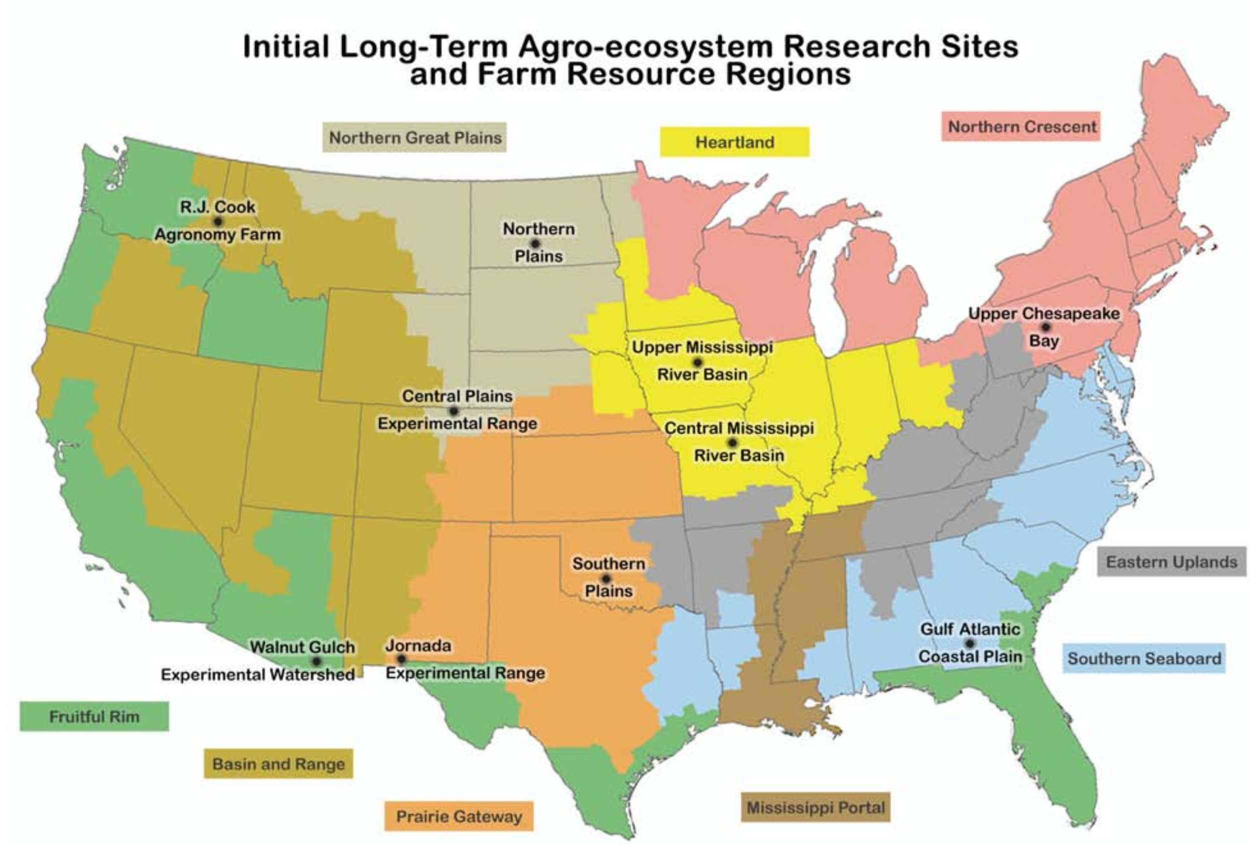


Figure 1 Ten initial LTAR network sites related to HUC2 (Hydrologic Unit Level 2 - Major Drainage Basins), NEON (National Ecological Observatory Network) Domains and Farm Resource Regions.

Table 1. Characteristics of the ten initial LTAR network sites selected in 2012.

LTAR Site and Location	Established	Record (years)†	Area (km^2)	Network Affiliations‡	Major crops, landuse, and livestock production
R.J. Cook Agronomy Farm, Pullman, WA	1999	12	0.57	LTAP, GRACEnet, REAP, NADP	Wheat, barley, pulses (peas, lentils, chickpeas)
Central Plains Experimental Range, Cheyenne, WY; Nunn, CO	1939	73	865	LTER, NEON, GRACEnet, NADP	Wheat-fallow, rangeland, beef cattle
Gulf Atlantic Coastal Plain, Tifton, Georgia; (Little River Experimental Watershed)	1965	44	334	CEAP, GRACEnet, NADP	Cotton, peanuts, corn, vegetables (~50% irrigated); poultry, beef cattle
Central Mississippi River Basin, Columbia, MO	1971	41	480	CEAP	Grain cropping systems, some pasture, riparian forest
Jornada Experimental Range, Las Cruces, NM	1912	100	780	CEAP, LTER, NEON, WNBR	Rangeland, beef cattle, wildlife
Northern Plains, Mandan, ND	1912	100	9.7	NEON, CEAP, GRACEnet, REAP	Small grains, row crops, beef cattle on grazingland

Southern Plains, El Reno, OK	1948, 1961	51	1,423	CEAP	Beef cattle, winter wheat, pasture, forages, prairie
Upper Chesapeake Bay, University Park, PA	1968	44	1,127	CEAP, GRACEnet	Row crops, dairy, pasture, forest
Upper Mississippi River Basin, Ames, IA	1992	20	6,200	CEAP, Ameriflux, GRACEnet	Corn-soybean with livestock (swine, beef, dairy)
Walnut Gulch Experimental Watershed, Tucson, AZ	1953	59	150	CEAP, EOS, Ameriflux	Rangeland, beef cattle, wildlife

[†]Through 2012

[‡] SCAN: Soil Climate Analysis Network (all sites); LTAP: Long Term Agro-Ecological Pilot; GRACEnet: Greenhouse gas Reduction through Agricultural Carbon Enhancement Network; REAP: Renewable Energy Assessment Project; NADP: National Atmospheric Deposition Program; LTER: Long Term Ecological Research; NEON: National Ecological Observatory Network; CEAP: Conservation Effects Assessment Project; WNBR: World Network of Biosphere Reserves; Ameriflux; EOS: Earth Observation System.

LTAR's Shared Research Principles

The LTAR network will provide regional test-beds where the long-term outcomes of agricultural germplasm, technologies, agrochemicals, management strategies, and policies to increase production and/or environmental protection can be evaluated via retrospective (i.e., historical) and prospective (i.e., predictive) research projects. These results will be accomplished via a hierarchical research strategy (Appendix A) built upon foundation science in four topical areas that yields four key product categories supporting four major outcome areas for US agriculture.

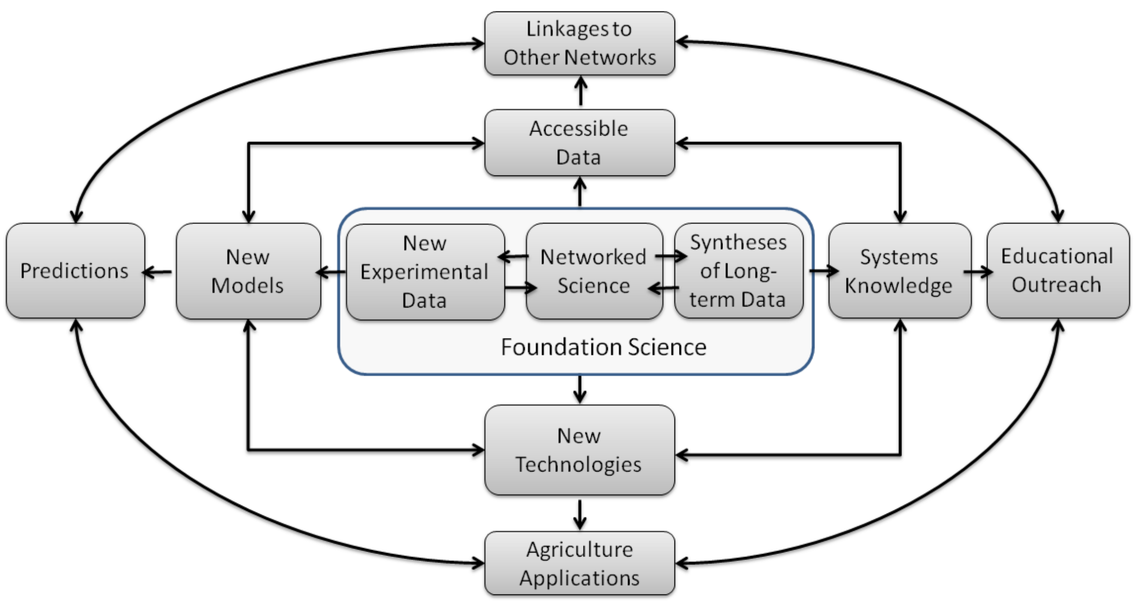


Figure 2. Overview of the foundation science activities of the LTAR network (figure center) resulting in key products (middle rectangle) that lead to an array of outcomes (outer ring).

This process outline in Figure 2 is driven by *societal concerns* related to food supply, climate change adaptation/mitigation, bioenergy, water/air/soil quality, biodiversity, and economic sustainability and livelihoods (Appendix B). The *foundation science* of the LTAR network will be directed toward knowledge gaps and technology needs under four topical areas (detailed in Appendix C):

1) ***Agro-ecosystem productivity***;
2) ***Climate variability and change***;
3) ***Conservation and environmental quality***;
4) ***Socio-economic viability and opportunities***.

The *products* from the network's foundation science fall under four categories:

1) ***new technologies and management practices*** that address key problems facing agricultural production and resource conservation;
2) ***new knowledge of processes and systems*** central to the long-term sustainability of U.S. agriculture;
3) ***improved agro-ecological models*** that apply data, technologies and/or knowledge to characterize how agricultural systems meet multifunctional requirements at regional, national and global scales;
4) ***comprehensive data sets*** that are globally accessible for scientific analyses within and beyond the LTAR network.

