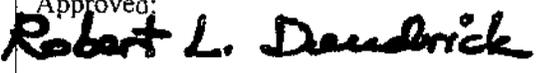
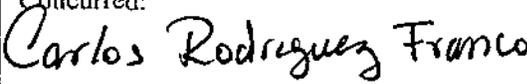


USDA-Forest Service RESEARCH WORK UNIT DESCRIPTION Ref: FSM 4070	1. Number FS-SRS-4353	2. Station Southern Research Station
3. Unit Location Otto, North Carolina Cordesville, South Carolina New Ellenton, South Carolina Blacksburg, Virginia Tallahassee, Florida		
4. Research Work Unit Title SRS-4353: Center for Forest Watershed Research		
5. Project Leader (Name and Address) Chelcy Ford Miniat, Coweeta Hydrologic Lab, 3160 Coweeta Lab Rd., Otto, NC, 28763		
6. Area of Research Applicability Regional, National, International	7. Estimated Duration 5 years	
8. Mission To evaluate, explain, and predict the interactions of water, soil, vegetation, and aquatic and terrestrial organisms in response to management regimes, natural disturbances, climate change and atmospheric pollutants at the watershed scale, and to provide the technical basis to sustain, manage, and restore forested watersheds and their fauna.		
9. Justification and Problem Selection Summary The myriad ecosystem services derived from forested landscapes are fundamentally realized at the watersheds scale. Demands for water, forest products, and other forest-derived amenities in a period of changing climatic conditions are taxing the capabilities of resource managers to sustain aquatic and terrestrial habitats along with other valued ecosystem services. Across the region, a combination of factors—biological influences on hydrologic processes, disturbance regimes, invasive species, climate and weather extremes, and increasing human populations and concomitant land use changes—impose considerable stresses on upland, wetland, and aquatic ecosystems from the mountains to the ocean. Land managers therefore have a complex situation: how to maintain the delivery of services, products, amenities, and opportunities while complying with numerous environmental obligations and occasionally conflicting policies and expectations. Research is needed to provide the foundation upon which strategies and techniques will be developed to restore, enhance, or maintain healthy watersheds across the landscape. The RWU will continue long-term monitoring of gauged watersheds, climate stations, and permanent plots, and conduct experiments across both high and low gradient hydrologic systems to provide the data and analyses necessary to support the development of tools and recommendations for sustainable forest resource management within the region and beyond.		
Signature	Title	Date
Prepared By: /s/ Gregory A. Ruark	GREGORY A. RUARK Assistant Station Director for Research	9/30/15
Recommended: 	CARL F. LUCERO Director, Landscape Restoration and Ecosystem Services Research	7/29/16
Approved: 	ROBERT DOUDRICK Station Director, Southern Research Station	7/29/16
Concurred: 	 Deputy Chief for Research & Development	8/2/16

Acting

SRS-4353 –Center for Forest Watershed Research

Otto, North Carolina

Cordesville, South Carolina

New Ellenton, South Carolina

Blacksburg, Virginia

Tallahassee, Florida

Project Leader: Cheley Ford Miniat

The Center for Forested Watershed Research (SRS-4353) encompasses two experimental forests and staff located at 5 duty stations. Accordingly, the Unit is uniquely positioned to address the complex interactions governing watershed processes that in turn affect land productivity, wildlife and aquatic habitat and clean water. The three Problem Areas reflect the Unit's capacity to address contemporary forest resource issues by capitalizing on long-term research and monitoring and a productive network of collaborators.

9. JUSTIFICATION AND PROBLEM SELECTION

Problem Area 1. Fundamental Processes and Interactions. Develop a fundamental understanding of the structure, function, and interactions among terrestrial, riparian, and aquatic components of forested watersheds. Fundamental knowledge on ecosystem structure, function and processes is required to restore, enhance, or maintain healthy watersheds, and tools integrating that knowledge are needed to provide a basis for management and policy options.

- a. **Effects of invasive, and non-random species gains and losses on ecosystem processes in terrestrial and aquatic systems.** Invasive species can fundamentally alter forest vegetation, wildlife and aquatic community dynamics. Rates of invasive species' introductions have dramatically increased in recent years, thereby altering ecosystem functions and provisioning of goods and services derived from the watershed. Correspondingly, changes in land cover and species composition due to nonrandom species loss can alter important hydrologic and biogeochemical processes such as carbon, water, and nutrient cycling, terrestrial and aquatic litter decomposition, and stream water quality, temperature and metabolism.

Long term changes in forest species composition following the extirpation of *Castanea dentata* by chestnut blight have likely affected water quantity. Since the 1970s, changes in species distribution and abundance have favored species with high transpiration rates which potentially has contributed to the increase in evapotranspiration and decline in streamflow. Additionally, recent losses of Eastern hemlock (*Tsuga canadensis*) caused by hemlock woolly adelgid (HWA – *Adelges tsugae*) infestation also have profoundly impacted the structure and function of riparian forests, particularly in the southern Appalachians. Our research over more than a decade shows that understory microclimate and plant-litter-soil biogeochemical feedbacks related to expansion of *Rhododendron maximum* (Ericaceae) inhibit tree seedling recruitment and limit development of overstory canopy trees. There also are both physical and biological consequences of hemlock replacement by rhododendron: rhododendron prevents the establishment of riparian trees capable of contributing large wood to streams, leaving many streams further impoverished of wood from already low historic levels, and dominated by inputs of rhododendron leaves, which provide low quality aquatic insect food and substrates for development of biofilms.

