*This is the Coweeta LTER addendum that Dan Childers and Henry Gholz, LTER Program Officers, requested in their cover letter of April 16, 2008. Details of what, when and how our research will unfold over the next six years with supporting citations are contained in the proposal. So that the addendum not exceed 10 single-spaced pages in 12 point font we refer to previously presented material by their original designations and focus our response on the four points listed in the cover letter. As detailed in **Section 3** of the proposal, the Coweeta LTER is a regional project that requires a greater disciplinary breadth than would be expected at an experimental research station. Research participants receive funding to cover certain direct expenses, while the project covers technician support and long-term measurements, information management, building and equipment maintenance costs, and contingencies. Participants complement or leverage the Coweeta LTER base funding and infrastructure with additional funding from numerous sources.*

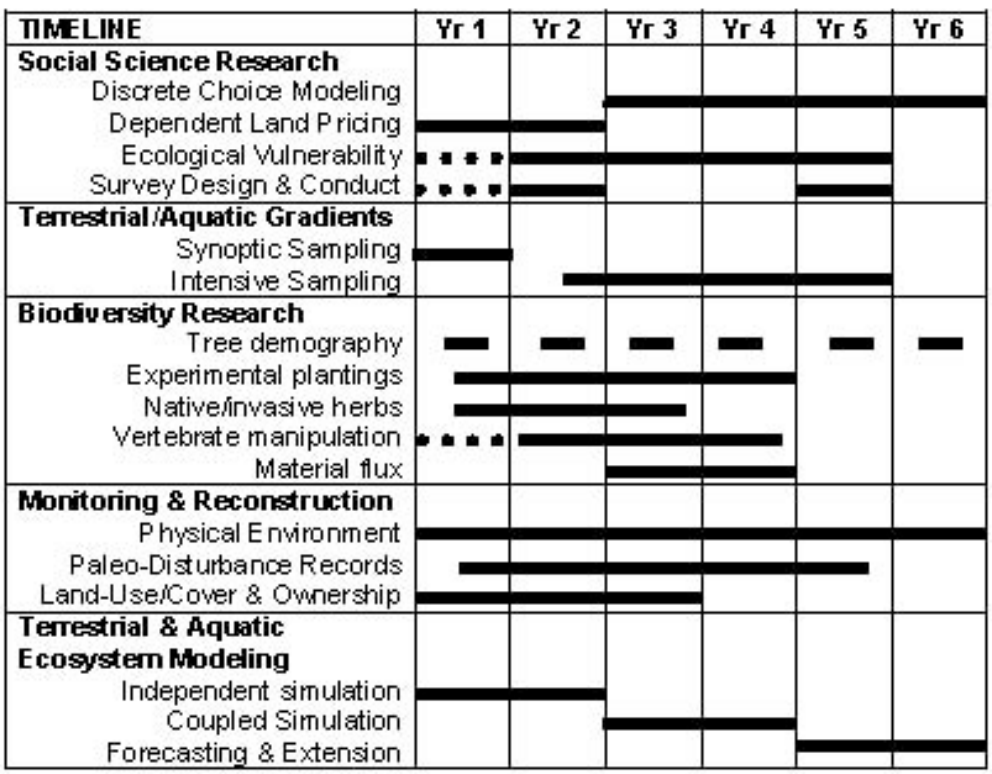
Project Objectives (point 1). The guiding question for our research over the next 6 years (2008-2014) is: ***How will key ecosystem processes and the focal ecosystem services of water quantity, water quality, and biodiversity in southern Appalachia be impacted by: (1) transition in land uses from wildland to urban and peri-urban; (2) changes in climate; and (3) interactions between changes in land use and climate including both on-site and off-site feedbacks?*** We will focus on the southern Appalachian study area as defined in Coweeta V (2002-2008), but our research design recognizes the contextual dependence of within-region processes on forces exerted by the Piedmont Megapolitan Region (**Figure 2.1**). Field activities will take place along gradients (**Table 2.1**) representative of the southern Appalachian socio-ecological variability in: regional basins, sub-basins, headwater watersheds, and hillslopes and riparian zones.