These LTAR products are designed to achieve 4 basic *outcomes* for our customers, partners, and stakeholders:

1) Agroecosystem productivity is sustainably enhanced by the development and application of new technologies;
2) Mitigation of and adaptation of agroecosystems to climate change is improved by more accurate predictions of resource responses to system drivers;
3) Stronger linkages to other long-term research networks improves conservation and environmental quality in agricultural landscapes; and
4) The socio-economic viability of, and opportunities for rural communities are enhanced through educational outreach by LTAR scientists and collaborators.

LTAR's Shared Research Strategy: Questions, measurements, protocols, data management and analyses

To address issues of broad geographic and temporal scope, LTAR's SRS is built upon a progressive approach that

- focuses research on priority research questions within the four LTAR topical areas,
- identifies a core set of variables and protocols for the network to adopt and reviews measurement variables and protocols used by sites to confirm comparability
- initiates new monitoring and experimentation,
- develops shared data sets from across LTAR sites, and
- conducts retrospective analyses of trends across LTAR sites, and modeling studies to generalize locally-derived observations and forecast future outcomes.

These topics are discussed in the next subsections.

Shared Research Questions: The SRS is founded on the concept that societal concerns drive the foundation science leading to relevant research questions (Table 2). These questions provide a cross-network framework to focus local research, with the expectation that they would be refined to address particular components of the topical area.

Common Historical Measurements: LTAR sites already perform many common measurements, albeit with some differences in specific variables and protocols (Figure 3). Measurements are being made of temporally continuous and spatially extensive meteorological conditions and precipitation events at all 10 sites. There are decadal records of basin-scale vegetation dynamics at 7 sites. Seven sites support the high-investment, high-maintenance equipment required to make continuous measurements of runoff, sediment yield and water quality.

LTAR sites offer some of the few records of soil moisture spanning more than a decade and many contribute to NRCS's Soil Climate Analysis Network (SCAN). LTAR sites also support studies of livestock at time scales required to see cyclic dynamics and irreversible changes. Additional sources of information, such as farmer-reported data (e.g., field specific management information on cropping, tillage, fertilization, pest management and irrigation practices) and the Agricultural Census are also available.

Considering Figure 3, the LTAR Network as currently composed has the potential to address the agro-ecosystem research questions listed in Table 2, and all data sets are considered important to the LTAR SRS. A first step in this process will be to compile metadata about methods for LTAR sites. Most sites have already completed this task through involvement in other networks and projects, and some have documented their methods in journal special issues dedicated to their long-term data and research. It will be important to start a methods/protocol exchange program within LTAR for all of the common historical measurements.

<table>
<tr><td colspan="6">Table 2. Summary of LTAR Network Shared Research Questions and Expected Outcomes.</td></tr>
<tr><th>Societal Concerns (Appendix B)</th><th></th><th>Foundation Science (Appendix C)</th><th></th><th>Research Questions</th><th>Expected Products</th></tr>
<tr><td>Food, fiber and fuel production, resource sustainability and system resilience</td><td>→</td><td>Agro-ecosystem productivity</td><td>→</td><td>How can production systems be intensified so that inputs decrease and/or outputs increase?</td><td>• New strategies to improve net primary production and crop yields;
• Improved nutrient and water use efficiencies of US food, fiber and bioenergy production systems;
• Quantification of greenhouse gas and water footprints and life cycle analyses of production systems;
• Better methods to evaluate economic value of ecosystem services.</td></tr>
<tr><td>Climate variability and change</td><td>→</td><td rowspan="2">Climate variability and change</td><td rowspan="2">→</td><td rowspan="2">How can agro-ecosystems increase production with climate change?
What strategies will help mitigate greenhouse gas emissions?
How can agriculture improve water supply and quality in the face of climate change?</td><td rowspan="2">• Recovery processes/lags from drought, floods or other extreme events;
• Carbon or greenhouse gas mitigation credits and markets;
• Monitoring and assessment tools that support adaptive management.</td></tr>
<tr><td rowspan="2">Water supply and quality</td><td>→</td></tr>
<tr><td>→</td><td rowspan="2">Agricultural conservation and environmental quality</td><td rowspan="2">→</td><td rowspan="2">How can production systems be made sustainable for both on and off-site effects?
How can management changes improve resource use efficiency?</td><td rowspan="2">• Indicators of soil quality and function;
• Valuation of ecosystem services;
• Scientific understanding to underpin conservation planning and agricultural land management;
• Monitoring and assessment tools to support adaptive management.</td></tr>
<tr><td>Ecological integrity and ecosystem health</td><td>→</td></tr>
<tr><td>Economic sustainability and livelihoods</td><td>→</td><td>Socio-economic ties to productivity, climate and environment</td><td>→</td><td>How can new or improved commodities be incorporated into agro-ecosystems to sustain ecological integrity, ecosystem health, and economic opportunity?</td><td>• Linkage of georeferenced socioeconomic data bases (US Census, ERS-ARMS, Ag Census) with biophysical modeling;
• Better understanding of motivation, incentives, and barriers to adoption</td></tr>
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				How do economic incentives and public policy affect the design and adoption of new production systems?	or change; • Better understanding of interactions between farm structure and supply of agro-ecosystem goods and services.

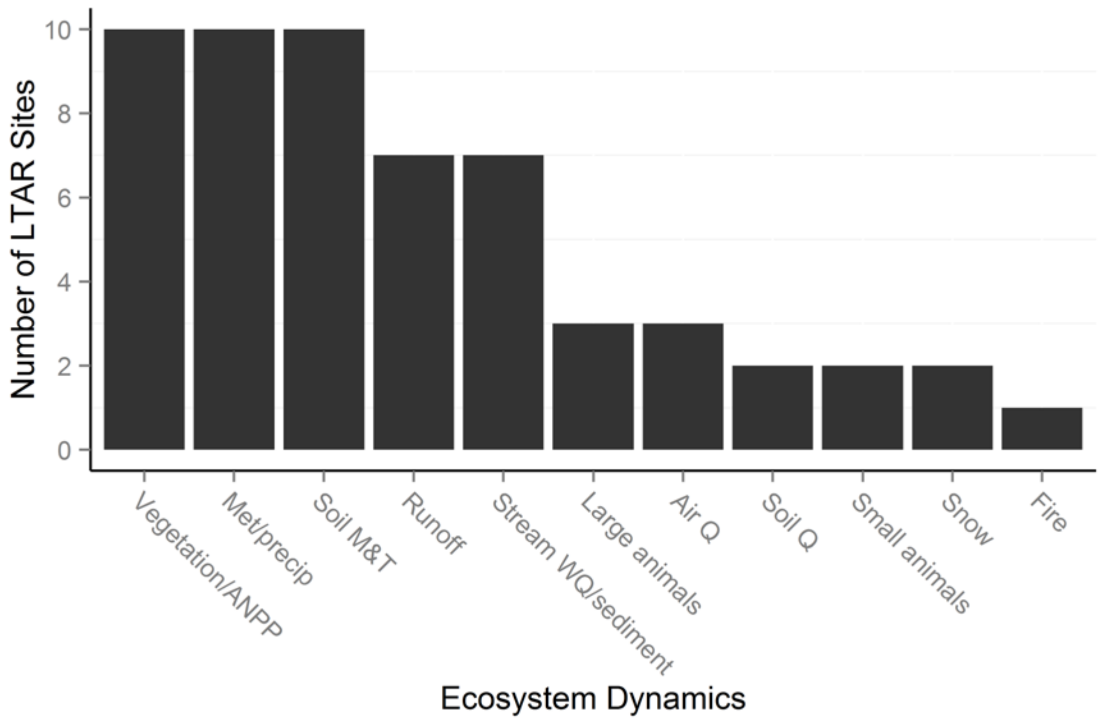

Figure 3. The number of LTAR Sites collecting long-term and ongoing data on hydrological and ecological dynamics.

Core LTAR Measurements: The shared LTAR research questions will require a set of cross-site measurements related to studies of key agro-ecosystem processes. An initial list was compiled of measurements that will support the SRS (Table 3). This is a first step in on ongoing discussion of shared measurements.

Shared Protocols: Efforts toward common methods and data protocols will be driven by 1) the cross-site datasets that are most easily compared and shared; 2) the datasets most urgently needed for initial cross-site research projects; 3) new long-term datasets that can be compiled for all sites; 4) the common instrumentation/protocols already in place; and 5) critical new instrumentation and/or measurements, where examples of each are given in Appendix D.

LTAR sites will work to adopt common protocols from the LTAR methods “catalog” as new measurements are added and as old equipment is replaced. In some cases, it will be expedient to initiate new cross-site research at a few select sites, and then validate or expand results to a larger number of sites. An example is constructing a nutrient budget at sites with a full complement of measurements, and augmenting this with partial budgets at other sites. To better understand drought, flood, erosion, vegetation and the impacts of climate change, all 10 sites have been instrumented with new sensors to monitor soil moisture at multiple depths and locations in the past two decades.

Table 3. Measurements required for LTAR foundation science and related discussion points.