Introduced wildlife and aquatic organisms, and natural changes in species distributions also affect ecosystem functions and properties. For example, the expansion of coyote's (*Canis latrans*) in the southeastern US has altered behavior and population dynamics of white-tailed deer (*Odocoileus virginianus*). Wild pigs (*Sus scrofa*) and the expansion of the range of armadillo (*Dasypus novemcinctus*) are likely affecting vegetation, afforestation, and ecosystem processes but have not been widely studied. Similarly, the species and age-class composition of native fish communities is influenced by changes both to the near-stream and instream environments. Managers need information and tools to help assess potential problems and develop remedial actions.

- b. **Hydrology, vegetation and soil productivity responses to climate change in unmanaged watersheds.** As atmospheric CO₂ concentrations increase and the earth's surface warms, variation in the hydrologic cycle is expected to intensify. Predictions for the Southeast include increases in the frequency and intensity of extreme events (e.g., intense storms and floods, and long dry periods creating deep droughts), and increasing air temperatures. Taken together, these changes will likely manifest as an increase in the variability of streamflow and water quality (e.g., stream temperatures and in-stream dynamics), with feedbacks and cascading effects to the forests and aquatic organisms that regulate and depend on these flow, temperature, and chemical characteristics. Climate change effects on streamflow are not as clear as might be expected across the U.S. and the regional physiographic gradient, perhaps because of ecosystem processes and human influences. Past and present human and natural disturbance, vegetation succession, and human water use can mimic, exacerbate, counteract, or mask the effects of climate change on streamflow, even in reference basins. Those uncertainties on stream hydrology are exacerbated in the lower coastal plain where freshwater tidal streams are being affected by sea level rise. The influence of both terrestrial and tidal hydraulics on biological and biogeochemical processes is not well understood, pointing to significant uncertainties across the southern landscape.

The effects of increased intensity and duration of drought events on sustaining minimum flows for aquatic organisms has become a major issue in regulating surface water withdrawals for human use. Droughts also are affecting wetlands systems, as the hydrologic regimes of many wetlands are strongly rainfall-driven. Climatic fluctuations and drought have the potential to alter processes such as water storage, interactions with groundwater, fire susceptibility, vegetation dynamics, and faunal habitat suitability. Mangrove wetland systems also are vulnerable to warming climates, and the interactions between vegetation and the aquatic communities will have direct consequences to the ecosystem functions and socioeconomic values. Finally, Southern cold- and cool-water stream systems and their faunas are particularly vulnerable to even small increases in temperature and changes in water quality.

Soils are the largest carbon (C) sink in terrestrial ecosystems and forested wetlands, especially mangroves, have exceptionally high C density. Long-term changes in forest soil C suggest non-equilibrium dynamics and current policy initiatives, based on the assumption that previously disturbed systems approach steady state over decades, focus on managing for long-term storage of C in forest soils. Surprisingly little is known, however, about how these systems are changing in response to previous human and natural disturbances. Although the return to forest conditions following agricultural abandonment is known to result in the accumulation of aboveground and belowground C, few long-term data exist for 1) non-agricultural systems undergoing afforestation and 2) forested systems with well developed, deep soil horizons. Our long-term soil biogeochemical record suggests that nearly a century post-disturbance soil C in deeper layers is not at equilibrium.

- c. **Interactions of climate change and land use / land cover dynamics on water quality, water quantity, and freshwater ecosystems.** The effects of climate change will not be uniform across all land cover and use types within the region. Warming and increases in hydroclimate variability will

affect the structure and function of systems differently depending upon the combined effects of the likelihood of exposure and inherent resistance and resiliency. We will examine the interactions of climate change, land use and land cover across the regional physiographic gradient, and span the continuum investigating the effects of: climate change on low-land tidally-influenced systems; changes in land cover, precipitation regimes and landslide triggering; and land use changes such as urbanization and river impoundments and how these may alter the vulnerability of watershed health and aquatic systems to climate change.

Changes in sea level will interact with land cover and topography to alter the reach of saline waters into freshwater systems, and thus the stage and reach of freshwater tidal creeks and rivers. Although vegetative dieback is an obvious impact of changes in salinity on riparian forests, very little is known about other interactions at the interface of the tidal- freshwater riparian zone. Accordingly, there are large uncertainties about changes in ecosystem processes and the associated implications within the rapidly urbanizing landscape of the lower Coastal Plain.

Enhanced hydroclimate variability in the region as a result of climate change, particularly extended droughts, threatens unique habitats that are closely tied to water balance and periodicity. The diversity of the southern Appalachians has depended on a broad temperature and moisture range, mediated by species interactions. Habitat diversity may buffer the impacts of future climate change, allowing for local refuges as temperatures rise, droughts become more frequent, or both. The long-term effect of climate change will depend on the extent to which habitat and species interactions amplify or buffer climate impacts. A common element of most community model scenarios is an increase in oak and hickory species and the potential for reduced canopy coverage, leading to a savanna-like forest composition and structure in the Southeast. At the same time, recent trends show instead increases in mesic elements, principally red maple and tulip poplar (see Problem 1a above). Similarly, impacts from recent extreme storm events have warranted examination of engineered structures and design guidelines.