Hillslope and riparian zone responses will be characterized at a spatial resolution relevant to the targeted processes using observational and manipulative approaches. Socio-ecological gradients of sub-basins and headwater watersheds will be intensively sampled using instruments, observational, arms-length, and face-to-face procedures. Regional basin patterns and responses will be extensively sampled using direct measurements, remote sensing products, socioeconomic databases, and government sources. Our research is organized into five thematic areas to achieve a regional understanding of the socio-ecological process entailed by our guiding question.

1. ***Parcel-Level to Regional Decision Making*****:** What are the links between private and public land use decisions and ecosystem services? The objective is to scale parcel-level decision-making to the region-level by comparing individual awareness of ecological consequences of land-use decisions over time and across populations in response to a local-to-regional regulatory overlay.
2. ***Longitudinal Variation in Hillslope, Riparian, and Stream Ecology*****:** How do differences in riparian and hillslope land cover, soils, and infrastructure alter water quality and quantity and flowpath connectivity from hillslopes to small streams to rivers? Our objective is to determine the magnitude and timing of sediment and nitrogen transport, retention, and transformation associated with land-use intensity.

3. ***Impacts of Climate and Land Use Change on Biodiversity*:** How do climate change and development affect biodiversity at local to regional scales, and what are implications for ecosystem processes? Objectives include (a) spatially and temporally replicated monitoring of forest biotic communities along representative gradients; and (b) experimental manipulations of focal species to estimate responses to climate variation and land-use intensity.
4. ***Baseline Data and Temporal Reconstruction*:** What are the long-term (emphasis on the last 150 years) climatic, geomorphic, and land use disturbance characteristics of southern Appalachia? Our objective is to resolve the relative magnitude of climatic- versus human-induced change and identify major turning points and disturbance frequencies.
5. ***Synthesis & Scaled Integration***: How can we integrate our understanding of hydrological, ecological and human social processes to understand the dynamics of key ecosystem services at the small catchment level and scale it to regional watersheds? The objective is to examine the interaction using our data archives, spatially explicit ecosystem modeling and measurements from the next six years.

Table 1. Timeline of activities associated with each thematic area over the next six years. (Solid line is period of principal effort; dashed line indicates initial and/or planning effort.)



<u>Biophysical Research in Relation to the Five LTER Core Areas (point 2)</u>. During the next six years our ecosystem-level research will examine effects of climate **x** land use to achieve empirical understanding of the ongoing socio-ecological transformation of the region. This research builds on our ongoing research within the five LTER core areas as discussed below and summarized in the last paragraph of this section. Research activities span thematic areas 2, 3 and 4, and link to thematic areas 1 and 5.

We take advantage of the existing mosaic of development within the region surrounding Coweeta to understand how land use will affect stream and forest productivity, the diversity and abundance of native and nonnative species, and the movement of materials into and from headwater streams. (**Table 2.3** lists metrics, sample intervals and investigators.) We will conduct extensive synoptic biogeochemistry sampling on approximately 40 streams selected from ca. 100 sites (in use or previously used by Coweeta LTER investigators), representing headwater systems governed by colluvial processes. Additional sediment and biogeochemistry sampling will be conducted in approximately five basin-scale sites along the main stem of the Little Tennessee representing transport-dominated sites and another eight sites on major tributaries that represent colluvial and alluvial sediment contributors to transport reaches. Physical measurements will include: channel width, stream slope, cross-section area, stream bed particle size distribution, large wood, and canopy cover. Water level and temperature will be monitored continuously, and bi-weekly composite samples will be collected to measure particulate and dissolved C, N, and P.

Synoptic results will be used to select nine streams along a longitudinal developmental gradient from forest (reference) to urban for intensive study. At each site, we will establish reaches of 30 channel widths to measure riparian vegetation, litterfall, vertebrate species occupancy, and algal standing crop. We will also measure stream metabolism and N-cycling using two-station diel oxygen budget and nutrient addition techniques. On a subset of streams, storm TSS and nutrient samples will be collected with ISCO samplers; Hydrolab sondes will continuously monitor temperature, dissolved oxygen, specific conductance, and turbidity. Terrestrial sampling transects co-located with each reach will extend orthogonally from the riparian zone to the upper slope. Six wells will be installed along the stream (three on either bank), 10 tension lysimeters (at two depths) and one automated TDR recorder to be sampled one month each season and analyzed for NO_3, NH_4, PO_4, TP, SO_4, Ca, Mg, K, Na, DOC, and DON. On installing lysimeters, soil and forest floor carbon and nitrogen will be sampled, and trees and shrubs will be inventoried. Herbaceous plants will be surveyed three times each growing season in years 2, 4 and 6. While this longitudinal gradient is a new effort, it incorporates field plots and research sites in-use by Coweeta LTER researchers for over 10 years.