Type	Measurement	Key Considerations
Plants and Animals	Species composition, biomass growth and development, harvest yield and quality	Sampling strategies (target species, spatio-temporal scales, use of ground-based and remote sensing technologies). Phenomics, community structure
	Plant nutrient concentrations, water and nutrient use efficiencies	Species considered, water and nutrient mass balances, cycles and flows, spatio-temporal scales, measurement technologies
Geography	Digital elevation map (DEM) and terrain attributes	LiDAR-derived, basis for hydrologic modeling, erosion estimates, hillslope modeling, terrain analysis
	Land cover/use (e.g., forest, range, pasture, cropland, water, urban buildup)	Patch, mosaic structure, spatio-temporal changes in land use/cover
	Remote sensing including multi- and hyper-spectral ground-based or satellite imagery	Linkage to processes, properties and practices including phenomics, water and nutrient stress, biomass accumulation, disease/weeds/pests, surface residue, management practices
Weather	Precipitation, air temperature, solar irradiation, humidity, wind speed and direction, soil weather	Measurements required for process-oriented models and to complement empirical data. Linkage to weather networks (e.g. SCAN), interpolation metrics (e.g. PRISM) and land management decision support (e.g. flex cropping, prescribed burning)
Water	Changes in storage, hydrographs for surface and ground water (e.g., streams, wetlands, lakes, runoff, artificial drainage, irrigation, aquifers)	Measurements required to characterize base and storm flow, estimate recharge, permitted withdrawals, other
	Evapotranspiration	Consumptive water use, evaporation at relevant spatio-temporal scales
	Water quality	Agricultural contributions to impairment, especially TMDLs (sediment, NO_3^-, NH_4^+, total P, O_2, temperature)
	Stream ecology	Habitat metrics (e.g., bank condition, bed condition, DO, temperature, indicator organisms)
Soil	Soil organic matter (labile, metastable, recalcitrant pools, fluxes), soil respiration, biological species, communities	Measurements required for process-oriented models (e.g. Century, CropSyst, CQESTR) and to complement related data. Statistical approaches (e.g. stratified random sampling). Degradation processes (organic matter depletion, decreased biological diversity), sensitivity/resiliency concepts
	Soil nutrient availability (e.g., N, P, K, S), reaction (pH), toxicities (e.g., Al, Mn, Na), EC, nutrient mineralization, CEC, base saturation	N_2 fixation, nutrient supplying power (ion exchange membranes, resins), acidification, salinization, soil resource sensitivity/resiliency concepts
	Soil physical properties [texture, aggregation (size distribution, stability), bulk density, infiltration, soil rooting depth, water characteristic curves, water content, temperature]	Soil degradation processes (e.g., compaction, erosion). Soil process, property characterization at appropriate spatio-temporal scales considering depth increments, terrain, soil classification. Linkage to soil weather
	Soil classification, morphology	NRCS soil survey, higher resolution soil survey, descriptions
Air	GHG flux	Soil gas exchange (CO_2, N_2O, CH_4) at relevant spatio-temporal scales, GRACEnet and other sites. Eddy covariance flux towers, static chamber measurements, soil oxygen sensors
	Particulate emissions (e.g., PM_{10}), deposition (e.g. SO_2, N compounds)	Linkage to air quality and NADP networks, wind erosion
Management	Agronomic and livestock management operations (tillage, planting, agrichemical applications), inputs (dates, rates, etc.)	Spatio-temporal scales and linkages to water and nutrient use efficiency, soil health, irrigation management
	Agricultural practice use (conservation farming, precision farming), location and size (CAFOs)	Data availability
Socioeconomics	Characterization of markets, farm structure and tenure, demographics, preferences, incentives/barriers to practice adoption	Survey information (USDA census, other), NASS, ownership, rented land, sources of labor

Ideally, shared measurements would be made with protocols common not only to LTAR sites, but also common to LTER, NEON, and other networks (Figure 4; Appendix E). This would facilitate comparative studies across a network of networks and including non-agricultural systems. LTAR sites are included in the LTER (currently 2 of 26 sites) and NEON (1 of 20 core sites; 2 of 40 relocatable sites) networks. LTAR sites are part of the Ameriflux program (2 of 103), the NRCS SCAN program (all of 100s), the NADP network (4 of 100s), the UN World Network of Biosphere Reserves, and the 15 core sites for the International Community Earth Observing System (EOS). The LTAR sites already participating in other networks have shared research strategies that will feed into the LTAR shared research strategy.

Since most LTAR sites have valuable continuous data records extending back decades, it may be unrealistic to consider changing all methods to a common protocol. In these cases, we will document that methods are nearly common, and use various QA/QC techniques to validate and compare those methods. Uncertainty introduced by different equipment (e.g., nitrate by flow injection vs. ion chromatography) and designs (e.g., flume geometry) will be documented and acknowledged. Though a common LTAR analytic center is not envisioned, a funded LTAR coordination of methods and protocols is a requirement for LTAR success.

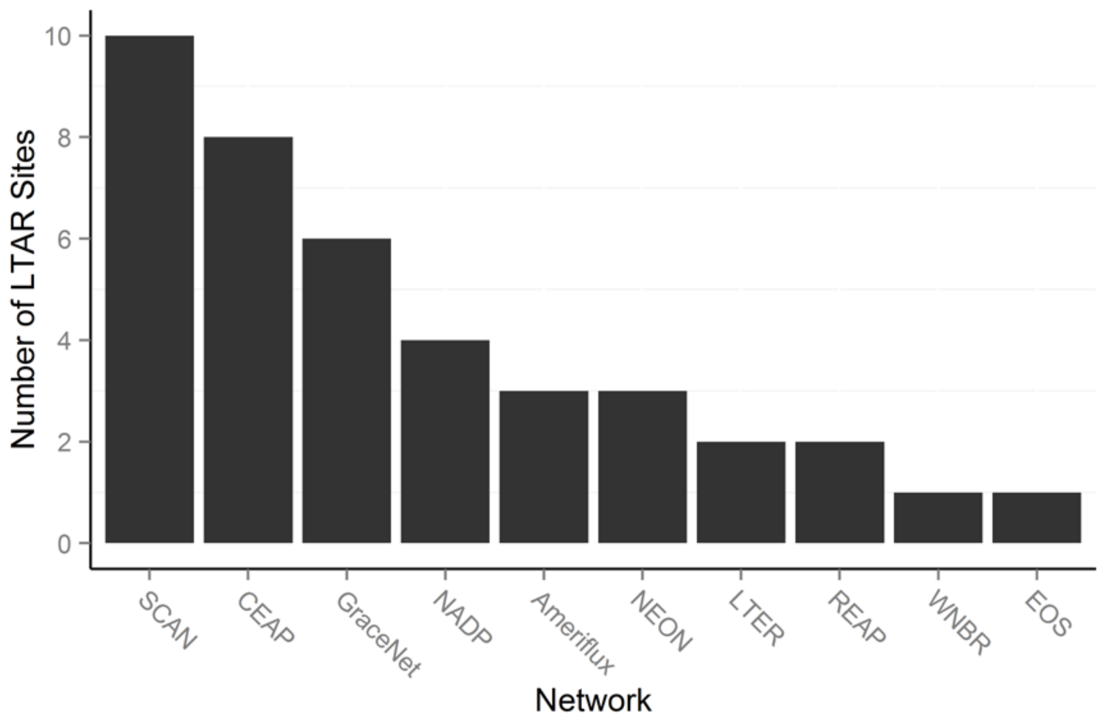

Figure 4. The number of LTAR Sites included in the SCAN, CEAP, GraceNet, NADP, Ameriflux, NEON, LTER, REAP, WNBR, and EOS networks (see Appendix E for acronyms and network information).

Data Management: The LTAR Information Management System (IMS) will provide protocol and services for collection, verification, organization, archives, access, bases for analyses, and distribution of data associated with LTAR network activities. Access to all LTAR information will be organized through a web-based LTAR portal (Figure 5). The goal of information management is to build and maintain an archive of LTAR data files that are fully documented, error free, and organized in useful ways. Our protocol for data collection and processing seeks maximum interaction between researchers and any data users.

Site and data management involvement will begin with the completion of a site-based research metadata survey by researchers; this will alert the LTAR network regarding any specific study and potential LTAR data sets. Once the LTAR IMS is implemented, researchers will then complete the required metadata documentation. All metadata documentation must be provided with any data set made available through our Web-based LTAR data portal.

The final responsibility for quality assurance (both in data and documentation content) will rest with the principal investigator who submits the data for inclusion in the LTAR IMS. To facilitate quality assurance, the data management staff will provide copies of data and documentation submitted by a principal investigator to that investigator upon request.

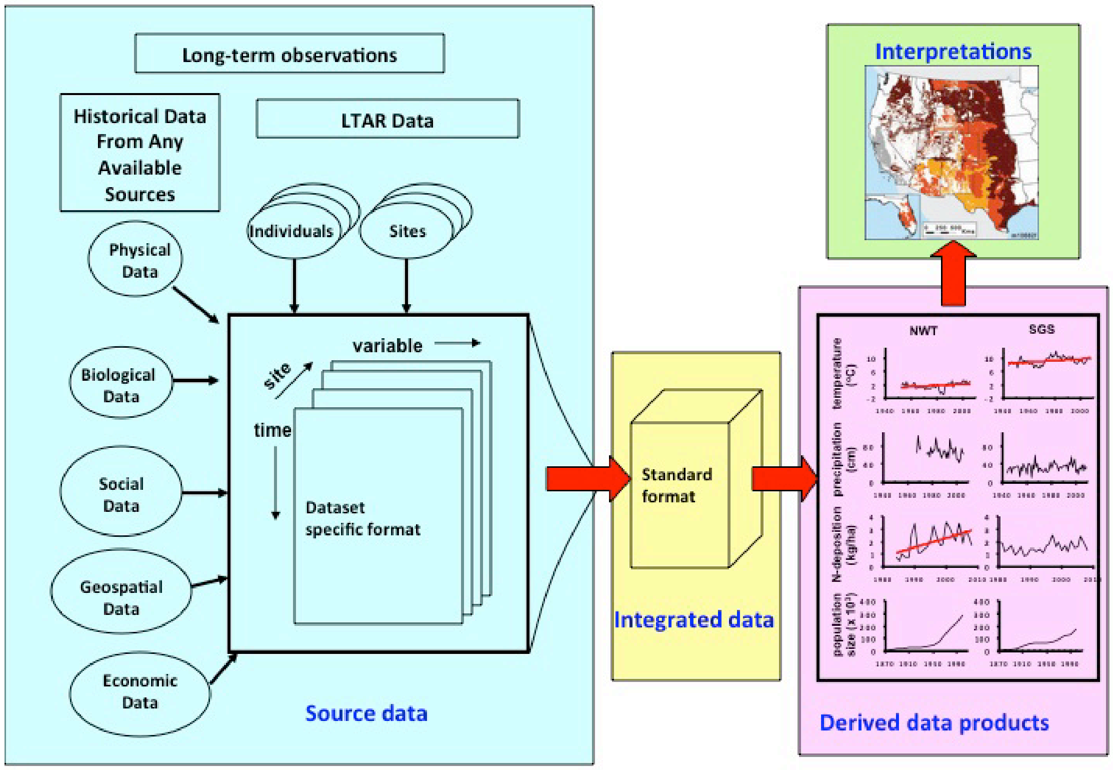

Figure 5. Data portal framework of LTAR Information Management System providing public access to source data, integrated data, derived data products and data interpretations (adapted from Peters, 2010).