Urbanization, channelization, mining, and other land use changes profoundly and often irreversibly alter aquatic communities, hydrology, and water quality at large scales. Reservoirs and dams impact aquatic communities by altering hydrology, stream temperatures, sediment and nutrient transport and deposition, habitat quality and connectivity, and by facilitating species invasions and fragmenting populations. Increasing demands on water resources have already led to calls for more reservoirs, and synergistic effects with climate warming may increase evaporation from and thermal impacts of reservoirs and both up and downstream habitat suitability for aquatic organisms.

Problem Area 2. To develop knowledge, methods and guidelines to evaluate the effects of natural resource management and policy on forested upland and wetland watersheds and aquatic systems.

Most of the forested landscape in the southeastern U.S. is privately owned and subject to some level of management. Given the complex interactions among ecosystem responses, climate change and desired goods and services, new insights and tools are needed to support informed land management practices. This need is particularly acute for the National Forests where the USDA Forest Service Planning Rule (2014) requires scientific involvement and monitoring to support adaptive forest management. The Rule requires the use of the best available scientific information to inform decisions. It also requires increased protection for water resources, watersheds, and riparian areas; the maintenance and restoration of aquatic ecosystems, watersheds, and water resources including public water supplies, groundwater, lakes, streams, and wetlands; and adoption of best management practices to protect water quality. In addition, the new Planning Rule stipulates an improved ability to respond to climate change and other stressors through an adaptive framework of assessment, planning and monitoring and new provisions intended to improve resiliency of ecosystems.

The ecosystem services and products provided by southern forests are critical to the health of the regional and national economy. While there is a long history of silvicultural research within the region, new silvicultural systems and tools are needed to help ensure sustainability of the landscape. Our research will play a key role in providing the best available scientific information on watershed structure and function in support of sustainability of the ecosystem services. We will also use models to synthesize the complex interactions among the forest resources, management regimes, invasive species, water resources, and changing climatic regime. Models provide the practical means to synthesize current conditions, assess future potential management scenario impacts, and design monitoring systems that will be sensitive to the critical factors which affect management outcomes. The long-term research being conducted at SRS-4353 (described below) provides the needed basis for developing models that can inform forest land management decisions.

- a. **Restoration of aquatic ecosystems, and forested watersheds.** Most forested watersheds throughout the region have a history of disturbance and alteration. Hence there is need for restoration and management activities, especially on public lands, that reinstate the desired ecological structure and functions. Developing knowledge to aid in restoring high- and low-elevation forests in the region in the wake of press- and pulse- disturbances will be a key focus of our research in the next five years. Active and adaptive management strategies will be required to transform degraded systems into more desirable states. Thus, land managers need science-based restoration strategies and methods to aid recovery of forest structure and function after widespread declines and losses of important species. Monitoring chronic acid deposition in high-elevation forests and understanding how the factors affecting acid neutralizing capacity of streams and soils in the southern Appalachian will be an important focus area. Additionally, the structure and function of riparian forests in the southern Appalachians have been significantly affected by eastern hemlock death due to the hemlock woolly adelgid (HWA) infestation. Over a decade of our past research shows expansion of *Rhododendron maximum* (Ericaceae) with understory microclimate and plant-litter-soil biogeochemical feedbacks that inhibit tree seedling recruitment and establishment of overstory canopy trees. Removal of this shrub, using tools such as prescribed fire coupled with a greater understanding of seed banks will inform land managers and help restore riparian forest structure and function. Preservation of HWA-infested hemlock stands requires intense management strategies using one of many control mechanisms to reduce or eliminate HWA populations. Depending in-part on the level of infestation, both chemical and biological controls have been effective in preserving hemlock stands. As the success of some of these control programs has increased, interest is growing in improving the health of treated hemlock trees and restoring hemlock stands through silvicultural practices. Hemlock tend to respond positively to canopy openings, for example, but more knowledge is needed regarding the physiological mechanisms and the interactions with biological and chemical controls. In the coastal plain, reestablishment of fire-dominated ecosystems is the principal management objective on National Forest lands. While prescribed fire research has a long history in this region, changes in climatic regimes, urbanization, and concerns about water quality, and how they may affect riparian, wetland, and aquatic fauna and ecosystems services remain. Correspondingly, the effects of restored longleaf pine forests on streamflow dynamics is poorly understood, hence knowledge is needed to learn the mechanisms/controls on its hydrology and water quality.
- b. **Implications of policy on watershed health and function.** Policies and legal mandates such as the Clean Air Act (CAA) & Clean Water Act (CWA) have profoundly improved water quality and habitats for both terrestrial and aquatic species. However, loss of forested wetlands remains an important issue in the region, particularly as a result of minor silvicultural drainage and development of forest lands. Interactions among management practices, climate change and uncertainties in the hydrology of managed forested wetlands convey important needs ranging from expanding our understanding of fundamental processes to modeling and assessment to provide the information needed by managers and policy makers to avert further wetland loss.

