USDA-FOREST SERVICE **RESEARCH WORK UNIT DESCRIPTION** Ref: FSM 4070	1. NUMBER FS-NE-4104	2. STATION Northeastern Research Station
	3. UNIT LOCATION Durham, NH 03824	

4. RESEARCH WORK UNIT TITLE

Forest Carbon Dynamics and Estimation for Sustainable Management

5. PROJECT LEADER (Name and Address)

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6. AREA OF RESEARCH APPLICABILITY	7. ESTIMATED DURATION
Nationwide	Five years

8. MISSION

To further understanding of the stocks and flows of carbon in forest ecosystems and their response to natural disturbances, environmental change, management practices, and land use change, and to provide science-based information and tools for landowners to assess carbon stocks and enhance carbon sequestration through sound forest management.

9. JUSTIFICATION AND PROBLEM SELECTION

On attached pages

10. APPROACH TO PROBLEM SOLUTION (Start at conclusion of item 9.)

SIGNATURE	TITLE	DATE
Recommended:	ASSISTANT DIRECTOR FOR RESEARCH	
	ASSISTANT TO STAFF DIRECTOR	
	STAFF DIRECTOR	
Approved: In Process	STATION DIRECTOR	
Concurred:	DEPUTY CHIEF FOR RESEARCH	

9. Justification and Problem Selection

This document outlines the future direction of forest research conducted by Research Work Unit (RWU) NE-4104 of the Northeastern Research Station, U.S. Department of Agriculture (USDA) Forest Service. The unit is located at the Forestry Sciences Laboratory in Durham, New Hampshire. RWU-4104 historically evolved as a unit that conducted research on sampling and forecasting forest attributes, including traditional growth and yield model development. Modeling has evolved over the last several decades to include processes and morphology, and to consider new variables such as carbon. In addition, new scientists with expertise in conducting research and assessments on carbon issues have joined the unit. The RWU mission statement reflects the urgency within industry, government, and the scientific world to understand, accurately report, and manage how carbon moves through and accumulates in forest ecosystems and products.

Issues of measuring and possibly enhancing forest carbon sequestration have attracted the attention of government policymakers, industrial and non-industrial landowners, conservation groups, and the scientific community. A number of companies are already trading carbon sequestration credits. The US scientific community will address many of these issues in the forthcoming "North American Carbon Program" (NACP)[1]. The research agenda of RWU 4104 is focused on gaining new knowledge, developing new models of carbon sequestration processes, and analyzing trends in US forest carbon storage in U.S. forests. This work will contribute towards meeting USDA Forest Service and Northeastern Station research goals, and will also contribute to the NACP.

Background and problems. Atmospheric carbon dioxide (CO_2) has increased dramatically since the Industrial Revolution, principally owing to the combustion of fossil fuels, and has affected climate and plant metabolism worldwide. However, less than half of the CO_2 emitted has remained in the atmosphere. The remaining part has been taken up and stored as organic matter in vegetation, soils, and river basins on land, or as organic sediments or dissolved bicarbonate in the sea. Measurements suggest that much of the terrestrial global uptake of CO_2 may be in North American forests, although the conclusion is controversial because the models and data are inadequate. Understanding the role of forests in CO_2 uptake is critical for knowing how the Earth's atmosphere and climate will evolve in the future, and for determining short-term mitigation options and long-term solutions to likely problems.

Atmospheric methane (CH_4) is second to CO_2 as an anthropogenic greenhouse gas. Concentrations of CH_4 have nearly tripled since 1700, but the rate of change has varied over time. Wetlands are a source of atmospheric CH_4 but forest soils may serve as methane sources, and forest products discarded in landfills may emit CH_4. Because of the expected small role of forests in methane emissions, and because of the ongoing work in this Unit on CO_2, CO_2 will continue to be the greenhouse gas focused on over the period of this RWU description.

To answer these basic questions, **information and models of plant and ecosystem carbon processes (photosynthesis, respiration, allocation, etc.) are needed to provide the scientific basis for sound carbon management decisions and policies. (Problem 1).** We are presently unable to account for observed interannual variability in forest carbon uptake and loss and do not understand how the component processes of photosynthesis, respiration, translocation, and allocation interact with the environment to affect carbon storage. A better understanding of these processes will provide the scientific underpinnings for sound management prescriptions designed to enhance carbon sequestration or minimize carbon loss from forestry practices. This knowledge will contribute to policy formation for enhancing carbon storage and for improving air quality.