Data Integration with Other Research Networks: LTAR data products may not be able to tell the full story of how to support sustainable intensification in agriculture at regional and national scales. Our intention is to support common metadata and documentation linking data products to international standards so that our products can be integrated with the other national networks, like LTER and NEON, as these technologies mature.

Data Submission: Data submission into IMS is expected from all LTAR researchers, LTAR collaborators, and their associates where data and information are derived, totally or partially, from publicly funded research in the USDA LTAR network. Other LTAR researchers are encouraged to submit their documented data for inclusion within the LTAR IMS to provide them with an archived backup, ensure its longevity, and provide online access to encourage synthesis efforts. Documentation forms will be available at a site to be determined. Documentation consists of metadata, data files, and any related details, which include objectives of the study, methods, as well as format and content of the data.

Data Access: Data will be made publicly available within 2 years of study completion. Submission of the data (and metadata) is required within this 2 year period unless the principal investigator can justify and requests a later date that is approved by LTAR leadership.

Data Re-use, Distribution, or the Production of Derivatives: Source data, integrated data and derived data products from this network are freely available for use and redistribution. Commercialization of products and interpretations using these freely available, public data are encouraged and allowed. Appropriate citation, acknowledgement, notification and collaboration are outlined and expected.

Data Acknowledgment: Individuals and institutions utilizing data from the ARS LTAR portal are requested to place the following acknowledgment in any publication in which these data are mentioned: "The USDA Long-Term Agro-ecosystem Research (LTAR) network provided data sets."

Retrospective Analyses: The network's varied data sets of erosion/sedimentation, water/air/soil quality, and invasive species (Figure 3) provide a ready opportunity for historical analysis of trends in resource and environmental quality change in response various drivers. A few examples related to the four topical areas are included here for illustration.

> *Agro-ecosystem productivity:* The LTAR network includes grassland sites across the southern U.S. During the early 21st century drought, a satellite-based record of above-ground net primary production (ANPP) at all sites could be used to generalize the functional response of grasslands to predicted climate change. Retrospective analysis in a natural setting at the regional scale could play a role in future grassland research, management and policy.
>
> *Climate variability and change:* The long-term climate records of LTAR sites permit coordinated quantification of the magnitude of temperature, humidity, and precipitation changes across agricultural regions of North America over at least four decades. For a multi-decadal analysis period, LTAR sites could be used to establish universal climatic descriptors and response variables (e.g., productivity, watershed runoff/erosion, pest severity). From this continental-scale assessment, we can begin to understand the sensitivity of agricultural systems to changes in the hydro-climatic conditions across the US and North America.
>
> *Conservation and environmental quality:* Historical advocacy for soil conservation and the evolution of cropping systems, planting technologies, pest control options and tillage practices have produced gradual, but profound,

changes in US farming systems. The diverse soil, water, pest, and environmental quality data sets of LTAR offer a unique opportunity for retrospective analysis of the beneficial and unintended consequences of conservation practices and programs, from no-till to nutrient and pest management.

Socio-economic viability and opportunities: There is increasing interest in the potential for use of market forces to encourage producers and landowners to adopt new systems or practices to protect water, soil, and atmospheric resources. LTAR data sets can be used to quantify impacts of practices on the desired endpoints and to improve and validate models that are a part of environmental marketing and trading programs in the government or private sector.

Modeling Studies: Ultimately, the success of LTAR will hinge on bringing both remote sensing and modeling to bear on the problems we are attempting to solve. Combining remote sensing with extensive geographic information systems (GIS) coverage and decade-long hydrologic data will increase the value and potential application of all three data sets. Some sites have already archived hundreds of images from satellite and high-altitude aircraft sensors, and most sites have on-going research based on currently orbiting sensors. An advantage of the LTAR network is that most of the sites have been involved either in model conceptualization or in preparation of data with which the models have been calibrated or validated. Model development has been, and will continue to be, a key strength of USDA research (Table 4).

Table 4. Some ARS hydrologic and resource models (for full citations see Renard et al., 2008).		
Model Acronym	**Title**	**Source**
ACTMO	Agricultural chemical transport model	Frere et al., 1975
ALMANAC	Agricultural Land Management Alternatives with Numerical Assessment Calculator	Kiniry et al., 1992
AnnAGNPS	AnnAGNPS agricultural nonpoint source pollution	Young et al., 1987
APEX	Agricultural Policy/Environmental eXtender	Gassman et al., 2010
CONCEPTS	Channel Evolution and Pollutant Transport System	Langendoen and Simon, 2008
CREAMS/GLEAMS	Chemical, runoff, erosion and agricultural management systems/groundwater loading effects of agricultural management system	Knisel, 1980 Leonard et al., 1987
EPIC	Erosion productivity impact calculator	Williams et al., 1984 Williams and Renard, 1985
GPFARM DSS	Great Plains Framework for Agricultural Resource Management Decision Support System (GPFARM DSS)	Shafer et al., 2000; Andales et al., 2005, 2006
KINEROS and AGWA	Kinematic runoff and erosion model with automated geospatial watershed assessment	Woolhiser et al., 1990 Semmens et al., 2008 Goodrich et al., 2012
REMM	Riparian Ecosystem Management Model	Altier et al., 2002
RHEM	Rangeland Hydrology and Erosion Model	Nearing et al., 2011
RUSLE	Revised universal soil loss equation	Renard et al., 1997
RZWQM	Root Zone Water Quality Model	Ahuja et al., 2000
SHAW	Simultaneous heat and water model	Flerchinger and Saxton, 1989
SPUR	Simulation of production and utilization of rangelands	Wight and Skiles, 1987
SWAT	Soil and water assessment tool	Gassman et al., 2007
SWRRB	Simulator for water resources in rural basins	Williams and Berndt, 1977 Williams et al., 1985
WEPP	Water erosion prediction project model	Lane and Nearing, 1989 Laflen et al., 1991

Concluding Remarks

The LTAR network was developed to address some of the great and vexing issues facing US food, fuel and fiber production. The network leverages long-term observational and experimental research efforts by USDA and its partners to (1) improve the science and management of agro-ecosystem productivity, (2) provide answers on how US agriculture with adapt to climate change and contribute to its mitigation, (3) underscore sustainable practices and strategies that conserve the nation's natural resources and enhance its environmental quality, and (4) provide the basis for objective evaluation of social and economic factors affecting the viability of alternative strategies and policies aimed at US agriculture.

Members of the LTAR network are committed to expanding the local relevance of their research to address national concerns through coordinated observation and experimental research and through sharing of common data sets. The SRS offers an overview of commonalities in research focus and data collection by the initial 10 LTAR network sites, establishes shared principals for the network's collaborative research and lays forth a progressive strategy to network research that moves from retrospective assessment of existing data to implementation of new data collection efforts via shared protocols and timely sharing of data.

Successful implementation of LTAR's SRS will require commitment to the SRS across all network sites, energetic leadership from each participant in the network, and the engagement of producers, partners and policymakers.

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Appendix A. Spatial and temporal hierarchies of agroecosystems: Discussion

LTAR's foundational science is targeted to understanding mechanisms linking and controlling the spatial and temporal dynamics of agro-ecosystem processes (e.g., hydrology, erosion, organic matter cycling, salinity, pest management, plant community structure and invasiveness, etc.) affecting the productive capacity of working lands and the services they provide (e.g., clean air and water, wildlife habitat, flood protection, recreation, etc.). Because these processes and their outcomes are impacted by concurrent and continually-changing trends in environmental condition, socioeconomic demand, and innovations in production and management technologies, systematic approaches are needed to extend the understanding developed at individual LTAR sites to the larger areas, with different management histories, that they represent.

Assessments of production, sustainability and resilience are needed at multiple spatial and temporal scales to compare agro-ecosystem performance under baseline (business-as-usual) conditions with performance from alternate technologies, production systems, and management strategies designed to increase production and/or reduce cost. The LTAR network will provide the spatially and temporally intensive mechanistic data and analyses necessary to properly interpret patterns of agro-ecosystem production and services that are documented via partner observational networks (e.g., the National Agricultural Statistics Survey, the Natural Resources Inventory, Economic Research Service data, NEON, LTER). Coupled with historical performance information, the intensive mechanistic process data will also provide calibration and validation information critical to conducting retrospective and prospective analyses reflecting the needs of diverse stakeholders including producers and policy makers.

Public-private collaboration to advance agricultural sustainability

Close collaboration between agricultural producers, scientists, and management and regulatory agencies is essential if long-term research is to effectively address the challenges facing our nation's working lands. The inclusion of producers in the design and implementation of long-term research programs enhances learning, communication and incorporation of research findings into producers' operations. Producer involvement also adds a critical reality check -- economic feasibility is an absolute requirement if any policy, plan, technology, practice, or incentive is to be implemented. The LTAR network is founded upon sites that include close, long-term collaborations between producers, scientists, and other stakeholders affected by agro-ecosystem condition. LTAR sites will engage producers and stakeholders in all phases of the research process, including the identification of key challenges and questions being studied, the design of experiments, the selection of indicators and methodologies for monitoring ecosystem processes, and the synthesis and interpretation of research findings. A long-term, site-based approach to agricultural research is essential for cultivating and maintaining these collaborations.