The CAA includes provisions to protect water quality through reduction and mitigation of airborne emissions. Information is needed to link functional responses to mitigation. Continued long-term monitoring of atmospheric deposition and stream chemistry provide data to drive these assessments provide the basis for modeling the potential long-term effects of emissions on stream water quality.

- c. **Integrating silvicultural systems in a watershed context.** Silvicultural systems and associated Best Management Practices (BMPs) provide guidance to protect forest soil and water resources while sustaining the provisioning of ecosystem services. New silvicultural practices and changes in watershed condition due to invasive species, climate change, etc. require prescriptions to protect and sustain basic soil, water and ecological functions. Changes in social and economic conditions will also affect silvicultural production. For example, demand for wood products for uses such as biofuels is likely to increase in the coming decades and may alter the current species choices to include non-native species. Technological advances in genetic engineering of non-native timber species that have historically been excluded from the Southeast due to climate are increasing rapidly. Better information and tools to support sustainable management prescriptions for these new silvicultural systems are needed.
- d. **Tools to assess effects of management and climate change on watershed health and function.** Models are fundamental for synthesizing scientific information and for providing a basis for developing management and policy recommendations. Models are particularly well suited for assessing the impact of climate change, land use change, and population growth on water supply, river flows, and aquatic ecosystems at scales ranging from the small watershed to the conterminous U.S. Correspondingly models linking hydrologic and biogeochemical processes can be effective in assessing water quality response to disturbances, soil C storage, green house gas emissions, as examples. While there are operational models applicable to the region, they all require validation for particular applications, and advances in the models must reflect the science. Accordingly, there's significant need to test and adapt existing models for application within the region, country and beyond. The models of particular relevance to our program include: the Soil and Water Assessment Tool (SWAT), developed by Agricultural Research Service, the Water Supply Stress Index (WaSSI) model developed by SRS scientists, and MIKESHE, a commercial hydrology, DRAINMOD Forest developed by North Carolina State University, and Forest DNDC developed by University New Hampshire.

In addition to ecosystem models, spatial decision support systems can be effective tools to protect infrastructure and anticipate potential consequences from engineered structures. With more than 50,000 road-stream crossings on National Forest lands in Region 8, managers charged with maintaining, improving, and decommissioning roads must balance the needs for safe, efficient movement of traffic with the mandate to provide adequate passage for aquatic organisms, all with limited funds. The Crossing Area Decision Support System (CADSS) provides managers with a desktop, GIS-based tool to integrate the costs and benefits of removing or replacing particular combinations of problematic crossings. This tool lets managers prioritize crossing based on information on species richness, presence of mussels and fish species, land ownership, and presence of natural heritage species.

Problem Area 3. Long-term hydrologic and ecological monitoring and research on forested upland and wetland-dominated watersheds. The RWU will continue long-term monitoring of surface and ground water stations, climate stations, permanent plots, and experiments. Studies will continue on both high- and low-gradient hydrologic systems from the Appalachian Mountains to the Coastal Plain. These data provide the cornerstone of the Center for Forest Watershed Research program and underpin the RWU's mission. While new approaches, tools and data networks will be required to answer contemporary questions, the value of maintaining these long-term watersheds cannot be overstated; the data they provide are critical for detecting change and trends, for discovery of ecological 'surprises,' and to inform,

advise, and support policies and decisions. These long-term records and experiments offer us the ability to formulate and answer new questions, as well as to revisit or recast original questions in an age of increasing human demands and changing global climate.

- a. **Long-term climate, hydrology, and vegetation monitoring within Experimental Forests.** Both the Coweeta Hydrologic Lab and the Santee Experimental Forest have long histories, 80+yrs and 40+yrs, respectively, of using long-term climate, hydrologic, and vegetation data to answer fundamental questions on management and watershed hydrology. Streamflow and vegetation at Coweeta and Santee have been established to assess reference conditions, post-hurricane conditions, and post-insect infestation conditions on community dynamics, among others. This information has provided the basis for hundreds of publications, and the continued development of the long-term database is poised to support critical advances in the development of simulation tools that are needed to scale from the watershed to the region and beyond (e.g., global circulation models).
- b. **Long-term stream temperature network.** Outside of the Experimental Forest boundaries, we have developed a network comprised of 204 watersheds distributed down the spine of the southern Appalachian Mountains from Maryland to Georgia to continuously monitor stream water and air temperatures. Our primary purpose is to investigate how broad traits of landscapes interact with local watershed features to influence the relationships between air and stream water temperature and to predict how water temperature and thus habitat suitability, particularly for cold- water adapted species, will respond to changes in climate.
- c. **Integration with Experimental Forest Research (EFR) network.** The EFR Network was established in 2006 by the Deputy Chief for Research and Development to provide the needed capacity for monitoring, experimental data collection, and data sharing to address complex national level questions. The network includes both the Coweeta Hydrologic Laboratory and the Santee Experimental Forest, selected to represent major biogeoclimatic zones across the U.S. SRS-4353 remains committed to effective development of the network. For example, in 2011 the Unit established the FACE wood decomposition experiment, incorporating nine experimental forests representing distinct bioclimatic zones to assess wood decomposition and the fate of wood-carbon. Considerable opportunity exists to utilize the EFR network for developing the information that is need for robust tools that can be applicable at large scales (e.g., national).