Southern Appalachia is characterized by the highest rainfall in the eastern US and the highest diversity of species. Asking if this diversity is threatened by the aridity forecast for coming decades is the basis for our local-scale research on montane habitats or organisms threatened by aridity, development, or both. Habitats and species will be identified by (1) prior and ongoing research, (2) climate modeling, and (3) results of the longitudinal research described above. Small-scale manipulations will be used to understand local mechanisms of species loss and gain and the consequences of biotic change to ecosystem function, particularly the movement of organic and inorganic materials from headwater streams. Methods will follow prior research and standard approaches for the selected taxa. Our local-to-regional scale research leverages (as it has for over a decade) support from many sources other than LTER and is organized to address two subquestions.

Question one addresses how climate and/or exurban development will affect the growth, reproduction, survival, and spatial distribution of diverse vegetative species. Studies include measures of climate effects on the composition and demographic rates (including migration potential and recruitment responses) of trees and herbaceous species derived from repeat census data on 12-15 mapped plots. Sites include our five gradient plots (area = .64 ha ea. sampled continuously for 17 yr) and our two gap sites (area = 5 ha ea. sampled continuously for 6 yr); these are nested manipulations within regional monitoring sites so that we have pretreatment and treatment/control at each location. Priority considerations for selecting ca. six new sites include high elevation, old growth, floodplain, land-use and the ability to create canopy openings. Protocols will follow those used in previous treatments and control plots. We will also target 10-20 herbaceous species we hypothesize will display a positive or negative response to increased temperature and drought in germination success, survival, growth, foliar chemistry, flowering and seed production. The seeds of target species will be planted in 24 replicate plots stratified by elevation (low vs. high), aspect (N-NE vs. S-SW) and land-use (reference vs. agriculture).

Question two addresses how species losses and/or gains affect species-mediated changes in biogeochemical cycling on community structure. A main emphasis will be using a comparative approach to examine how exotic understory herbs (e.g., *Microstegium vimineum*) affect ecosystem carbon and nitrogen dynamics across the longitudinal developmental gradient. Paired plots will be established along the gradient within invasions and 100 m ahead of the invasion fronts. (The understory herbs we are targeting form a continuous understory in forests that previously had a sparse native understory.) Our initial work suggests that the invasion fronts move rapidly in the Southeast, and carbon and nitrogen cycling are accelerated in invaded relative to non-invaded areas. The unique carbon isotope values of some of the invasive plants will permit a level of resolution in understanding carbon flow into inorganic and organic pools not usually achieved in ecosystem studies. By extending current studies in the Coweeta Basin to the longitudinal gradient, we will complement physical and chemical measures with biotic parameters to explain stream stoichiometric responses of retention and export of N and P. We will focus on the contribution of leaves from different tree species to decomposition in streams and invertebrate populations, and variation in stream salamander and bird populations.

Finally, we will continue collecting environmental measurements in the Coweeta basin complemented by physical, biotic and socioeconomic measurements from the regional environmental monitoring network and other sources (**Tables 2.1**, **2.2**, and **2.6**). These data are critical to the proposed research for detecting local-to-regional patterns, defining boundaries, delimiting gradients, and model parameterization. (Data handling procedures are described on-line and in **Section 3**.)

Our research over the next six years builds on long-term data we have been collecting at Coweeta in the ***LTER core research areas*** at regular intervals over space and time. It now includes over 70 years of climatic data; stream flow and water chemistry; and structural biotic measurements. We have used this data archive to establish and understand the existing conditions across our study region prior to manipulation or observation. Proposed experiments examining the ***movement of inorganic*** *and* ***organic matter*** build on our spatially and temporally extensive stream monitoring data. Our research into ***primary productivity*** and ***populations*** will continue our long-term replicated monitoring of herbaceous understory and forest tree growth, as well as leaf area and aboveground biomass, productivity and transpiration, germination success, seedling survival, flowering, and seed production. As for ***disturbance patterns****,* we are creating a decadal reconstruction of historical environmental and land-ownership patterns across the region over the last 200 years.