Carbon stocks, the aggregate sums of carbon stored on land (organic matter in vegetation and soils or stored in harvested wood) and in the oceans (e.g., organic or inorganic carbon in the water column or sediments), include economic resources such as timber. Changes in stocks can also either moderate or amplify atmospheric CO_2 increases. Any possible efforts to manage carbon through sequestration of atmospheric CO_2 in terrestrial systems require observations and models to verify changes in stocks. International agreements to manage carbon also need reliable data on changes in carbon stocks and uncertainties of the stocks and changes at the national scale. Projecting future U.S. forest carbon budgets is also important for providing information to aid policymakers planning programs and activities to mitigate atmospheric greenhouse gas emissions. The important factors for the forest carbon budget at the national scale are management; disturbances such as fire, insects and wind; and land use and environmental change. Thus, **research is needed to develop comprehensive historic, current, and projected estimates, including estimates of uncertainty, of national-level forest and forest-related carbon stocks and stock changes under a variety of management, disturbance, land use change, and environmental scenarios (Problem 2).**

Carbon at the national-level is also a sustainability issue. The USDA Forest Service works within a broader interagency group for reporting the state of the nation's forests. This group has adopted the Montreal Process Criteria and Indicators as the framework for reporting. RWU NE-4104 currently has the leadership role in this effort for one of the seven Montreal process criteria for sustainability: Criterion 5—Contribution of forests and forest products to the global carbon cycle. This RWU also provides the leadership role in estimating the greenhouse gas emissions and carbon sequestration association with U.S. forests and forest products annually since 1990 for the U.S. Environmental Protection Agency (EPA) Greenhouse Gas Inventory Report. Industry has recently shown a renewed interest in managing for forest carbon.

Quantitative uncertainty analyses are necessary for users of Forest Service research covered in Problem 2 to successfully apply assessments of U.S. forest carbon budgets to diverse goals such as climate policy development or project-level forest management. Uncertainty analyses of the system of models employed to estimate carbon budgets include: identifying or defining uncertainty; quantifying uncertainty for individual elements as it propagates through the system; and assessing influences on uncertainty. The ultimate goals of such analyses are to reduce uncertainty and provide usable information for policy and management.

Information is also needed about carbon stocks and carbon stock change for managing forest stands and forests at scales that aggregate to the national-level. Research is needed to **develop methods for estimating, monitoring, and forecasting changes and trends in forest and forest-related carbon stocks, and provide related tools and information for sustainable management of forests (Problem 3)**. Quantitative methods, particularly in the areas of sampling, modeling, and uncertainty analysis, provide results that are repeatable, objective, and scientifically-based.

Research in scientific sampling aims to provide methods to estimate quantities of interest with minimal error and expense, be it for research or management purposes. In studies of forest carbon dynamics, quantities of interest range from rates of gas exchange at the organ-level to stocks of carbon and rates of exchange between the biosphere and the atmosphere at the regional-, national-, and global-levels. Managers and researchers need methods that provide reliable and statistically defensible estimates of carbon and nutrient stocks for each component of the ecosystem, including belowground components. Also of interest are efficient methods to gauge the success of treatments to reduce forest-fire fuel loads.

The use of models in forestry is widespread, including amongst forest managers and field foresters. Examples abound and include the familiar stocking guides, growth projection methods, and reverse-*J* diameter distribution curves. However, as forestry evolves and forest managers must account for new and more integrated concerns such as spatial harvest scheduling restrictions and sustainability criteria, more complex and flexible models are required. Changing climate, land use regulations and increasing environmental restrictions all factor into the need for more innovative modeling approaches. Model adjustments for unforeseen management regime changes, for example, should be able to be handled at the time of the intervention. Methods that handle such changes, planned or unplanned, as new information arrives are essential to the future of sound forest management.

Uncertainty considerations are essential elements of sampling, modeling, and application of Forest Service research by clients outside of the Agency. Identifying the value of information, with the ultimate goal of reducing uncertainty in samples and model output will improve support for management and policy decisions. Quantitative uncertainty analysis is commonly used to identify contributions of the parts of a system to the whole and to express a level of confidence or expectation in numerical quantities. In other words, quantitative uncertainty analysis allows us to forecast the probability of an event or outcome.

Benefits and likelihood of solving the problems

Results from Problem 1 research will be of value to other researchers, program managers, and industrial land managers, and will help inform policymakers. The work will also directly contribute to the success of the NACP. Successful completion of Problem 1 will result in new knowledge and models of use to the scientific community, forestland managers, and resource management and energy policymakers. The scientific community and NACP will benefit from measurements and predictive models of plant and forest carbon uptake and loss. These data and models will help achieve the NACP goal of understanding and quantifying regional and national patterns of C uptake and loss. Successful completion of Problem 1 will allow us to inform land managers about the consequences of likely or potential management decisions on forest carbon sequestration. Policymakers in the Forest Service, Department of Energy (DOE), EPA, other agencies, and in Congress will be able to better predict the consequences of policy decisions on land carbon uptake.