10. APPROACH TO PROBLEM SOLUTION

Problem Area 1. Fundamental Interactions

Problem 1 will be addressed through a combination of field and laboratory studies as synthesized below.

a. Effects of invasive species, and non-random species gains and losses on ecosystem processes in terrestrial and aquatic systems.

- i. *Hydrologic impacts of species changes:* We will investigate the ecological and hydrological impacts of non-random losses and gains of forest and freshwater species, native and non-native. We will extend our research to address questions involving fundamental changes in species used for the Southeast timber industry as well by comparing *Eucalyptus* spp. and *Pinus taeda* water use along a hydrologic gradient.
- ii. *Water budget components:* We will conduct fundamental research on transpiration, interception, reference evapotranspiration, and streamflow dynamics at the individual, stand, and watershed scale to understand how species composition affects water budget components.
- iii. *Extirpations by invasive species:* We will continue research on the effects of eastern hemlock loss, black locust proliferation and mortality, and American chestnut loss on ecosystem processes. New research on physiological mechanisms determining susceptibility to hemlock woolly adelgid infestation will be conducted in a series of cross-RWU manipulative and observational studies.
- iv. *Riparian shrub layer feedbacks:* We will conduct a large-scale experimental removal of rhododendron and its associated O-horizon leaf litter in riparian corridors once dominated by eastern hemlock into which rhododendron has since expanded. We will collaborate with outside partners to examine the effects of rhododendron removal on a suite of ecosystem properties and processes in riparian forest and their adjacent stream reaches.
- v. *Effects of invasive mammals on ecosystem functions and predator-prey relationships:* We will continue research on the movement and population ecology of wild pigs and coyotes and the effects of these species on other wildlife. This work will include assessment of potential effects of pig control programs on coyotes, as well as evaluation of various strategies for pig control.
- vi. *Effects of introduced rainbow and brown trout on native brook trout:* we will expand on efforts to understand the mechanisms responsible for expansion of rainbow and brown trout into habitats historically occupied by brook trout.
- vii. *Determine habitat use, movement, and ecological relations of American eels (*Anguilla rostrata*) in Atlantic slope watersheds:* American eels in small high-elevation low productivity streams coexist as members of diverse fish communities for 3-20 years. We will continue research understand the mechanisms that permit eels and other fishes to coexist and to predict the influence of disturbance to major habitat features such as substrate composition.

b. Hydrologic and forest and soil productivity responses to climate change, including greater hydroclimate variability.

- i. *Hydrologic response to extreme events:* We will study the effects of climate change on streamflow, drought on low flows, altered precipitation temperature and water table regimes on forested wetlands, including mangroves, and increased temperature on warm- and cold-water systems.
- ii. *Mechanisms driving changes in evapotranspiration:* We will conduct research focused on elucidating the mechanisms of streamflow changes in reference basins in the southern Appalachians and Coastal Plain to provide a robust perspective on a hydrologic process that

accounts for 60–80% the water flux from forested watersheds. We'll employ a suite of cutting-edge tools and approaches including sap flow, eddy covariance, remote sensing and scintillometry, and automated infrared gas analysis and stable isotope mass spectrometers.

- iii. *Mechanisms affecting net ecosystem exchange of carbon and carbon sequestration:* We will conduct research focused on elucidating the mechanisms of forest and soil productivity changes in reference and managed basins using advanced tools and approaches. We will conduct experiments to determine the factors regulating gains and losses of soil C assessing long-term changes in soil and aboveground carbon pools and fluxes in established experiments and monitoring plots.
- iv. *Forested wetland responses to hydroclimate variability:* Studies of forested wetland responses to shorter-term drought cycles have provided a conceptual basis for understanding the potential effects of longer-term climate change, but hydrologic and modeling studies are still needed to understand how different wetland types may respond under different land use scenarios and how adjacent land management may mitigate these effects.
- v. *Cold- cool, and warm-water aquatic systems responses to global warming:* Our cold-water stream temperature networks (described above in Problem 3b) and watershed-wide faunal sampling is our first step toward understanding warming effects across the gradient of stream temperature regimes.
- vi. *Soil carbon sequestration:* We will synthesize long-term data on above- and belowground carbon pools and fluxes across reference and disturbed forested watersheds and explore likely mechanisms of deep soil carbon loss. We will also conduct studies to quantify carbon and greenhouse gas fluxes in forested wetlands, spanning tidal and non-tidal hydrologic regimes, and further refine Forest DNDC to predict C cycle dynamics.

c. Interactions of climate change and land use/land cover dynamics on water quality, water quantity, and freshwater ecosystems.