Social Science Research in Relation to the Five LTER Core Areas (point 4). Rapid human in-migration to southern Appalachia provides a unique opportunity to understand the relation between ecosystem services and land-use decisions. Ecosystem services are benefits that humans directly or indirectly receive from the natural environment at different temporal and spatial scales. Private land-use decisions result from individuals comparing the marginal benefits and marginal costs of various land uses, not simply comparing the quantity or quality of a given resource. This research spans thematic areas 1 and 4, and links to thematic areas 2, 3 and 5 while contributing to the five LTER core areas as summarized in the last paragraph of this section.

Over the next six years we will address the following two questions:
1. How are private land use decisions made and how do these decisions relate to changes in the provision of the ecosystem services of water quality, water quality, and biodiversity?
2. What are the ecological vulnerabilities and risks created by changes in the provision of ecosystem services and how does civil society respond to the inequality of these services across communities?

Awareness of the ecological consequences of land-use decisions changes in response to a local-to-regional regulatory overlay over time and across populations. We will focus on the interaction between land use decisions and the knowledge, attitudes, and preferences of individuals; the nature of governance; and the structure of land ownership (including parcel morphology, location, value, and use). We will answer question one by combining hedonic analysis of property records with information from repeat surveys and face-to-face interviews of property owners to determine their attitudes and preferences related to ecosystem services. We will also study how behavior reflects awareness of regulatory overlays by modeling the effect on land prices of developmental density restrictions associated with water supply protection.

We will also examine how private land use decisions relate to the land value of properties with conservation easements. Estimating values of properties without an easement will allow us to infer the value of properties with easements prior to donation, to serve as an explanatory variable in a discrete choice model. The model will reflect the perceived net benefits to the property owner of contributing an easement as a function of property value, owner tenure and income, ownership of adjacent land, parcel size, and surrounding easement activity. This model will be used to assess the net benefits to contributing land owners and the gross benefits to adjacent land owners for participating in the "Land Use Program" enacted by The North Carolina General Assembly reducing taxes on property used for agriculture, horticulture or forestry. We will also measure the effect of development density and water supply protection on land prices. The State of North Carolina's Water Supply Watershed Protection Act enacted in 1998, mandates minimum 2-acre lot sizes in certain watersheds in order to maintain and/or increase county-wide ecosystem values.

With question two we seek to understand the political ecological mechanisms connecting civil society to long-term ecological changes producing vulnerability and risks on particular parcels of land. We will address this question using organizational data on structural changes in city and county governments and environmental groups. This will be followed by face-to-face interviews with officials and property owners to sample across the range of operational processes and ecological politics associated with water quality, water quantity, and biodiversity.

As the basis for answering both questions we are developing comprehensive spatial and temporal parcel ownership datasets for Buncombe County, NC (French Broad River drainage) and Macon County, NC (Little Tennessee River drainage) from publicly available records back to the early 19th century (section **2.5d**). The dataset includes: parcel geography and sales; building age and configuration; zoning; stream locations; soil erosion potential; land cover; and context based on consumer (e.g., energy consumption) and demographic (e.g., ethnicity) area profiles. As digital records come on line for other counties, we anticipate developing comparable datasets for Rabun, Jackson, Haywood, and Swain Counties – all of which lie within or straddle our two focal drainages. The dataset will be used to target property owners for face-to-face interviews, ensure that results from our repeat survey are spatially explicit, and connect biophysical research results (above and sections **2.5b** and **2.5c**) to known human behavior. It will also be used to estimate past disturbance rates and settlement intensity for synthesis and scaled integration (below and subsection **2.5d**).

We are also compiling a database on the evolution of city/county government structures and functions from information on elected officials, zoning, land use plans, and water regulations. This will be complemented with civil process information from governmental and non-governmental records on procedures, planning, meetings, and funding levels. In tandem with hedonic model results, this database will guide observations and interviews with property owners (along the longitudinal developmental gradient) and with government and non-governmental representatives. We will implement a repeat survey of property owners in the Little Tennessee and French Broad River drainages in years 2 and 5 that will be continued into the future to track local-to-regional change and the evolution of response to change. The survey will likely include a participatory GIS component so property owners can identify areas of personal importance, along with areas that are protected, vulnerable, already damaged, or should be protected. Finally, rapid biotic surveys will be conducted at regular intervals along the longitudinal developmental gradient to detect changes and lag times in species composition and richness in tandem with transformation on identifiable land parcels.