Knowledge Gaps, Information and Technology Needs

To advance agro-ecosystem science and inform agricultural and resource decision-making, the LTAR network will build a foundation of information on the temporal dynamics of processes affecting both agricultural productivity and ecosystem services, controlling agro-ecosystem stability (resistance to change) and the ability to recover from negative impacts (resilience), and the effects that decision-making at multiple scales (e.g, individual producer, local cooperative, regional production targets and storage and processing logistics; state-interstate-federal permitting processes, environmental protection statues and regulation of access to natural resources; and/or national-international commodity stockpiles, planting projections, and market response) has on our ability to sustain and increase agricultural production. LTAR network sites are selected in part for their representation of the 10 major US agro-ecosystems, the 21 HUC 2 watersheds within the lower 48 US states, NEON eco-climatic zones (i.e., Domains), and to complement existing monitoring or research networks by filling geographic gaps and providing unique long-term datasets or data collection opportunities not possible at existing sites.

The allocation of land, labor, and capital to achieve human goals is a fundamental socioeconomic dimension adding enormous complexity to agro-ecosystems. While LTAR sites are representative of their region, they also serve as unique focal points for intensive research on temporal dynamics of process impacts that cascade through agro-ecosystems in response to human decision making (population demographics, policy and socioeconomic preference), technological advancement (e.g., germplasm breeding, bioengineering,

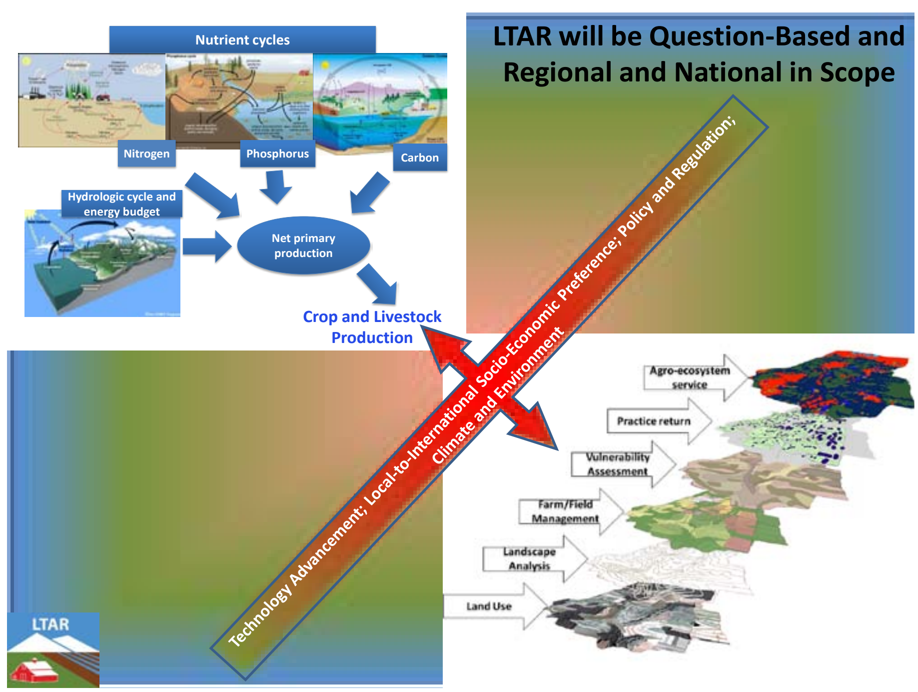

Figure A1. LTAR will examine the temporal dynamics of anthropogenic and environmental impacts across multiple spatial scales.

pest management chemistries, agronomic management practices) and environmental change (Figure A1).

To capture the dynamic interactions among agro-ecosystem processes in space and time, all sites in the network will adopt an intensive-extensive research approach designed to quantify the impacts of anthropogenic inputs of nutrients, pesticides, energy, and genetic material (Figure A2).

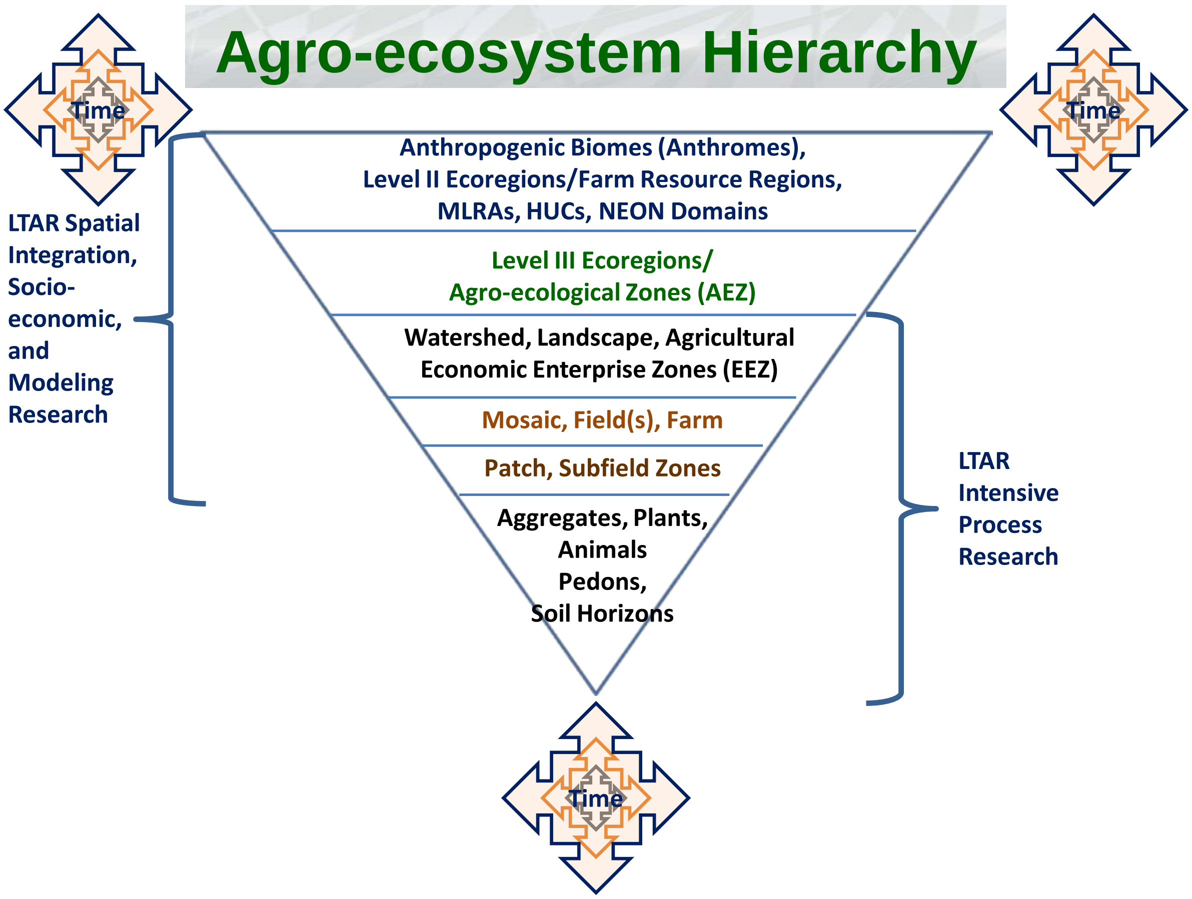

Figure A2. The transfer of matter and energy through agro-ecosystems is both hierarchical and continuous through space and time (MLRA: Major Land Resource Area, HUC: Hydrologic Unit Code, and NEON: National Ecological Observatory Network).

These goals will be accomplished through a combined intensive-extensive research approach that highlights the impacts of management and policy on the provision of agro-ecosystem services. Research at all LTAR sites will compare the spatial and temporal dynamics of process responses to four general scenarios:

1) Business as usual -- adherence to current dominant regional commodities production and standard management practices.
2) Maximized commodities production -- adoption of management strategy suites yielding maximum yield of current dominant regional commodities.

3) Maximized economic return -- adjusting inputs of energy, water and agrichemicals so as to maintain peak average use efficiencies of inputs with respect to yield and quality of dominant regional commodities.
4) Sustainable intensification -- adjusting scenario #3 inputs to maximize production of non-commodity ecosystem services.

The spatial scale at which all scenarios can be implemented will vary among LTAR sites primarily due to land ownership. However, each LTAR site will maintain:

1) Intensive, long-term experiments collecting data on NPP and yield, soil organic matter dynamics, and water and nutrient use efficiencies.
2) Extensive surveys of net primary production, commodity yield and quality, ecosystem process indicators, and ecosystem services provision.
3) Ground truth support for coordinated inventory and remote sensing campaigns initiated by LTAR, partner agencies, and public-private research teams requesting access to the LTAR network.

The adoption of this tiered intensity approach will render the LTAR network an excellent vehicle for research addressing agro-ecosystem impacts from (e.g.):

1) Cyclical return interval events (El Nino, rainfall/drought intervals, climate change, etc.),
2) Unintended anthropogenically-mediated shifts in stressors of agro-ecosystem services (invasive species, pesticide use and gene pool shifts, genetically-engineered crops, etc.), and,
3) Intended (or projected) impacts from ecosystem use changes (e.g., bioenergy crops, environmental/conservation policy shifts, water rights reallocation, etc.).

The combined long-term, intensive-extensive research approach will reduce uncertainties associated with scaling experimental data for regional production or policy assessments. This improved capability will enhance the ability to evaluate trade-offs between intensified commodity production and the sustainable delivery of non-commodity agro-ecosystem services. Improvements in the applicability of research information to long-term outcomes are anticipated in the following areas.