- i. *Sea-level rise effects on tidally-influenced ecosystems:* The Santee Experimental Forest (SEF) is the only EFR in the Nation with a gauged freshwater tidal stream. Combined with the long-term, upland watershed hydrology monitoring, the SEF provides unique capabilities to address fundamental questions regarding the interactions of physiological and biogeochemical processes with the tidally-influenced riparian zone hydrology.
- ii. *Future forests:* We will create replicated future forests experiment (FFE) by selective removal to achieve composition and stocking levels that are consonant with prevailing forecasts. By conducting our studies in current and 'future' communities across different elevations and drainage classes we will generate a broad range of environments to evaluate the role of interactions. The two experimental components within treatment plots across an FFE watershed are thinning to promote fast transition and burning for slow transition.
- iii. *Landslides and land cover:* We will continue modeling and field studies on the effects of forest species composition, tree height, and age on soil cohesion and the resulting cascading effects on debris flow triggering.
- iv. *Landslides and aquatic communities:* We will continue annual basin-wide monitoring begun in 1992 of fish habitat and fish abundance and distribution following a flood and debris flow (including three pre-flood years) in a mountain watershed.
- v. *Barriers in aquatic systems:* Our research into the effects of reservoirs focuses on upstream and transition zone dynamics as well as downstream influences on aquatic organisms in the southeastern U.S. will continue and become more critical over the next several decades.

Anticipated outcomes in Problem 1:

- Quantification of the rates of carbon sequestration among ecosystem components will provide needed information to support programs designed to minimize carbon emissions from forest land

- management practices.
- Improved tools, especially Forest DNDC will be developed to facilitate project-specific assessments of management effects on carbon and greenhouse gas emissions.
 - Long term monitoring will enable increased precision of estimates for the regional water balance and improvements in the quantification of forest mediated evapotranspiration. The outcome will have significant ramifications regionally, and provide a precedent for other regions.
 - More complete understanding of the potential consequences of sea level rise on ecological functions of freshwater tidal riparian zones and the potential corresponding interactions with climate change and land development scenarios.
 - Increased understanding of the implications of sea level rise at the coastal-terrestrial interface.
 - Improved effectiveness of control strategies for wild pigs and increased understanding of the effects of invasive large mammals on the ecology of forested watersheds.
 - Development of tools to assess the vulnerability of road cross drainage structures/stream crossings.

Problem Area 2. To develop knowledge, methods and guidelines to evaluate the effects of natural resource management and policy on forested upland and wetland watersheds and aquatic systems.

Problem 2 will be addressed through a combination of field and laboratory studies as synthesized below.

a. Restoration of aquatic ecosystems and forested watersheds.

- i. *Acid sensitivity in southern Appalachian watersheds:* We will examine the sensitivity of high elevation watersheds in the southern Appalachians to acidic deposition and the potential for restoration through liming by analyzing relationships among stream chemistry and the following catchment characteristics: soil A horizon and total profile depth, soil and forest floor chemistry, litterfall nutrients, total extractable cations, total digestible cations, and lime requirement.
- ii. *Manipulation of riparian zone vegetation-rhododendron removal:* We will conduct rhododendron and forest floor (soil O-horizon) removal experiments in riparian corridors once dominated by eastern hemlock. Our experiments will investigate restoration potential and methods in these degraded areas. We propose replicated (intensive) field experiments at the plot scale, and un-replicated observational (extensive) measurements at the stream reach scale.
- iii. *Manipulation of riparian zone vegetation-recruitment patterns and mechanisms:* Increased light and nutrient availability in response to rhododendron removal may result in higher rates of tree seedling recruitment; faster growth of existing seedlings and saplings; and higher recruitment of herbaceous species, including spring ephemerals, herbaceous annuals and longer-lived perennials. Recruitment may occur via seed dispersal or by viable seeds stored in the soil. Ability of plant species to store seeds in the soil (i.e., seed bank) could be a mechanism to recover rapidly following hemlock loss and rhododendron removal. It is unknown, however, whether there is a viable seed bank under rhododendron that could respond to increased resource availability following removal.
- iv. *Ecology and physiology of eastern hemlock:* We will assess the effectiveness of daylighting treatments on tree physiological status and carbon balance of eastern hemlock using both short and long-term indicators of physiological stress. We will measure leaf-level gas exchange, chlorophyll fluorescence, and leaf-level concentrations of C, N, and total nonstructural carbohydrates (TNC) and conduct these measurements on infested and uninfested trees, and also in infested trees where predatory beetles have been released for a decade.
- v. *Stream habitat restoration research:* We will partner with management to assess, design, construct, and monitor stream habitat restorations in the southern Appalachians. Our research

will focus on changes to aquatic communities and assemblages, including species composition, growth, and production

- vi. *Watershed restoration*: The Santee Experimental Forest is developing a plan with the Francis Marion National Forest to study the effects of longleaf pine restoration at the watershed scale. The work will be the first watershed-scale study to assess the hydrologic processes and changes in the water balance associated with longleaf pine.
- vii. *Foraging ecology of red-cockaded woodpecker*: We will continue collaborative research aimed at understanding characteristics of good quality foraging habitat for this endangered species to identify thresholds in habitat attributes that affect population vital rates. New research will use a manipulative approach to identify the relative influence of habitat features and breeding group size on reproductive success.