Information produced as a result of Problem 2 research is of immediate importance to a number of users. Estimates of the U.S. forest sector carbon budget are needed for the United States to report to the Montreal Process on Sustainability. Criterion 5 consists of three indicators on the contribution of forests and forests products to the global carbon cycle. These will be included in a report on the "State of the Nation's Forests", produced by an Interagency Group including the USDA Forest Service. In response to the United States ratifying the United Nations Framework Convention on Climate Change in 1992, the U.S. Environmental Protection Agency must publish an annual "Greenhouse Gas Inventory of Emissions and Sinks", including carbon sequestration by forests. The State Department has also required this information during international greenhouse gas treaty negotiations. Ecologists and atmospheric scientists need this information for balancing the global carbon cycle.

If Problem 2 is solved, the immediate net benefit to users is that reporting requirements can be met using reliable estimates. Knowing that the US forest carbon budget is correct will contribute greatly to narrowing uncertainties in the global carbon cycle. This information provides scientists with real clues for determining the processes in the global budget. Knowing how management and other effects impact the C budget allows the U.S. government to optimally plan for reducing net CO_2 emissions to the atmosphere. This information will be useful for providing options for sustainable management of forests. The research effort will likely provide solutions to this research problem, because of the increases in knowledge, computing power, and remote sensing technology, and improvements in the USDA Forest Inventory & Analysis design. However, the estimates will still include uncertainties, particularly in the projections for the future.

Addressing the uncertainty component in Problem 2 will provide information required by users, and enhance the overall transparency of carbon budget estimates (that is, it helps identify how parts are related). The U.S. EPA is a major user of the forest carbon budgets developed by this RWU, and the information provided must meet standards set by the Intergovernmental Panel on Climate Change (IPCC). Both organizations view quantitative uncertainty analysis as an essential part of reporting greenhouse gas (carbon) inventories[2].

We anticipate success in applying quantitative uncertainty analysis methods to carbon budget projections. Such analyses can define the value of information contributing to an assessment; we can incorporate new information to update carbon budgets as we identify useful models or data. Such an iterative process is a characteristic of applied science, and a measure of its success is its contribution to management, policy, or the direction of future research. Similarly, a possible indicator of our success in addressing uncertainty in forest carbon budgets will be an evolution, or change, in the questions asked. Persistently addressing the same questions is an indicator of limited success.

Results from research on Problem 3 will be of value to forest managers, foresters, other researchers, USDA, DOE, USDA Forest Service Forest Inventory and Analysis (FIA), and will help inform carbon policymakers. A part of the President's Climate Change Initiative includes improvements to the current voluntary emissions reduction registration program under section 1605(b) of the 1992 Energy Policy Act. This effort involves several departments and agencies of the federal government [DOE, EPA, DOC (Commerce), and USDA]. USDA is revising the accounting rules and guidelines for agricultural greenhouse gas activities, and the USDA Forest Service is making the revisions for forestry activities. This RWU was chosen to update the set of forest-level carbon budget default tables, which are principally used in economic and regulatory/planning models. When completed, these will be the standard set of carbon budgets used in this Interagency effort. As the completion of this work is required, the likelihood that it will be accomplished is high. The carbon on-line estimator (COLE)[3] is a tool that will make carbon statistics available for the estimates at scales including the entire nation, state, county, or user-drawn polygons. This effort is linked to Problem 2 accomplishments. Forest industry, FIA, and the USDA Forest Health Monitoring Program have shown much interest, including sponsorship, in this tool.

10. Approach to Problem Solution

Problem 1. Information and models of plant and ecosystem carbon cycle processes (photosynthesis, respiration, allocation, etc.) are needed to provide the scientific basis for sound carbon management policies.

To define the research needed to solve Problem 1, it has been separated into two elements: modeling plant and stand processes and whole ecosystem studies.

Element 1 – Modeling plant and stand processes.

