RESEARCH WORK UNIT DESCRIPTION Ref: FSM 4070	1. Number FS-SRS-4703	2. Station Southern Station
	3. Unit Location Auburn, Alabama 36849	

4. Research Work Unit Title
Forest Operations Research to Achieve Sustainable Management

5. Project Leader (Name and address)
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6. Area of Research Applicability	7. Estimated Duration
National	5 years

8. Mission

To provide the science and technology integrating ecological and engineering disciplines to achieve economically and ecologically-viable forest operations which are necessary for sustainable and socially-acceptable forest resource management.

9. Justification and Problem Selection

Forest operations are the critical connection between the forest management plan and the realization of desired future conditions. Forest operations are the physical actions which change the forest, altering structure, composition, condition, or value in order to meet society's needs for clean air and water, forest products, wildlife, recreation, and other benefits. On every type of forest ownership, the forest operation is the tool selected by the land manager to shape the future and provide value and benefits in the present. Forest operations are the source of both the benefits of management and the negative impacts. Forest operations generate value for society through improved forest conditions and product outputs. They also impact ecological processes and leave an imprint on the landscape.

The basic challenge facing resource managers is matching the requirements of the management plan to the capabilities of the forest operation. Modern resource management involves the consideration of a wide variety of factors and often seeks to optimize the attainment of multiple objectives. Protecting water quality while enhancing carbon sequestration and producing economically-competitive forest products might serve as an example. There is not adequate information available for resource managers to make rational selections of forest operations in new prescriptions. In some cases, technology has not yet been developed to meet the functional requirements of management prescriptions within economic and social constraints. In other cases, even basic scientific knowledge about the interactions among modern forest operations systems and ecological processes is inadequate to define technology and development needs.

Signature	Title	Date
Recommended:	Assistant Director for Research	
	Assistant to Staff Director	
	Staff Director	
Approved:	Station Director	
Concurred:	Deputy Chief for Research	

The challenge of advancing forest operations science and technology is particularly critical in the southern United States. With approximately 40 percent of the nation's timberland, the South is currently producing two-thirds of nation's pulpwood, about half of its plywood and hardwood sawtimber, and 43 percent of the softwood sawtimber. Reductions in commodity output in other regions have dramatically increased pressures on the southern forest resource. At the same time, regional population growth is applying increasing demand for recreation and resource protection on public lands. As forest use increases, the impacts of forest management are of greater concern. Permitting for new forest products facilities has been denied on the basis of anticipated cumulative landscape-scale effects. The efficacy of water quality regulations is being questioned and voluntary BMP's are being reconsidered. With over 70 percent of the southern forest in private ownership, management solutions must be developed for a wide range of scales and conditions. Terrain and forest type in the 13 southern states range from hardwood swamps to Appalachian mountain stands to the piney woods of east Texas to the drained pocosins in the Carolinas. The diversity of forests, terrain, social values, management practices, ownerships, and markets presents complex demands on forest operations. Increasing demands for forest benefits, coupled with increasing concern about the negative effects of forest management are highlighting the need for a wide range of management tools (forest operations).

While the focus of the planned research work will be in the southern United States, forest operations across the nation face many common challenges. Environmental impacts, equipment performance and costs, and advanced technology and planning tools are research topics that have application beyond the southern region. Where appropriate, a national perspective will be developed to permit application of research results to other areas of the country.

For the last 30 years, this Research Work Unit has been providing new techniques, technologies, and basic science to improve forest operations. Building on this body of knowledge and research capabilities, new advances in forest operations will be pursued in four new problem areas.