Hierarchical Approach for Comparability, Consistency, and Partnership Development

Each LTAR site will provide data and test the broad hypothesis that ***net primary productivity and yield, food safety and quality, and use efficiency of agricultural inputs can be increased while maintaining or improving delivery of ecosystem services***. Specific objectives and experimentation will vary among LTAR sites, but all sites in the network will develop a program and appropriate partnerships to address the temporal dynamics of key agro-ecosystem processes across spatial scales. Each site will necessarily shift emphasis among scales and processes as funding and expertise allow and will contribute leadership and support to cross location and network syntheses as appropriate. Conceptual presentations of key processes the fully-implemented LTAR network will address at different spatial scales are presented in Figures A3-6. Each figure also identifies activities and products that are anticipated from long-term research at each spatial scale. ***The capacity to implement this conceptual framework and to improve delivery of anticipated products will serve as the primary criteria for partnership, coordination with other monitoring and research networks, and prioritization of future research.***

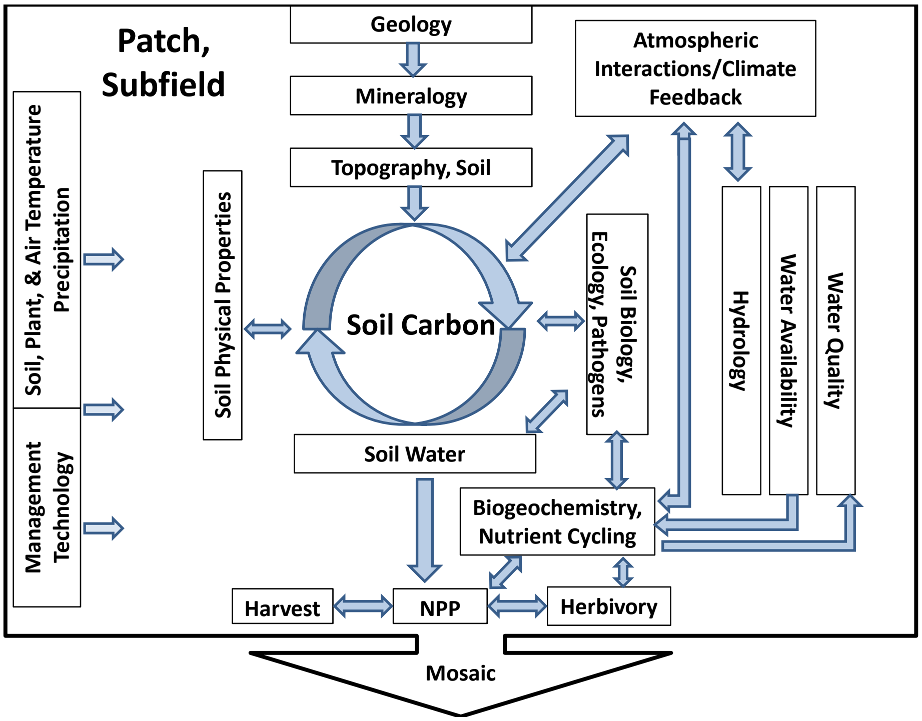

Figure A3. At the Patch, Subfield scale, the primary regulators of NPP and yield are: growing season length and temperature, water availability, nutrient availability, and soil ecology. While typically the target of technology development to improve agricultural output, these patch characteristics vary in response to geologic, mineralogic, and topographic combinations as well as to each other. At the patch level, the availability of water and nutrients drives individual plant vigor, as regulated by complex interactions among soil mineralogy, chemistry, and microbiology. Plant vigor affects not only crop quality from a commodity perspective, but also drives complex interactions between communities of pathogens, commensal organisms, and herbivores as well as feedbacks to water quality and atmospheric composition. As such, LTAR sites will:

- Quantify the linkages between these processes and their spatial/temporal range and variability within landscapes;
- Develop and use metrics characterizing NPP quantity and quality. Metrics will include but are not limited to water use efficiency, nutrient use efficiency, disease control efficiency, carbon storage efficiency, net GHG flux, and the efficiency of carbon allocation to desired output components (e.g., grain, total biomass, nutritional quality);
- Quantify the effects of climate and temperature on process rates and fluxes within and between patches;
- Quantify the potential of agricultural management practices and technological developments to enhance NPP and the mechanism(s) through which they increase or sustain NPP; and
- Quantify the input costs required to maintain NPP and the indirect costs associated with maintaining secondary outputs.

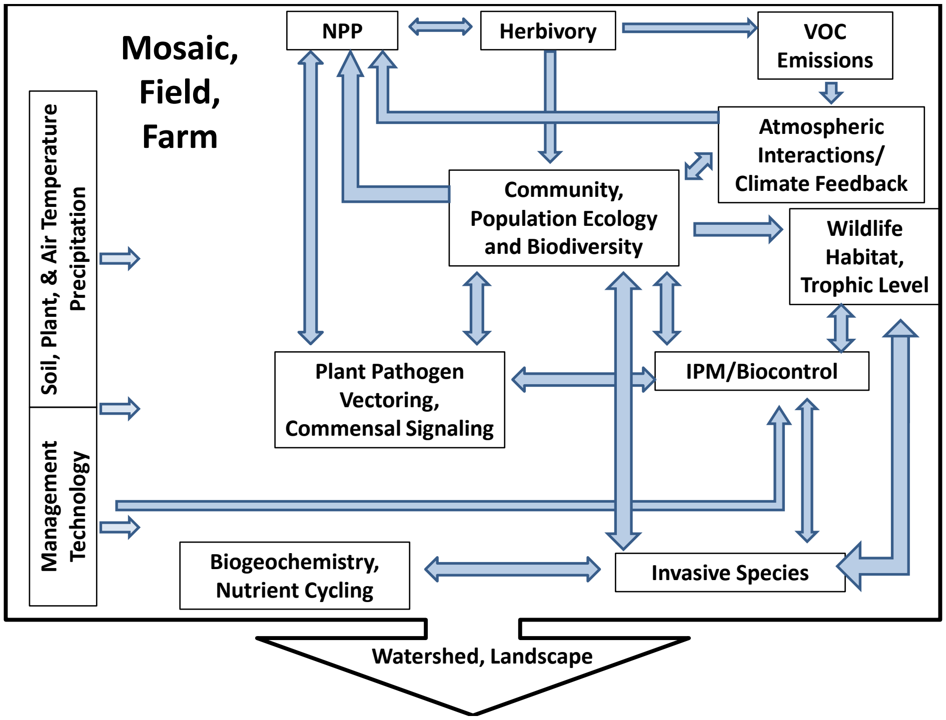

Figure A4. Patches within landscapes vary in size and distribution depending upon the "point-of-view" held by any given occupant of the landscape. These points-of-view (e.g., vegetation palatability, weakened disease resistance, plant distress signaling through volatile organic compound emission) affect plant population ecology and NPP as well as the use of an area by mobile species. Such use patterns can be categorized as mosaics of patches and are the level at which producers focus their management of water and agrichemical application, integrated pest management (IPM) and biocontrol program implementation, wildlife management, and invasive species control. LTAR sites will characterize mosaics of patch organization at each site including but not limited to:

- Distributions of NPP and productivity of key agricultural products;
- Indices of herbivore preference;
- Indices of community integrity and diversity;
- Mechanisms of plant-commensal signaling and feedbacks to community distribution and diversity and to atmospheric composition;
- Impacts of managed pest control on natural and pest populations and diversity;
- Scalar analyses of pest and wildlife sensing and exploitation of landscape mosaics;
- Associations between biogeochemical cycling and pest/wildlife use of mosaics; and
- Mechanisms influencing invasive species exploitation of mosaic components.

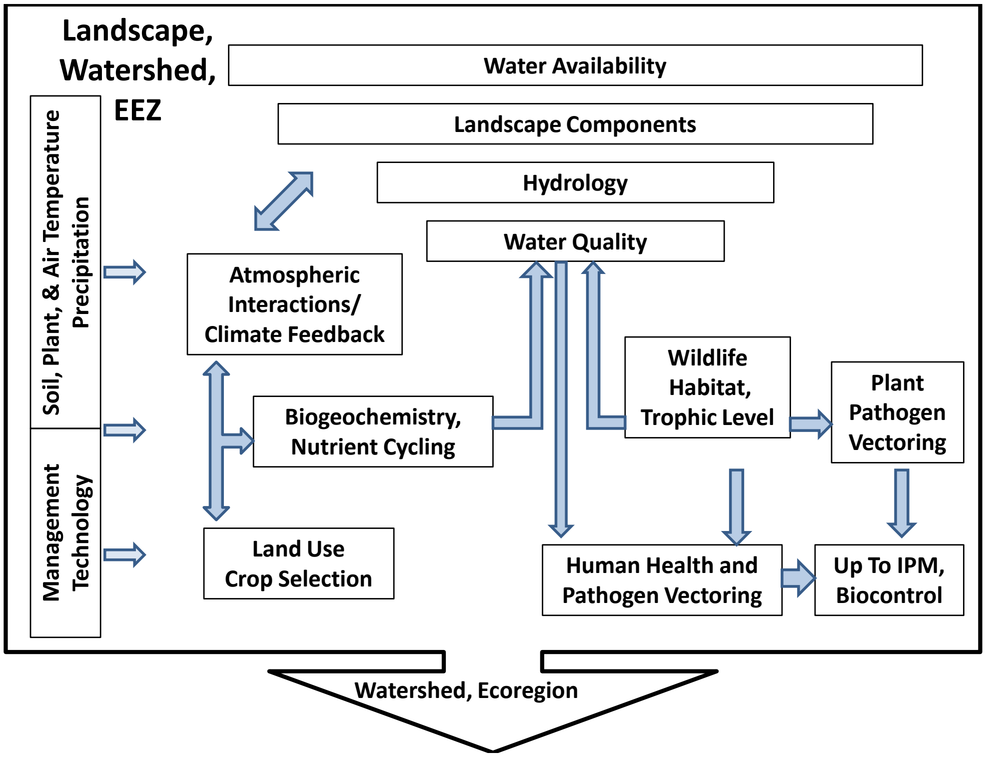

Figure A5. The aggregate effect of matter and energy flow between patches and mosaics of patches in a landscape reflects geology, hydrology, and soils, in addition to land use, management, and regulatory decision-making. The landscape, watershed, economic enterprise zone (EEZ) level is where outcomes (e.g., profit margin, food contamination, water quality) are most easily observed and understood by policymakers and the general population. The LTAR sites will characterize connectivity between mosaics in a landscape, including: 1) mechanisms and pathways by which water, nutrients, pesticides, and pathogens are transported; 2) how land use and management decisions affect routing and distribution; 3) interactions between landscape components and wildlife habitat quality; and 4) interactions between wildlife and the vectoring of plant and human pathogens. LTAR sites will develop and use metrics of connectivity that may include but are not limited to:

- Surface and subsurface topography and water permeability and associated hydrologic routing and flow;
- Indices of wildlife habitat
- Pathogen and parasite distribution;
- Mechanisms and thresholds of plant pathogen vectoring and impact;
- Source areas of water quality contaminants;
- Patterns of association between crop/technology/management practice selection, soil depth, mineralogy, organic matter content, and plant water availability, water and nutrient use efficiency, and NPP.