Since the mid-1980's, there has been much progress in the development of relatively simple process models based on carbon-balance and pipe-model theory (e.g., CROBAS and Pipestem) that describe and forecast carbon allocation and accumulation at tree and stand levels. These "pipe models" have proven very useful for analyzing and comparing different physiological theories of stand development. Because of their simplicity, these models also have potential applicability in the management of carbon stocks and in forecasting the effects of management activities on forest carbon dynamics. More importantly, they also provide detailed tree-level information. In recognition of this potential, IUFRO recently established a working group devoted to the advancement of "process models for forest management." Our RWU is developing a computer platform called AMORPHYS, which contains the process model in a form that can be used by managers. However, the full potential of this platform to aid management at the stand or forest level will be realized only after (a) the nitrogen-balance is incorporated into the process model and (b) efficacious calibration procedures are worked out.

Approach:
Tree response to nitrogen (and other nutrient) levels in CROBAS and Pipestem has been successfully modeled under an assumption of functional balance. However, both of these models originally were developed for softwoods. Other models have assumed that photosynthetic production is a function of variable foliar nitrogen concentration. To synthesize the two approaches, an adaptive hypothesis will be pursued with general constraints that may apply to a wide range of species. Data from the literature will be used for testing the hypotheses. This work will be accomplished jointly with Dr. Annikki Mäkelä, University of Helsinki.

In the most fundamental sense, the parameters of management-oriented process models comprise morphological ratios and specific metabolic rates. A model may be calibrated by measuring or estimating these fundamental parameters at each location of application. Estimation may entail either sampling in the time domain or process modeling at the level of photosynthetic production, or both. The modeling approach has required such detailed physiological and environmental information that application of the resultant tree- or stand-level model becomes impractical for management purposes. However, we have demonstrated, under a few simplifying assumptions, that the fundamental parameters of our models combine into identifiable sets of aggregate parameters, which can be estimated by statistical procedures. We will investigate Bayesian procedures with the aim of using a combination of mensurational data, known physiological characteristics, and environmental information to facilitate calibration.

Accomplishments planned in the next 5 years include:
1. A derivation of an optimal control model of plant carbon and nitrogen balances and its incorporation into AMORPHYS. The optimal control model is intended apply generally to both gymnosperms and angiosperms, providing new theory to (a) assist in the interpretation of nutrition experiments and (b) provide a more complete scientific basis for the modeling of forest growth and sustainability.

2. Bayesian estimation (calibration) of the tree-growth parameters of AMORPHYS, utilizing a mixture of physiological and empirical data. This is one step of the methodology needed to develop AMORPHYS for application.

Element 2 – Whole ecosystem studies.

Carbon sequestration in a forest ecosystem represents the difference between photosynthetic uptake and respiratory losses. These processes are affected by environmental and biological conditions in complex, nonlinear ways. To study these processes we measure CO_2 exchange of these component processes as well as in the aggregate. Additional measurements of forest structural characteristics (e.g. species composition, biomass, leaf area index), soil parameters, and meteorological variables are being taken by Unit personnel and colleagues from the University of Maine and the Woods Hole Research Center. Specific studies are listed below in planned accomplishments. RWU4104 is requesting funding to continue to conduct measurements at the control tower. This will insure control measurements, which currently rely on external funds. Measurements at all towers are used to develop, parameterize, and test models of ecosystem C exchange.

Approach:
Area averaged, whole ecosystem CO_2 exchange can be measured on a temporal scale ranging from seconds to years with the micrometeorological technique of eddy covariance. Carbon exchange from ecosystem component pools (such as soils) can be measured with chamber systems. RWU 4104 researchers have been at the forefront of applying these methods to the study of forest C exchange and sequestration. In collaborative, externally funded projects, we will continue studies of the causes of interannual variability of forest carbon uptake in a commercial, softwood forest (the Howland forest AmeriFlux site) in central Maine. With collaborators from the University of Maine, University of New Hampshire, Woods Hole

Research Center, International Paper Company, and others, we will also carry out experimental, whole-ecosystem manipulation studies to test our knowledge of how nitrogen inputs and harvest practices affect forest C sequestration.

One of the key questions of the NACP relating to the study of ecosystem carbon sequestration is how results from research towers that have a natural spatial scale of a few tens of hectares can be scaled up in a meaningful way and applied to large regions. We will address these issues in a collaborative study with workers from Harvard University. This study will use models to integrate data from aircraft flights, a tall tower, and the Howland site as a test of some of the concepts to be applied in the NACP.

Accomplishments planned in the next 5 years include:
1. An analysis of the sources of interannual variability in forest carbon sequestration will be completed. A data record will be created, and predictive models of plant and forest carbon uptake and loss will be developed. This work is a collaborative project with researchers from the University of Maine and the Woods Hole Research Center.

2. Assess the impact of anthropogenic nitrogen on forest carbon exchange processes and carbon sequestration. RWU 4104 leads this DOE funded collaboration consisting of researchers from the Universities of Maine, New Hampshire, Georgia, and Colorado, and the Woods Hole Research Center.