A basic requirement to improve forest operations is to develop a better understanding of the effect of forest operations systems on the ecological processes of forest ecosystems (Problem 1). Fundamentally, forest operations are designed to produce changes in ecological conditions and processes. Therefore, it is essential to have basic knowledge about how forest operations affect ecosystems. Particular concerns center on the machine/soil interaction, soil productivity, erosion, hydrology, and water quality impacts, and disturbance of vegetation. New perspectives on the spatial and temporal dimensions of ecological disturbance resulting from forest operations are required. This information is vital to inform policy decisions about regulating the impacts of forest operations. For example, critical policy decisions such as new water quality regulations are being debated without sufficient scientific basis. Restrictions on various forest operations are proposed based on limited understanding of the complex alternative impacts which may occur. Current debate over thinning to reduce fire risk in the western United States, for example, must compare the impacts of wildfire to potential interventions. The basic science data is also important foundational knowledge to guide the development of mitigation techniques and application guidelines. Findings should be valuable to land managers in estimating the effects of prescribed operations. The results of these studies will also be directly applied by other scientists and policymakers.

Based on an understanding of ecological processes, new and innovative methods and technologies must be developed to reduce or eliminate the ecological impacts of forest operations (Problem 2). Best Management Practices (BMPs), for example, are current recommended methods to prevent or minimize water quality impacts of forest operations. In the southern U.S., these guidelines are mostly voluntary. Many western states, in contrast, have strict Forest Practices Acts with mandatory requirements. In many cases however, the scientific basis of BMPs, whether mandatory or voluntary, is lacking. Research needs to be conducted to understand the validity and applications of existing guidelines. In addition, new technologies such as soil amendments, erosion control techniques, and low-impact management methods in riparian zones, offer potential improvements in managing the impacts of forest operations. New knowledge can inform the development of improved BMPs. Forest access designs for roads and trails are another critical element of total management impacts. Information on the efficacy, cost, and application of methods to minimize impacts will be useful to policy makers, land managers, contractors, and other scientists. This research will result in improved methods and guidelines and ultimately reduced adverse impacts from forest management.

Selecting appropriate forest operations to achieve management goals requires better information about the performance, cost, and operational ranges of new and existing forest operations systems (Problem 3). Resource managers face increasingly complex management situations. Constraints of partial cutting, multiple-entry operations, changing diameter distributions, smaller tract sizes, maximizing utilization, and new product specifications place new demands on forest operations. Managers must have practical, cost-effective forest operations tools to manipulate the forest and achieve desired conditions. However, there is a lack of scientific information about the outcomes of prescribed manipulations with new management conditions as well as the application of new technologies to meet management needs. National Forest managers, in particular, are proposing unique prescriptions designed for ecological objectives rather than conventional commodity output. Management guidelines for salmon protection in the Northwest or red-cockaded woodpecker habitat in the South define desired forest conditions. Forest operations are complex systems of people, equipment, and techniques interacting with the complexity of naturally varying ecosystems. Research is needed to define how forest operations perform across the range of forest conditions. Studies of new technologies such as fuel reduction treatments and systems for sensitive sites need to be conducted to establish production expectations. Research is also needed to evaluate alternative techniques for forest access including road construction and obliteration. From the land manager's perspective, costs are important determinants of treatment feasibility. From the contractor's perspective production and costs are important variables in maintaining financial health. Costs also affect the competitiveness of the forest industry in a global economy. All of these users need better information on performance and economic factors in order to effectively control the costs of forest management through appropriate selection and application of forest operations. In addition, a better understanding of productivity, costs, and performance across a wide range of operational conditions can lead to the development of more efficient systems or highlight the need to pursue innovation in extending the feasible range of existing operations.

Finally, in addition to selecting equipment and operations, the complex prescriptions of sustainable management require new approaches to acquire and utilize site-specific information in the planning and management of forest operations (Problem 4). Modern forest management recognizes the variation and complexity of natural landscapes. Prescriptions are increasingly complex as they become more site-specific. Rather than a blanket application of even-aged management, new prescriptions recognize and consider a wider range of factors. For example, maintaining ecological processes may require delineation of buffers, adjacency considerations, gradients of treatment, identification of point features which must be created or maintained. The information density of current prescriptions is higher than ever before. In order to effectively manage operations in this new environment, information must be acquired, manipulated, and applied to monitor and control operations. New technological advances in computer-aided decision support tools, remote sensing, and equipment monitoring provide tools to process information. Tools need to be developed to support the entire range of forest operations from access development, operation scheduling, to tactical operational management and monitoring. However, practical applications are mainly undeveloped. Research needs to be conducted to determine the feasibility of collecting and utilizing various types of information. This problem area will provide tangible tools and methods to increase the efficiency of forest operations. The findings will be utilized by other researchers as well as managers. Improving the use of information in forest operations will reduce costs and impacts through more efficient operation.