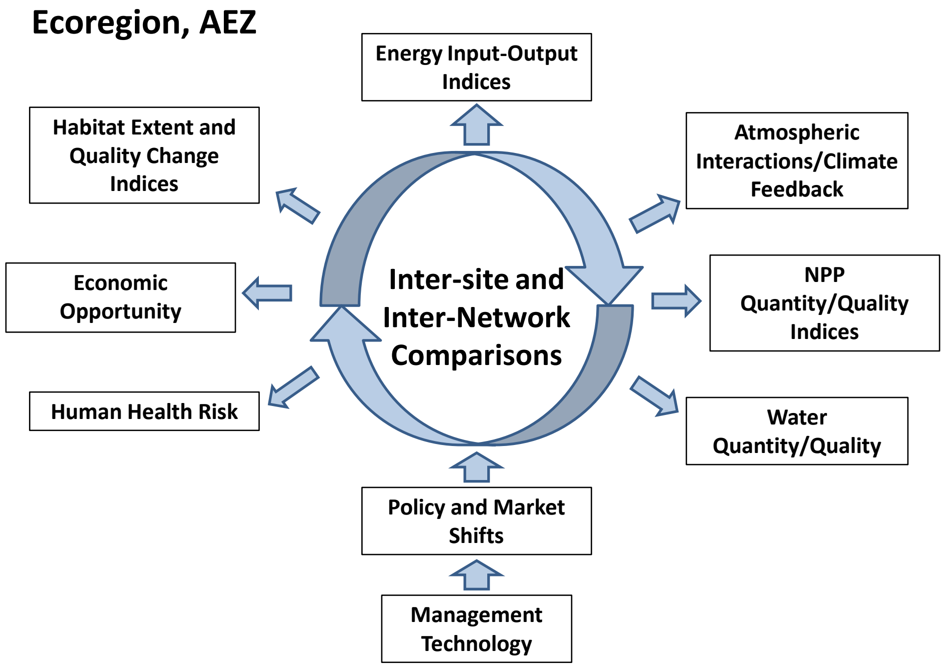

Figure A6. At the Ecoregion/Agro-Ecological Zone (AEZ) level, LTAR sites will share data and information with other research and monitoring networks and natural resources inventories to develop summaries on how resource competition and national/international policy and market shifts affect:

- The relative contributions of each ecoregion to atmospheric and climatic feedbacks;
- The provision of ecosystem services within and between ecoregions;
- The risk to human health contributed by agriculture within and among ecoregions;
- Relative levels of economic opportunity and social equity within and between ecoregions;
- Wildlife habitat/quality and populations within ecoregions; and
- The energy balance required to maintain ecosystem resilience within ecoregions.

When fully implemented, the LTAR network will address regional and national issues related to production, climate change, sustainability, and socioeconomic issues related to agriculture. As with this "living" document, the institutional relationships needed to scale and apply the understanding coming from the LTAR network to the whole of the national agricultural system will grow organically, but start from the approach presented here.

Appendix B. Societal Concerns

The LTAR Shared Research Strategy is driven by societal concerns related to food supply, climate change adaptation/mitigation, bioenergy, water/air/soil quality, biodiversity, and economic sustainability and livelihoods.

Food, fiber and fuel production, resource sustainability and system resilience

LTAR will coordinate the assessment of agricultural production, sustainability and resilience across multiple scales. The diversity of conditions across the US has led to a wide range of agricultural production systems, from pasture and range lands, to diverse crop production systems for grain, oilseeds, and fiber, to integrated crop and livestock operations, to specialized enterprises (e.g., fruit, nuts, vegetables and fish). These agro-ecosystems make use of varying internal and external inputs (soils, water, nutrients, etc.) to provide ecological services such as water filtration, wildlife habitat, or the utilization of greenhouse gases, in addition to their agricultural production. The ability of production systems to adapt to changing conditions (both adverse and beneficial) while sustaining basic societal and ecosystem services into the future is the core issue that the LTAR network is designed to address. LTAR recognizes that the sustainability of agricultural productivity and resource conservation are regulated by: 1) natural geological and soil patterns of local landscapes; 2) temperature, moisture and biotic patterns that vary across regions and the continent; as well as 3) the direct and indirect forces of politics, sociology, and economics.

Genotype, Environment and Management (GxExM) interactions

LTAR will coordinate the development of improved varieties, crops, management practices and systems that are resilient to anticipated variations in climate. Climate responds dynamically to natural and anthropogenic influences. All agricultural systems are vulnerable to climate variability and change, some more than others. Floods, droughts, and extremes of heat and cold are examples of climatic variations that present challenges to agricultural producers. In addition, water-limited agro-ecosystems appear especially sensitive to rising atmospheric CO_2, with stomatal responses that may help offset the effects of some climate changes. Walthall et al. (2012) surveyed the literature relating crop yields to temperature changes, concluding that major crop yields may begin to decline with additional temperature increases. Data on climate variation, rising CO_2, and the response of agricultural ecosystems to these variations at multiple scales are needed to inform both the agricultural community and policy makers. Because similar variations in climate can produce different responses in different agroecosystems, this necessitates a network approach to studying these effects.

Water supply and quality

LTAR will coordinate research that links production practices, climate variability and land use change on water resources across broad spatial and temporal scales. Water is a vital resource to agricultural, natural, and urban areas and is under increasing pressure from growing demand, quality impairments, and land use changes. Agricultural production systems influence both the quantity and quality of water supplied to downstream users. In addition, because it is a major source of water for irrigation and rural communities, the quantity and quality of groundwater is also of concern.

Ecological integrity and ecosystem health

LTAR will conduct comprehensive research that supports the development of agricultural management practices and systems that improve ecological integrity and heath. Ecological integrity and ecosystem health encompass the agro-ecosystem functions (e.g., production of food and fiber, supply of clean water and air), consider threats to agro-ecosystems (e.g., erosion, desertification, soil degradation, groundwater depletion), and overlap with the concept of ecosystem resilience. Additionally, embedded within agricultural landscapes are habitats that support natural populations of birds, animals, insects, fish, amphibians and microorganisms that interact with the agro-ecosystem to varying extents. The value of these habitats is seen in the public support for conservation of natural lands and waters, even when surrounded by intensively managed croplands and pasturelands.

Economic sustainability and livelihoods

LTAR will provide a framework for assessing agricultural economics and sustainability at the scales relevant to producers, agribusiness, policy makers, and society as a whole. Agriculture is a critical sector of the US economy. Even after accounting for agricultural imports and government subsidies, the US agricultural sector is a net income producer. The larger agricultural economy includes the suppliers of seeds, chemicals, fertilizers and machinery and the companies that consume commodities to produce value added foods and other products. However, there is continuous change in the agricultural economy due to consolidation, new technologies and other factors. These changes highlight concerns about the economic viability of many production systems and in some areas the very survival of entire rural communities. In addition, the external costs of policies and practices designed to mitigate impacts of agricultural production on water and air quality need to be quantified.

Appendix C. Foundation Science

The *foundation science* of the LTAR network will be directed toward knowledge gaps and technology needs under four topical areas:

1) ***Agro-ecosystem productivity***;
2) ***Climate variability and change***;
3) ***Conservation and environmental quality***;
4) ***Socio-economic ties to productivity, climate and environment***.

1. Agro-ecosystem productivity: *How can production systems be intensified so that inputs decrease and/or outputs increase?*

Central to the sustainability and management of all ecosystems are the processes controlling productivity, with net primary production (NPP) the overarching metric. The LTAR network will provide baseline information on the major processes controlling the NPP and yields of US agro-ecosystems, enabling retrospective evaluation of historical trends and forecasting of future changes. A priority objective is to advance simulation models that enable accurate prediction of effects of improved strategies on agricultural productivity at farm, regional and national scales. SRS activities related to this objective are expected to yield:

- New strategies to improve net primary production in US agro-ecosystems and to close the gaps between potential and "county average" yields;
- Improved nutrient and water use efficiencies of various production system x crop variety combinations;
- Quantification of greenhouse gas and water footprints and life cycle analyses of US food, fiber and bioenergy production systems; and
- Better methods to determine monetary and other values of ecosystem services.