3. Determine the impact of a shelterwood harvest on carbon sequestration in a spruce-hemlock forest, contingent on continued external funding. Operating costs are supported by the DOE in collaboration with International Paper, Ltd., the University of Maine, and the Woods Hole Research Center.

4. Determine how results from eddy-flux towers can be scaled up in a meaningful way and applied to large region, using data collected over northern Maine and adjacent parts of Canada in collaboration with researchers from Harvard University and the University of New Brunswick.

<u>Environmental Consideration for Problem 1:</u> Fieldwork is expected to be carried on privately-owned forests and have no impact on soil stability, water quality, or sensitive resource values. The research is therefore covered under FSH 1909.15, Chapter 30, "Categorical Exclusion from Documentation in an EIA or EA". Where there are environmental concerns regarding particular studies, these will be evaluated within individual study plans. If needed, Environmental Assessments or Environmental Impact Statements will be prepared with and approved by cooperating District or Forest staffs.

Problem 2. Research is needed to develop historic, current, and projected estimates, including estimates of uncertainty, of national-level forest and forest-related carbon stocks and stock changes under a variety of management, disturbance, land use change, and environmental scenarios.

To define the research needed to solve Problem 2, it has been separated into 2 elements.

Element 1 – Determine estimates of carbon stocks and stock changes (including carbon in harvested wood) under a variety of management, disturbance, land use change, and environmental scenarios.

The current research approach to produce national level carbon budgets is to use USDA Forest Service Forest Inventory and Analysis data, coupled with the FORCARB2 modeling system. Improvements and updating of data and models are continually needed. Research on future projections of carbon budgets involves work with the Resource Planning Act (RPA) Timber Assessment models at the USDA Forest Service Pacific Northwest Research Station (PNW). Future research will augment these approaches by incorporating geographic information system software and remote sensing techniques, through partnerships with collaborators. Most of the research will focus on CO_2 dynamics. A comprehensive carbon budget, however, would also include estimates of CH_4. Currently, CH_4 estimates are calculated for carbon in landfills from discarded wood products. Development of CH_4 emissions estimates for US forests will be undertaken if collaborative opportunities arise later in the 5-year period of this RWUD.

Accomplishments planned in the next 5 years include:

1. Complete work on base estimates of US forest carbon stocks and stock changes from 1953 to 2002, with projections through 2050, including forest products. Results must be transparent, well-documented, and verifiable.

2. Conduct scenario analyses to determine future impacts of changes in management, disturbance regimes, and environmental scenarios as compared to the base scenario.

3. Develop a method to produce annual rather than periodic estimates of historical and current national-level forest carbon budgets. Annualized FIA data, if available, will be incorporated into the estimation method. Approaches to provide estimates of non- CO_2 greenhouse gases will be explored.

4. Evaluate new techniques and methods for improving the spatial resolution of the estimates, and produce county-, state-, and eco-region estimates that are consistent with national estimates.

5. Produce reports on national carbon estimates as required and funded in response to national needs.

6. Complete contributions to the Intergovernmental Panel on Climate Change's effort on Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. This activity involves writing sections on methods to estimate carbon changes in dead wood, forest floor, and soils in forests and land becoming forests; reviewing and providing text and default factors for other forest carbon pools, reviewing other chapters on agriculture, grasslands, non-CO2 greenhouse gases, and uncertainty; working with scientists and analysts from other nations; and attending international meetings. The final document should be completed by December, 2003.

Element 2 – Determine uncertainty of carbon stocks and stock changes, and improve estimation techniques through the use of uncertainty analysis.

Uncertainty analyses for the carbon estimation models that constitute FORCARB2 are being developed using Monte Carlo simulations, as discussed below in Element 3 of Problem 3. This approach facilitates improved estimation by identifying variables with the greatest influence on uncertainty, which then leads to incremental model improvements. Explicitly accounting for covariability of uncertainties in the separate parts of the carbon budget estimation process is an important characteristic of uncertainty analysis. This same approach to linking parts is extended to incorporating new information, such as from other models.

Accomplishments planned in the next 5 years include:

1) Complete a quantitative uncertainty analysis of the current system of inventory data, forest projections, and empirical carbon estimation models to describe uncertainties for the US forest carbon budget.

2) Extend the assessment of U.S. forest carbon stocks and flows to incorporate information from a range of alternate forest models.

3) Scale forest carbon budgets to provide stand-level as well as national carbon estimates.