10. Approach to Problem Solution

Problem 1. Develop a better understanding of the effect of forest operations systems on the ecological processes of forest ecosystems.

Forest operations are prescribed to implement silvicultural management objectives and may affect critical biological, chemical, and physical processes that sustain soil-plant ecosystems. The extent and long-term implications of anthropogenic disturbances through forest operations are not well characterized to fully understand the specific changes and their role in long-term sustainability. Numerous investigations have established relationships among machine systems, machine components, and soil impacts, but an incomplete understanding of the machine-soil interaction and the impact on soil sustainability and productivity still exists. Actions which alter soil physical properties have direct and indirect impacts on the soil's ability to provide essential nutrients, adequate air and water supplies, and the physical framework to support adequate biological response. The overall result can be a loss or reduction of soil and site productivity which cannot be fully restored by mechanical and/or chemical amelioration. A significant challenge exists to understand more completely the complex machine-soil interaction in terms of temporal, spatial, vegetative, site and climatic differences, and to integrate the results into a comprehensive systems approach to management for sustained above and belowground productivity.

Disturbances are imposed on forest systems by forest operations through repeated trafficking and ground-disturbing operations in the course of harvesting, site preparation and regeneration activities. The stresses applied to impacted soils are typically expressed in terms of changes in select soil physical properties including bulk density, porosity, water content and soil strength. These measures of soil compaction often do not fully convey the changes in soil structure and nuturient dynamics which can impact soil nutrient capacity, aeration status, water infiltration, water availability, organic matter sequestration and decomposition, and rooting potential. Soils subjected to compaction experience higher packing density at the expense of large voids favoring the formation of more water holding, or capillary pores, but reducing infiltration, hydraulic conductivity, air exchange, nutrient supply, root growth, and microbial activity. The net result is a soil environment with lowered capacity to supply essential nutrients and water, lowered biological productivity, and increased erosion potential. Tillage systems are employed with greater frequency to improve soil physical conditions for improved air and water infiltration and lowered soil strength but further degradation of soil qualities is often the result with loss of aggregate stability, accelerated decomposition of organic matter, loss of essential nutrients, and exposure of important microbial communities to increased temperature and dessication.

Hydrological impacts also result from forest operations. Removal of vegetation affects evapotranspiration and soil temperatures, altering water cycling in the forest. Soil disturbance can either enhance or inhibit infiltration, affecting overland flow. Vegetative changes and the application of fertilizer or chemicals affect water chemistry. The complexity of water quality impacts requires integrated studies that evaluate multiple variables over several scales from microsite to watershed. Field studies will provide the basic data and process information to validate modeling tools for predicting the effects of forest operations across a range of conditions.

Accomplishments planned for the next 5 years:

1. Evaluate and validate hydrology, erosion and water quality models for application to managing forest operations in the South.
2. Quantify the nature and extent of impacts from forest operations under various management regimes and assess biological significance.
3. Develop more accurate characterization of soil impacts both spatially and temporally as a function of terrain and prescription in various regions of the country.
4. Quantify the effects of intensive management practices on water quality.
5. Develop a better understanding of erosion processes in all aspects of southern forest operations.

Problem 2. New and innovative methods and technologies to reduce the ecological impacts of forest operations must be developed.

Implementing ecologically acceptable techniques and technologies in forest operations depends on a sufficient understanding of the ecological processes in forested lands. Then, based on the functional requirements of ecological factors, new forest operations can be developed which address those concerns.