Our social science research over the next six years will complement our biophysical research and build on long-term data collected at Coweeta in the ***LTER core research areas***. The parcel ownership dataset is central to determining changes to the ecohydrology of watersheds (re-routing of natural flow by above ground and below ground modifications and barriers, e.g., driveways and septic systems) that in turn affect the ***movement of inorganic*** *and* ***organic matter***. Our repeat survey in combination with face-to-face interviews and rapid biotic surveys provide instantaneous measures of biotic integrity that relate directly to our measurements of ***primary productivity*** and ***populations***. Finally, our decadal reconstruction of land-ownership and land-cover change across the region over the last 200 years is fundamental to determining the signature ***disturbance patterns*** for southern Appalachia and their rates of change.

Modeling Efforts (point 3). We will use three component models to integrate and scale the results of our ecological and socioeconomic research from headwater to basin. The three component models are well advanced individually (see **2.5d**) and have already been implemented in small catchments and larger drainages in our study area. They have some degree of overlap in function, but are generally complementary in their goals and structure. There is a close integration between the empirical socioeconomic and biophysical research outlined above (proposal subsections **2.5a-d**) and our modeling approach.

Biotic Modeling Goals - SLIP. Climate change is mediated by species interactions, but current models miss the interaction and don't account for the effect of competition on species responses to climate. Our long-term empirical studies of demographic responses (i.e., birth, growth, survival, and dispersal) to climate variation in experimental gaps and along environmental gradients provide direct data on these interactions. Our measurements on species-specific physiological responses serve to translate observations into demographic rates that determine population dynamics. Our approach is to parameterize the relationships involving climate and species interactions and to explore scenarios of future climates to understand biodiversity impacts using the Scalable Landscape Inference and Prediction (SLIP) simulator.

Hydrologic Modeling Goals - RHESSys. The ecohydrologic modeling portion of our study has as its focus the dynamics of water, carbon and nutrient (WCN) cycling within watersheds in response to land use and climate change. RHESSys provides spatially explicit simulation of all major stores, fluxes and transformations of these components at multiple spatial and temporal scales from patch to regional watersheds. It includes above and below ground primary production, soil and litter WCN storage and transformation, and dissolved organic and inorganic substance flux through hillslopes and into receiving water bodies. While RHESSys is sensitive to life form and species for all WCN cycling processes and can simulate multiple species within a patch, it does not have the ability to directly model dynamics of species change over time. Therefore, species change will be prescribed in uncoupled mode or gained from SLIP in coupled mode, while providing back soil water and other environmental limitations to productivity. It provides, in turn, spatially and temporally varying inputs to SPIRAL.

Stream Nutrient and Carbon Spiraling Model - SPIRAL. Understanding the relationships between stream size, energy inputs, and longitudinal linkages requires explicit recognition of transport and exchange components in streams. Streams are not merely a gutter of terrestrial output nor an independent box of in-stream processes. They are systems continuously linked by the downstream transport of organic materials input from adjacent terrestrial systems subject to various physical, biotic and socioeconomic processes. Our current research on nutrient spiraling assumes an infinitely dendritic reach in which all contributions are of equal concentration to in-stream content. The goal over the next six years is to examine biological processing of materials as they are transported down stream within a hydrologic network using results from sampling along the longitudinal developmental gradient. We will use SLIP to examine and predict changes in nutrients and carbon along the Little Tennessee River from his headwaters in Rabun County (Georgia) to the Needmore Gage below Franklin (North Carolina) as a function of terrestrial impacts, seasonality, and discharge effects on particle entrainment and deposition.

During the next 6 years we will focus on integrating model efforts to understand the spatial distribution and feedbacks between terrestrial water, carbon, and nutrient cycling (RHESSys); stand growth (RHESSys, SLIP); dynamics of forest communities based on individual demography (SLIP); stream segment and network flow regime (RHESSys); and aquatic ecosystem metabolism (SPIRAL). We will initially apply them in an iterative fashion, for example, using summary outputs from stand dynamic models to provide patch species composition, size and age class distribution for ecohydrologic modeling. Together, they will be used to generate predictions and assessments of past, current and future responses of water quantity, water quality and biodiversity in response to changes in land management and settlement, and climate change. Following the iterative application of models, we will explore coupled versions that simplify individual components but allow for more interaction and feedback. The specific scenarios we plan to explore include combinations of climate change forecast for the region (www.narccap.org) in combination with land use change (see proposal).