Problem 3. Develop methods for estimating, monitoring, and forecasting changes and trends in forest and forest-related carbon stocks, and provide related tools and information for sustainable management of forests.

To define the research needed to solve Problem 3, it has been separated into three elements: sampling, modeling, and uncertainty analysis.

Element 1 – Sampling

RWU scientists and colleagues have broad expertise in design-based methods for sampling both discrete and continuous populations. Design-based, double-sampling approaches will be investigated for the estimation of stocks of coarse woody debris with the aim of increasing the efficiency of these point methods. Adaptive sampling procedures will be investigated for the estimation of stocks of fine woody debris (also known as fine fuels). The vertical profiles of foliage and branches in a canopy may also be estimable with double sampling procedures. These profiles and the inherent stocks of foliage and branches are essentially vertical fuel profiles; however, they can also be used to gauge gross production rates in process-based models. Funding opportunities may lead to additional areas of focus.

Designs and estimators will be developed from theory. The unbiasedness of estimators will be proven, if appropriate. Protocols will be developed and time trials conducted, both locally and in selected mountainous areas of the west that feature heavy fuels loading. Analyses and simulations will be conducted to optimize sampling efficiency, balancing cost and sampling error. Workshops will be conducted and a textbook will be written to facilitate technical transfer.

Accomplishments planned in the next 5 years include:

1. A textbook for students and researchers: "Sampling Techniques for Natural and Environmental Resources." To be published by CRC Chapman Hall.

2. Sampling methods for coarse and fine woody debris: development, field, and simulation testing. Double sampling strategies for more efficient estimation will be included.

3. Integrated software system written in Java (platform-independent) for analyzing data from various coarse woody debris sampling designs.

4. Regional workshops on the application of estimation methods for coarse woody debris in collaboration with colleagues at University of New Hampshire and RWU 4155.

5. National workshop on the Tier 3 approach (see NACP), and contribute to documentation on protocols.

Element 2 – Modeling

Research in this element will focus on developing new techniques for modeling various interconnected elements within the forest ecosystem. Research will focus on methods for modeling changes and trends in both short- (e.g., FIA periodic and annual data) and long-term (e.g., growth studies, tree-ring and climatic series) temporal measurement series. For example, changes in treatments in long-term experiments such as the RWU NE-4104 density study at the Bartlett Experimental Forest in New Hampshire, equates to a change in regime in the management specifications. Likewise, the interplay between climatic (exogenous) and stand dynamic (endogenous) factors also may create changes in regime with regard to species composition and growth dynamics within managed forests. Models to handle management and disturbance regime changes are currently non-existent in forestry. Methods for the optimal combination of models and the observational sample record can be developed using time-domain statistical techniques. Such methods may be thought of as optimal monitoring and will be developed to be run in real-time (such as in eddy-flux tower experiments—Problem 1) or with the extended data record in hand.

The Unit occasionally receives requests that involve minor programming on the FIBER growth and yield model. Our FIBER programmer will continue to address these requests as funding permits.

Accomplishments planned in the next 5 years include:

1. Bartlett density study, at the Bartlett Experimental Forest, is a long-term (almost 40 years) study of silvicultural manipulation in northern hardwoods established by scientists in RWU

NE-4104. Study records and data will be compiled into a usable form. Analyses will be done on the last 25 years data to produce silvicultural and management recommendations. Remeasurements must also be scheduled and conducted.

2. The first version of the Carbon Online Estimation Model (COLE)[3] is almost completed for producing carbon estimates associated with FIA data online. Version 1 works with older periodic sampling designs. Version 2 of COLE will be completed. It will deal with temporal change and spatial analysis and display as the new annualized data become available. This work is a collaborative project with National Council for Air and Stream Improvement (NCASI) and FIA scientists, with funding from the Forest Health Monitoring Program.

3. With requested funding, a post-doctoral associate, PhD student, or "scientist-in-training", will complete and release an operational version of the AMORPHYS process model of forest growth. This model is intended to produce forecasts of time courses of a large suite of tree- and stand-level variables, including carbon stocks and fluxes, net primary productivity, foliage mass, and traditional timber-related variables. The model will utilize a consistent framework for large regions using data collected by USDA Forest Service, Forest Inventory and Analysis group, and provide land managers with a larger suite of variables. The model will apply to forests of the Northeastern United States.

4. Produce stocking guide models that include information about stand structure to help silviculturists and forest managers practice sustainable management for carbon and other objectives.

5. Tree-ring methods for modeling of long-term responses to temporal stand and climatic changes will be extended, incorporating new developments in statistical theory. These models may be applied to monitor and analyze carbon flux series resulting from long-term research in Problem 1.