For example, access is necessary to implement management. However, access represents a significant cost as well as a potential for adverse impacts. Increased awareness and concerns related to forest road sediments and their exclusion from waterways emphasize the need for environmentally acceptable road and stream crossing designs. Innovative access system and stream crossing designs/modifications can provide a feasible balance between environmental and economic trade-offs required for sustainable, forest systems. New approaches such as road obliteration may provide an engineered solution for many problems associated with forest road management. Considering the impact roads have on the forest ecosystem, more work needs to be undertaken to design road systems which are acceptable based on the goal of sustainable forestry practices.

Economically-viable timber production depends on the timely re-establishment of stands, often using extensive site preparation and artificial regeneration. Generally, effective site preparation must create appropriate soil conditions (physical and chemical) and reduce vegetative competition while minimizing undesirable ecological effects. Site preparation, for example, has been cited as a major source of soil erosion and sedimentation on forestlands. It is also an energy-intensive treatment with significant costs. Innovative approaches such as limited-area site prep may provide major cost savings both economically and environmentally. Limited-area site prep allows managers to treat only the specific areas for seedling establishment, thereby reducing prescription costs (labor, fuel, etc.). This form of site prep also confines the necessary site disturbance of the operation to the immediate planting areas, thereby minimizing the environmental impact of the management activity.

In response to requirements of the Clean Water Act, many states established Best Management Practices (BMPs) for forest operations. However, many of these guidelines are based on limited research, applied in conditions beyond their original intent, or do not represent the application of current technology. Filter strip widths, stabilization of exposed soils, and drainage structures such as water bars and turnout ditches, are all BMP subjects which need re-examination. New approaches to erosion control may alter the need for some current BMP practices, for example. Better modeling of sediment transport can provide more refined and site-specific direction on filter strip widths. Recommendations for new BMP's may need to be developed as our understanding of the impacts of forest operations improves.

A specific area of concern is forest management activities in riparian management zones (RMZ). Historically, the most common BMP strategies restricted management activities in RMZs to protect water quality. However, a greater understanding of the dynamics of RMZs has led to the consideration of alternative management strategies. It is possible to actively manage these areas to enhance the ecological functions which protect water quality. Alternative management practices in RMZs such as, partial cutting, physical barriers, and vegetative RMZ enhancement should be investigated.

Accomplishments planned for the next 5 years:

1. Evaluate the effect of alternative management practices in upland sites and riparian zones, including partial cutting, physical barriers, and vegetative RMZ enhancement.
2. Investigate the effectiveness and implementation of BMP's as a function of site factors including slope, soil types, ownership. Develop and improve the scientific basis for prescribed BMPs.
3. Examine the effectiveness of various site prep methodologies including spot and limited-area treatments in ameliorating soil productivity.
4. Evaluate alternative methods of reducing sediment yield from forest access development, use, and obliteration.
5. Compare the effect of alternative forest operations on carbon cycling and emissions.

Problem 3. <u>Better information about the performance, cost, and operational ranges of new and existing forest operations systems is needed.</u>

Every prescription for a forest management activity establishes a set of functional requirements for potential operations. These requirements may include ability to handle certain size material, process certain products, operate on particular slopes, etc. The land manager and contractor must find the "best" match between prescription requirements and system capabilities. What determines "best" is a wide range of tangible and intangible values including factors such as operating cost, labor content, timing and seasonal operability, and social acceptability. Thus, selection of appropriate systems requires extensive information on how current operations perform in new prescriptions, as well as how new technologies may perform. Performance will be measured in terms of factors such as production, energy consumption, labor input, and capitalization.

Some studies may be conducted on a particular machine, while other studies must be conducted with a systems approach to examine interactions among various system functions, overall system performance, and total costs. For example, the interaction between harvesting and site preparation is complex and significant. Site prep must often mitigate the effects of harvesting treatments while creating suitable planting conditions, yet the costs of site prep are seldom allocated back to harvesting.