2. Climate variability and change: *How can production systems adapt to increase production in the face of climate change?*

Considerable opportunities exist for agriculture to assist in mitigating climate change as well as to adapt to climate variability and change. Six of the original 10 LTAR sites contribute to ARS's Greenhouse Gas Reduction through Agricultural Carbon Enhancement Network (GRACEnet), which estimates the soil carbon status and net greenhouse gas emissions within the context of productivity of baseline and alternative agricultural systems. The findings point to varying controls on greenhouse gas emissions across systems, with dominant processes ranging locally from heterotrophic respiration to methanogenesis to denitrification. The LTAR network will leverage and expand activities related to GRACEnet, with an overall goal of developing adaptive strategies for US food, fuel and bioenergy production systems, improving their resilience and guiding adaptation and mitigation efforts. To do this, the LTAR network will elucidate and forecast the effects of climate change on processes important to the nation's agricultural systems, from weather, to erosion (water and wind) and sedimentation, to hydrology (soil moisture, flooding, runoff) to pest cycles. It is expected that shared research activities will also inform and support:

- Recovery processes/lags from drought, floods or other extreme events;
- Carbon or greenhouse gas mitigation credits and markets;
- Monitoring and assessment tools that support adaptive management.

3. Agricultural conservation and environmental quality: *How can production systems be made sustainable for both on and off-site effects?*

Originally focused on protecting against soil erosion to avoid both soil degradation and downstream sedimentation, modern conservation strategies now strive to achieve a broad suite of ecosystem services, from sustaining soil health to mitigating the off-site impacts of agriculture to creating habitats for beneficial species. Research on the effects of field management on the chemical, physical and biological components of soil health has been critical to the development and successful adoption of conservation systems. The processes controlling soil health intersect with biogeochemical processes occurring at broader scales (landscape, water- and air-shed) to produce a range of off-site impacts, from nutrient, pesticide and pathogen transfers in runoff to declines in biodiversity. LTAR research will support productive, sustainable agro-ecosystems that conserve the nation's natural resources, promote soil health and enhance environmental quality. The network's SRS strategy is designed to integrate across multi-scale processes that link agricultural management to environmental impact. Specific outcomes of this research include:

- Indicators of soil quality and function;
- Quantitative/predictive knowledge of concentrated flow and artificial drainage processes;
- Valuation of ecosystem services;
- Scientific understanding to underpin conservation planning and agricultural land management;
- Monitoring and assessment tools to support adaptive management.

4. Socio-economic ties to productivity, climate and environment: *How do economic incentives affect the design / adoption of production systems to address intensification, climate change, and sustainability? What are the economic and policy constraints to enhanced productivity of agricultural systems? How do markets, infrastructure, and land tenure promote or inhibit adoption of new practices? What are the impacts of producers' risk tolerance? How can increased agricultural productivity best enhance rural economic conditions? How do the decisions of individual landowners and agricultural producers, when aggregated within a landscape, impact environmental outcomes?*

The sustainability of US agriculture hinges upon balancing resource and environmental constraints with the incentives and limits provided by market, policy and social forces.

Changes in markets, production systems, policy, land use patterns, and social realities affect the decisions by farmers/ranchers, cooperatives, industries, consumers and policy makers across all food, fiber and biofuel productions systems. Linking socio-economic drivers with decision-making at all scales is critical to understanding past trends and predicting future outcomes for US agriculture. The LTAR network will provide a platform for assessing costs and benefits of management and policy decisions in US agriculture, from field practice adoption to industry evolution to consumer choice. The network will leverage partnerships with other USDA agencies (e.g., USDA-ERS, USDA-NASS, USDA-NRCS, USDA-FSA) to develop databases and models that improve our understanding of the causes and consequences of decision-making across the nation's food, fiber and biofuel production systems. Anticipated products/outputs of LTAR network efforts include:

- Linkage of georeferenced socioeconomic data bases (US Census, ERS-ARMS, Ag Census) with biophysical modeling;
- Better understanding of motivation, incentives, and barriers to adoption or change;
- Better understanding of interactions between farm structure and supply of agro-ecosystem goods and services.

Appendix D. Common methods and data protocols: Examples

Efforts toward common methods and data protocols will be driven by 1) the cross-site datasets that are most easily compared and shared; 2) the datasets most urgently needed for initial cross-site research projects; 3) new long-term datasets that can be compiled for all sites; 4) the common instrumentation/protocols already in place; and 5) critical new instrumentation and/or measurements. Examples of each are given here:

1) Meteorological and/or precipitation data and measurements of soil moisture and/or temperature are already available and on-going at all 10 sites. Protocols for data collection and QA/QC will be compared and, where possible, standardized. All sites have existing GIS datasets. A concerted effort will be made to compile, standardize and upload these data for web access. This will be the foundation for most research efforts.
2) Cross-site research projects involving subsets of LTAR sites have already been initiated within the ARS Water Availability and Watershed Management National Program. The Principal Investigators on these projects have begun to compile the cross-site data suitable for their projects. These efforts will be coordinated for the LTAR sites to meet both the quick-turnaround needs of on-going projects and the long-term vision of the LTAR.
3) All 10 LTAR sites are using satellite images and/or aerial photography for research. With little effort and a commitment to network-wide coordination, a set of measurements from a single satellite (logically, MODIS EVI) will be compiled across all sites for common research.
4) Common data access through existing portals will be considered. Some data for LTAR sites are already coordinated through site affiliation with the LTER, Ameriflux, SCAN and NADP networks. Long-term data have been processed with common protocols for 5 LTAR sites through ARS STEWARDS (Sustaining the Earth's Watershed, Agricultural Research Data System (http://www.ars.usda.gov/is/AR/archive/aug06/data0806.htm) and for 3 sites through ARS EcoTrends (http://www.ecotrends.info). Data from 6 sites are being contributed to common databases through ARS GRACEnet, and 6 sites through ARS REAP data systems. Meteorological data from many sites are available through the NOAA Environmental Real-Time Observation Network (http://www.isos.noaa.gov/) and the NOAA National Climate Data Center (http://www.ncdc.noaa.gov/oa/ncdc.html).
5) Seven of 10 LTAR sites have measurements of vegetation characteristics, runoff and stream water quality and quantity. These are highly valuable datasets for research, and worth the effort and expense to expand to all relevant sites. Only 2-3 sites have data on air and soil quality. New measurements at more sites will be initiated building upon the CEAP soil characterization database. No sites have a standard protocol for compiling socioeconomic information. This will be a challenge to standardize and

initiate at all sites. It is recommended that the LTAR network partner with ERS, NRCS and Universities in developing common datasets in this area.

Appendix E. Working as a network within a network

Ideally, shared measurements would be made with protocols common not only to LTAR sites, but also common to LTER, NEON, and other networks (Table E1). This would facilitate comparative studies across a network of networks and including non-agricultural systems. The LTAR sites already participating in other networks have shared research strategies that will feed into the LTAR shared research strategy.

Table E1. Long-term data collection networks co-located and/or cooperating with LTAR Sites.

Program	Mission	Sites	Citation and/or Web Site
Ameriflux network, established 1996	To provide continuous observations of ecosystem level exchanges of CO_2, water, energy and momentum spanning diurnal, synoptic, seasonal, and interannual time scales.	103 sites in North America, Central America, and South America; including 87 sites in the US	Wofsy and Hollinger, 1998; Hargrove et al., 2003 http://public.ornl.gov/ameriflux/
GRACEnet (Greenhouse gas Reduction through Agricultural Carbon Enhancement network), established in 2002.	To identify and further develop agricultural practices that will enhance carbon sequestration in soils, promote sustainability and provide a sound scientific basis for carbon credits and trading programs.	36 sites across the USA	http://www.ars.usda.gov/research/programs/programs.htm?np_code=204&docid=17271
NADP (National Atmospheric Deposition Program), established 1978	To collect data on the chemistry of precipitation for monitoring of geographical and temporal long-term trends.	Over 250 sites spanning the continental US, Alaska, Puerto Rico, and the Virgin Islands.	http://nadp.sws.uiuc.edu/
NASA/EOS (NASA Earth Observing System) Program, the first mission launched in 1997	To provide systematic, continuous global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans from low Earth orbit for a minimum of 15 years.	25 Missions and Programs with a series of satellites, a science component, and a data system	http://eospso.gsfc.nasa.gov/
NSF/LTER (Long Term Ecological Research) network, established 1980	To understand long-term patterns and processes of ecological systems at multiple spatial scales.	26 programs in a wide variety of habitats	Hobbie et al., 2003; http://www.lternet.edu/
NSF/NEON (NSF National Ecological Observatory Network), established in 2002	To establish and sustain the scientific infrastructure and develop the intellectual capital needed to address critical questions about changes in ecological systems and to evaluate the impacts of those changes.	20 core and 40 relocatable sites across the US, [due to be built out by 2017]	www.neoninc.org
UN/MAB/WNBR (United Nations, Man and the Biosphere Programme, World Network of Biosphere Reserves), proposed in 1974	For knowledge-sharing and exchange of experience, research and monitoring, education and training, and testing of participatory decision-making, thereby contributing to the emergence of "quality economies" and to conflict prevention.	507 biosphere reserves in 102 countries	http://www.unesco.org/mab/mabProg.shtml
USDA/CEAP (Conservation Effects Assessment Project), established in 2003	To improve efficacy of conservation practices and programs by quantifying conservation effects and providing the science and education base needed to enrich conservation planning, implementation, management decisions, and policy.	42 watershed studies	http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/ceap

USDA/NRCS/SCAN (Natural Resources Conservation Service Soil Climate Analysis Network), established 1991	To 1) integrate information from existing soil-climate data networks; and 2) establish new data collection points through partnerships with federal, state, local and tribal entities.	The current SCAN network includes 191 remote sites in the US and Puerto Rico.	Schaefer et al., 2007 http://www.wcc.nrcs.usda.gov/scan/
USDA/REAP (Renewable Energy Assessment Project)	To determine the amount of residue needed to protect the soil resource, to compare economic implications of using stover as a bio-energy feedstock vs. as a source of C to build SOC and sequester C, and to provide harvest rate recommendations and guidelines.	24 sites across the US	http://www.ars.usda.gov/research/programs/programs.htm?np_code=212&docid=21224