Element 3 – Uncertainty

Methods for quantitative uncertainty analysis can be very specific to the system under study. Similarly, definitions of uncertainty can vary. A generally applicable approach to uncertainty analysis is to employ probabilistic definitions of uncertainty and develop analyses through numerical techniques such as Monte Carlo simulations. Defining input uncertainties (as marginal and joint distributions) is often the most difficult step of the process. At times, maximum likelihood estimation or resampling techniques are useful for developing the probability distributions to define uncertainty.

Accomplishments planned in the next 5 years include:

1. Implement improvements to a standard set of forest carbon budget tables as part of the update of forest carbon accounting rules and guidelines needed by the US Department of Agriculture, including estimates of uncertainty.

2. Develop and implement estimates of uncertainty in the COLE model.

3. Integrate the national carbon assessment with site-specific data where such samples are available and integrate location-specific simulation models of forest carbon.

Environmental Consideration for Problems 2 and 3: Research is generally conducted in an office environment, with at most occasional visits in the field. This approach is expected to have no impact on soil stability, water quality, or sensitive resource values. The research is therefore covered under FSH 1909.15, Chapter 30, "Categorical Exclusion from Documentation in an EIA or EA". Where there are environmental concerns regarding particular studies, these will be evaluated within individual study plans. If needed, Environmental Assessments or Environmental Impact Statements will be prepared with and approved by cooperating District or Forest staffs.

COOPERATORS

Scientists from RWU-4101 typically cooperate with non-RWU scientists and personnel to complete the research, development, assessment, and technology transfer tasks. Such cooperation is necessary because the research problems addressed by the RWU are usually large and complex, with many interacting factors. A diverse set of users with a range of skill levels must be considered when developing and disseminating the information and products.

For instance, research conducted on understanding carbon cycling processes often involves contributions by university scientists from the University of Maine, University of Colorado, or the Woods Hole Research Center. Experiments are conducted on industry lands operated by the University of Maine. Project personnel participate in the Ameriflux network to ensure data produced follows accepted scientific standards that maximize potential data usefulness. Research on the national-level forest carbon budget is tied strongly to users in USDA, the US Environmental Protection Agency, and the State Department, with funding from the USDA Forest Service Northern Global Change Program. For the work to continue to be policy-relevant, scientists must devote a significant amount of time to interacting with these users and producing required reports, such as the annual Inventory of U.S. Greenhouse Gas Emissions and Sinks published by US EPA, and in 2003 USDA is now asking for a corresponding more detailed inventory report for forestry and agriculture. Extramural cooperation with other non-governmental organizations such as NCASI, a non-profit forest research organization has proven valuable in the development of COLE, a flexible web-based tool to disseminate carbon estimates to users at scales including national, regional, state, county, and user-defined regions. Development of new techniques to sample down dead wood has been greatly enhanced by scientists from University of New Hampshire, Swedish University of Agricultural Sciences and Yale, with interest from foresters with the State of New Hampshire. Table 1 is a list of cooperators and collaborators working with RWU scientists effective December, 2002.

Table 1. Cooperators with RWU scientists, effective December, 2002.

Cooperators	Location
US Forest Service	
Forest Inventory Results Enterprise	Washington, DC
Rocky Mountain Research Station	Ft. Collins, CO
Forest Health Monitoring Program	Washington, DC
FIA, NE Station	Newtown Square, PA
Forest Products Laboratory	Madison, WI
Northern Global Change Program	Newtown Square, PA
PNW Research Station	Portland, OR
RPA Program	Washington, DC
Southern Global Change Program	Raleigh, NC
Other Federal Agencies	
U.S. Department of Energy	Washington, DC
U.S. Environmental Protection Agency	Washington, DC
Universities	
Harvard University	Cambridge, MA
Oregon State University	Corvallis, OR
Rutgers University	New Brunswick, NJ
Swedish University of Agric. Sciences	Umeå, Sweden
SUNY, ESF	Syracuse, NY
University of Colorado	Boulder, CO
University of Georgia	Athens, GA
University of Maine	Orono, ME
University of Minnesota	St. Paul, MN
University of New Hampshire	Durham, NH
University of Helsinki	Helsinki, Finland
Virginia Tech. Univ.	Blacksburg, VA
Yale University	New Haven, CT
Non-Governmental Organizations	
National Council on Air and Stream Improvement, Inc.	Lowell, MA
Woods Hole Research Center	Woods Hole, MA

STAFFING

Table 2 lists the current staffing in the RWU; Table 3 lists the RWU funding for the last 3 years.