Model performance will be evaluated by its predictive skill for key variables and as a check on internal consistency. For water quality and quantity, important variables are peak and low flows, rates of change (hydrograph form), inorganic and organic nutrients, suspended sediment concentrations, and loads and stream metabolic cycling rates. Key terrestrial ecohydrologic variables include space/time patterns of soil moisture, riparian groundwater levels and chemistry, and unsaturated zone water chemistry. For biodiversity, evaluation is based on predictive distributions of demographic rates and long-term predictions of abundance (basal area and biomass), composition, age and size. The long-term data sets available for the Coweeta basin (currently being analyzed or already published on) provide a rich source of information for model evaluation.

The following details on our modeling activities over the next six years complement those in Table 1:

Year 1: Independent model component simulation from patch to small catchment and regional drainages; diagnostics for streamflow water quantity and quality including nitrogen concentrations; terrestrial patterns of canopy leaf area and patch scale structure and composition from prior stream and patch sampling. Light dependence of large trees analyzed from a combination of remote sensing and growth measurements.

Year 2: Change in temperature and soil moisture affecting demographic rates for individual species determined from regional climate gradient and local measurements on Coweeta gap and gradient sites. Independent simulation and loose model coupling by file transfer based on a) RHESSys runoff quantity and quality, riparian leaf fall as spatially and temporally variable lateral inputs to the stream nutrient spiraling model; and, b) patch and hillslope soil moisture information from RHESSys to SLIP and SPIRAL. Coupled results for the spatial and temporal patterns of stream ecosystem processes and terrestrial patterns of canopy biodiversity compared to results from uncoupled models. Data assimilation methods developed for hydrological, ecological and land use components using existing Coweeta LTER data.

Year 3: Tightly coupled RHESSys and SPIRAL model using current and historic conditions applied to colluvial forested and agricultural catchments, scaled to large regional drainages. Incorporate new data sets including parcel-level environmental management practices from repeat survey and face-to-face interviews. Diagnostics based on ability to simulate changing runoff regimes across historic land use and sensitivity of simulated water quality to forest species composition (e.g. *Acer, Quercus, Pinus)* and land use (forest, agricultural, urban).

Year 4-5: Adaptation of historical land-use reconstructions and ecological community forms with inferred and synthesized climate drivers within coupled models. Simulations operated for time slices (i.e., decadal periods) and long sequences (i.e., 1850 to present). Future land-use alternative scenarios developed with downscaled climate projections to forecast future water quality, quantity and biodiversity predictions in ensemble mode. E.g., what species transitions are likely to occur under future scenarios of climate change? Which life history stages will allow some to expand and others to decline? What allocation priorities exist for water to meet terrestrial biota, in-stream biota, and human consumption needs over time?

Year 6: Complete long (i.e., 1850-2050) simulations demonstrating sensitivity of specific interactions and feedbacks between model components, the influence of system memory (e.g., land-use history), and operation of models in real-time. Water use will be estimated by combining growth and soil moisture data from past decades with simulation of the timing of environmental change. Biomass increments from past decades coupled with prediction will provide C and N dynamics that depend on individual species. Co-funding supports near-term forecasting using data assimilation methods and weather forecast models.

Summary. Southern Appalachia remains a mountainous rural refuge in the Southeast, yet the influence of Atlanta 120 miles southwest of the Coweeta Hydrologic Laboratory via four-lane highway cannot be ignored. Our research during the next funding cycle (2008-2014) builds on the strong tradition laid down in previous funding cycles of process-based ecosystem research within a socio-ecological setting. This presents conceptual and operational challenges that we have overcome with proven and novel empirical and modeling approaches to achieve scientifically and socially relevant understanding. We are confident that the Coweeta LTER program has the potential to lead the ecological community in socio-ecological research. We also expect our results will be of considerable interest to policy makers, planners, and regulators in southern Appalachia and the Piedmont Megapolitan Region.