b. Implications of policy on watershed health and function. We will utilize established experimental sites and modeling tools to quantify the effects of forest management practices on water, carbon and nutrient dynamics. This work will establish the extent to which silvicultural practices, including changes to identified minor drainage, may affect the jurisdictional status of forested wetlands. We will partner with various state and Federal Agencies to conduct long-term monitoring and research on the losses, gains and distribution of aquatic organisms and their habitats above and below reservoirs licensed by the Federal Energy Regulatory Commission (FERC)

c. Integrating silvicultural systems in a watershed context. We will leverage established silvicultural experiments to quantify water and watershed effects over the long-term. Findings from this work are especially important for validating ecosystem and soil biogeochemical models. The Unit will collaborate with Dept. of Energy, university and private industry in the development of sustainable biomass production systems with respect to water quality and soil productivity.

d. Tools to assess effects of management and climate change on watershed health and function. Our development, testing and application of models will include both hydrologic systems and forest biogeochemistry. The hydrology modeling will focus on physical hydrology and the distinctions between high- and low-gradient systems in managed and unmanaged conditions. The effects of silvicultural (e.g., prescribed fire, harvesting) and restoration on water quality will employ WaSSI, Forest DRAINMOD and SWAT models. We will also conduct research in the application of remote sensing data to assess hydrologic processes, carbon stocks and watershed condition. Biogeochemical modeling will focus on the carbon balance and greenhouse gas emissions in managed forests. We will also continue to improve our Crossing Area Decision Support System (CADDs), a desk top tool designed to optimize decisions about stream crossing structure repair or replacement. Finally, we will use the WaSSI model to quantify the contribution of State and Private Forest lands to water supply.

Anticipated outcomes in Problem 2:

- Improved understanding of the range of sensitivity to SO₄ deposition related to site soils and parent material.
- We expect that removal of rhododendron, with and without the partial removal of the O-horizon, will improve degraded forests by: allowing recruitment of trees and herbs; increasing forest floor decomposition rates; increasing soil pH, nutrient availability and nutrient cycling rates; and, subsequently, raising stream pH and acid neutralizing capacity (ANC).
- Increased understanding of seed bank dynamics and the ability to respond to increased resource availability following rhododendron removal using fire.
- A better understanding of how restoration may be accelerated through increasing available light to understory and recovering eastern hemlock trees.

- The ability to assess forest response to altered climate regimes and forest management practices will be improved as a result of field-based research supporting model development and application
- Forest DNDC, which is recommended by USDA as the model to assess carbon dynamics in forested wetlands, will be further refined and validated.
- Improvements in strategies, priorities, and decision making for placement and repair of stream crossing structures to facilitate aquatic organism passage.
- Public information materials, databases and map products that can be used by forest managers to convey the importance of water supply from state and private forests.
- Identification of critical habitat attributes for the red-cockaded woodpecker to improve habitat restoration and management for this species.
- More effective design for longleaf restoration that considers implications to the water budget.

Problem Area 3. Long-term hydrologic and ecological monitoring and research on forested upland and wetland-dominated watersheds

Problem 3 will be addressed through a combination of field and laboratory studies as synthesized below.

a. Long-term climate, hydrology, and vegetation monitoring within Experimental Forests.

- i. *Water quality and quantity monitoring in the Coweeta and Santee Experimental Forests:* We will continue sub-daily monitoring of stream discharge and weekly sampling of water quality parameters in the 16 gaged watersheds in the Coweeta Basin and the 3 gauged sub-watersheds in the Turkey Creek Watershed.
- ii. *Climate network:* We will measure and record precipitation and climate –sensitive variables in the Coweeta and Santee Experimental Forests. We will continue long-term partnerships with NADP and NDDP to measure atmospheric and dry chemical deposition, respectively.
- iii. *Vegetation plots:* We will continue to measure species composition, growth, and soils (in a subset of watersheds) in the permanent plots to track changes in diversity and productivity in the reference watersheds. Remeasurement at Coweeta is scheduled for 2020, and will not need to be completed in this RWUD. Remeasurement at Santee is scheduled for 2018. Soils at Coweeta will be sampled in 2016.

b. Long-term stream temperature network. We will continue to maintain our network of air and water temperature monitoring sites located in over 200 headwater Appalachian watersheds from Maryland to Georgia. Data will be used to refine predictions of stream temperature at scales ranging from individual stream reaches to headwaters of the Appalachian region. We will leverage our temperature data in partnership with other agencies and organizations to analyze and predict relations of climate change to aquatic community structure.

c. Integration with Experimental Forest Research (EFR) network. Investment in the Coweeta Hydrologic Laboratory and the Santee Experimental Forest will enhance national monitoring efforts and improve monitoring to support emerging remote sensing technologies. We will seek out new and existing ways to host EFR data on FS servers to increase our visibility and encourage use of the data. New efforts within SRS will allow cross-site analyses among ERFs to facilitate NFS forest planning.

Anticipated outcomes in Problem 3:

- Models will be developed and tested to predict the effects of management, climate, land use change on hydrology, water quality, carbon pools, sensitive aquatic fauna, and ecosystem services
- Work conducted across the Coweeta Hydrologic Lab and Santee Experimental Forest, and other SRS ERF sites, will exemplify approaches to realize the values of long-term monitoring.