Table 2. Current (2003) staffing in RWU 4104.

Position Title, Series	Grade	Perm/Term/Temp	Number of Positions
Biologist, 401	9	Term	1
Programmer, 2210	12	Perm	2
Research Biologist, 401	12	Term	1
Research Forester, 460*	14	Perm	3
Research Plant Physiologist, 435	1-12 1-14	Perm	2
RWU Coordinator, 301	9	Term	1

* One of the Research Foresters serves as Project Leader.

Table 3. RWU funding ($000) for each of the years 2000-2003.

Fiscal Year	Direct Appropriations	Funding From Other NE Units	Outside Funding Used by Unit*	Total
2000	540	437	145 (+17 OH)	1,122
2001	564	460	688 (+58 OH)	1,712
2002	578	496	576 (+57 OH)	1,650
2003	601	388	864 (+64 OH) (anticipated)	1,853

*Funds from successful proposals used for cooperative agreements, operating funds, salaries for terms, with amounts for overhead (OH) listed separately.

Table 4 (see next page) lists the distribution of the estimated average RWU scientist-years and costs needed through the 5-year RWU lifetime for each problem to be considered fully funded. This research will require an average of 6.5 scientists per year, at an average annual RWU cost of $2,138,000, along with some additional funds to be obtained externally through successful grant proposals. The advantage of relying on some successful grant proposals is that they often bring additional support from clients, and they allow us to leverage available funds to conduct more research now. However, funding is contingent on: available requests for proposals on topics related to our work; rules which allow for federal agencies to qualify to use the funding, or arrangements with our collaborators to use the funding; being successful at being awarded the funding; and, having time to write the proposals.

As the budget allows, personnel requirements above the proposed ten permanent FTEs will be met through the use of temporary technicians, post-doctoral term positions, or cooperative agreements and graduate students. Exact personnel needs depend on the specific needs of our research clients. An additional consideration is that one of the scientists will consider retirement in approximately 5 years. The RWU must plan for his knowledge and skills to be carried on, with possible outreach or development of another scientist (or other scientists) to continue work in this research area.

Table 4. RWU scientist full-time equivalents (FTEs) in each problem area over the five-year planning period, and required funding.

Research Problem Area	RWU scientist FTEs for each year of the RWUD				
	1	2	3	4	5
P1—Processes of forest carbon cycling	1.5	1.5	2.0	2.0	2.0
P2—National-level forest and forest-related carbon stocks and stock change	2.5	3.0	3.0	3.0	3.0
P3—Methods and tools for estimating, monitoring, and forecasting for sustainable management	2.0	1.5	2.0	2.0	2.0
Scientist FTEs	6	6	7[b]	7	7
Support FTEs	4	4	4	4	4
Total RWU budget ($000)	2,045	2,045	2,200	2,200	2,200

[a] All cost estimates include overhead of 25%; [b] New FTE is a scientist-in-training, or "junior" scientist ($100K). This scientist will be added only if the level of direct appropriations increases sufficiently.

If the requested level of funding is not achieved, the number of employees in the Unit will eventually drop back to the number of permanent employees listed in Table 2. If no additional funding is achieved, permanent employees will be lost through attrition, and no additional employees will be hired to replace them. If the requested level of funding is not achieved in this five year period, we will hire no term scientists, or cooperative agreements will be reduced, resulting in eliminating annual reports on national-level forest carbon estimates, eliminating or delaying further development of an operational version of AMORPHYS, eliminating publications and development on the COLE web tool, limiting field testing of new sampling methods on coarse woody debris, delaying scenario analyses of the US forest carbon budget, and limiting participation in ongoing or new special assignments. Scientists will do more administrative tasks as less support staff will be available.

Funding at a level higher than stated will result in a higher probability of success for publications, especially for the whole ecosystems studies. More funding translates into less time spent not developing grant proposals, freeing up time to complete the research. Additional funding would also be directed at technology transfer of existing research or at raising the public's awareness of our research. Higher funding could permit greater participation in North American Carbon Program-related activities.

Endnotes:

1. Wofsy, S.C., and R.C. Harriss. 2002. The North American Carbon Program (NACP). Report of the NACP Committee of the Interagency Carbon Cycle Science Program. Washington, DC: U.S. Global Change Research Program. 56 p. http://www.carboncyclescience.gov.

2. See *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, IPCC 2000; *Procedures Manual for Quality Assurance/Quality Control and Uncertainty Analysis,* USEPA 2002.

3. See http://www.fs.fed.us/ne/durham/4104/products/cole.shtml