11. ENVIRONMENTAL CONSIDERATIONS

The RWU-4353 program of research includes activities that are not expected to have a significant adverse effect on the quality of the human environment. The environmental effects of specific actions will be considered during the development of study plans, at which time the existence of extraordinary circumstances related to the proposed action and any categorical exclusions will be documented as a part of the study plan as described in FSH 1909.15, Chapter 30. For research involving the use of toxicants, environmental considerations will be further evaluated through Environmental Assessments or Environmental Impact Statements prepared with, and reviewed by the cooperating District or Forest staffs. For research having the potential to affect a plant or animal species that is federally listed as endangered or threatened or proposed for such listing, RWU-4353 will consult with District or Forest biologists and the U.S. Fish and Wildlife Service as per Section 7 of the Endangered Species Act of 1973, as amended.

Key Cooperators: Research described in this document involves collaborations with individuals at universities throughout the US and abroad, private organizations, and state and federal governments. Within the USDA Forest Service, this research involves collaboration with other Research Work Units at the Southern Research Station and other Stations, State and Private Forestry, and the National Forests.

Southern Research Station Research Work Units:

SRS-4552--Insects, Diseases, and Invasive Plants of Southern Forests
SRS-4854--Eastern Forest Environmental Threat Assessment Center
SRS-4855--Center for Integrated Forest Science

Federal Agencies:

Environmental Protection Agency - Region 4
National Aeronautics and Space Administration
National Science Foundation
Oak Ridge National Laboratory
US Agency for International Development
US Department of Energy
US Department of Interior, National Park Service
US Geological Survey
USDA Agricultural Research Service
USDA Forest Service, National Forests nationwide: Francis Marion, Pisgah, Nantahala,
USDA Forest Service, Region 8, Regional Office, USDA Forest Service
USDA Forest Service, Region 8, State and Private Forestry, Forest Health Protection
USDA Forest Service, International Programs
USDA Forest Service, Northern Research Station
USDA Forest Service, Pacific Northwest Research Station
USDA Forest Service, Pacific Southwest Research Station
USDA Forest Service, Rocky Mountain Research Station
USDA Natural Resource Conservation Service

Universities:

Land Grant, minority, and private institutions of higher learning, nationwide, including:
Univesidade Eduardo Mondlane (Mozambique)
Auburn University
Clemson University
College of Charleston
Duke University
Florida A&M University
Furman University
George Mason University
James Madison University
Michigan Technological University.
North Carolina State University
Oregon State University
State University of New York - Buffalo State
Texas A&M University – Corpus Christi
Univeristy of Massachusetts-Amherst
University of Dar es Salaam (Tanzania)
University of Georgia

University of Illinois
University of Indiana
University of Krakow (Poland)
University of Maryland
University of Michigan
University of Minnesota
University of New Hampshire
University of North Carolina Charlotte
University of North Carolina-Asheville
University of North Carolina-Chapel Hill
University of North Georgia
University of Pennsylvania
University of South Carolina
University of Virginia
Univesidade Eduardo Mondlane (Mozambique)
Virginia Tech University
Warsaw University of Life Sciences (Poland)
Western Carolina University

State Agencies:

State natural resource and forestry agencies, nationwide:

Alabama Department of Conservation and Natural Resources
California Department of Forestry and Fire
Georgia Department of Natural Resources
National Association of State Foresters
North Carolina Department of Environment and Natural Resources (NC DENR)
North Carolina Wildlife Resources Commission
South Carolina Department of Health and Environmental Control
South Carolina Department of Natural Resources
South Carolina Forestry Commission
Southern Group of State Foresters
Tennessee Wildlife Resources Agency
Virginia Department of Game and Inland Fisheries

Private organizations (non-profit and industry):

Abengoa, Inc.
Joseph W. Jones Ecological Research Center
Land Trust for the Little Tennessee
NCASINational Council on Air and Stream Improvement
The Fire Learning Network
The Nature Conservancy
Trout Unlimited
Weyerhaeuser Company
World Wildlife Fund

International organizations:

International Union of Forestry Research Organizations
International Peat Society
Millennium Challenge Corp.

12/13. STAFF AND COSTS

The RWUD describes an ambitious five-year plan of work. Based on a staffing level of ten Factor-4 scientists and a current (FY 2016) budget of approximately \$2.7 million in FRRE funding, we expect to implement many areas of research described in the RWUD.

Staffing Plan: RWU Staffing and Funding

Problem Area	<i>Scientist</i> per year of the RWUD				
	2016	2017	2018	2019	2020
1	5	5	5	5	5
2	4	4	4	4	4
3	1	1	1	1	1

The unit consists of 10 permanent full-time scientists, two are supported with funds provided by the US Dept. of Energy through work conducted by the Forest Service Savannah River Site (Region 8). We have one post-doctoral research scientist on external funds who splits her time between Problem Areas 1 and 2 (not counted in the above table). In addition, we have three Emeritus Scientists (not counted in the above table) working in Problem Area 1. Final allocations of scientist time across problem areas will depend on the interests and abilities of scientists that we hire as well as the external funding brought to the Unit.