Fiber recovery efficiency of various forest operations is becoming more important. Increasing demands for products from the southern forest are creating new markets. Merchandizing for value is becoming a real possibility with implications for improving the feasibility of intermediate stand treatments. Research needs to be conducted to determine the optimal place to conduct merchandizing with impacts on nutrient cycling of residues and value recovery. Short rotation hardwoods are a growing source of fiber and energy. These production systems will be studied for their efficiency, cost, and attainment of biological and environmental objectives.

Transportation from woods to processing facility represents nearly half the delivered cost of fiber for forest products. Transportation cost is also very susceptible to variations in energy cost. Optimizing the efficiency of forest product transportation can have significant advantages for industry and society. Determining root causes of transportation delays, developing more efficient scheduling and dispatching methodologies, maximizing merchandizing in the woods, are all potential lines of investigation.

Forest operations face unique demands when prescriptions are applied to small tracts or low-volume stands. In these applications, overhead costs such as moving and downtime become prohibitive. Small-scale forest operations are promoted as alternatives to conventional forest equipment, particularly for uneven-aged management systems. Yet these machines typically have low production rates, limited capacities, and prime movers that are not purpose-built for forest use. Most of the available equipment is also designed for small, uniform softwoods (plantation forestry). Research is needed to evaluate and demonstrate equipment capabilities in uneven-aged applications and mixed stands that will be typical of southern forest management on the vast acreages of NIPF landowners.

Finally, forest operations are business enterprises that employ people. People control the machines, make decisions, and get injured. Forest work is some of the most hazardous industrial work in the U.S. Manual operations, such as many proposed forest health restoration and stewardship activities, are the most hazardous. Research needs to examine issues of operator training, safety behavior and performance, motivation, personnel protection standards, and the total costs of labor in forest management.

Accomplishments planned for the next 5 years:

1. Identify and evaluate the costs and performance of current forest operations technologies across a range of operational conditions that characterize new management prescriptions.
2. Evaluate new systems for operating on difficult or sensitive sites such as wetlands in the South, soft soils in the Lake States, steep slopes of the Appalachians and western mountains, and erosive soils.
3. Examine new technologies which address demands of modern forest operations.
4. Quantify energy consumption in forest operations as measures of total efficiency, carbon emissions, and life-cycle analysis for forest management.
5. Examine forest operations applicable to small and/or low-volume tracts, including small-scale operations and landowner/operator activities.
6. Evaluate the range of forest operations available for fuel reduction and forest health treatments, synthesizing selection and application criteria for managers.
7. Investigate utilization and product recovery of forest operations with particular emphasis on merchandizing and utilization of small-diameter materials, including short-rotation woody crops.
8. Investigate safety of woods work, including the validity of existing personnel protection standards in alternative conditions.
9. Evaluate alternative methods of developing forest access and transport.

Problem 4. New approaches are needed to acquire and utilize information for planning and management of forest operations across landscapes.

The use of computer tools has increased in planning forest management activities concurrently with the development of spatial information technology, particularly GIS and GPS. Planning systems developed using these tools, however, have focused primarily on silvicultural activities and largely ignored implementation issues, contributing to costly misapplication of expensive equipment that does not achieve management goals. The problem is one of scale: forest operations are applied at a site or stand level, whereas silvicultural planning is most often done across landscapes. Methods and technology will be developed for integrating site- and landscape-level planning to seamlessly integrate design of landscapes for multiple objectives while minimizing costs of achieving those goals. Studies will develop new approaches for spatial optimization of landscapes, particularly methods for tactical scheduling of harvesting, regeneration, and road building activities that make efficient use of resources and minimize overall costs.

Previous studies have demonstrated variations in total costs and impacts of forest operations linked to unique site conditions. Specific factors, such as tree density and size, slopes, trafficability and weather conditions, and tract shape or size, can combine in many ways to influence machine and system efficiency, particularly in harvesting. Applying a fixed set of equipment in such fluid conditions can result in inconsistent business performance for both contractors and procurement entities, and therefore higher product costs. Better operational planning tools could help contractors respond to unique conditions in a rational manner, making more effective and efficient use of their investments. Studies will be conducted to develop tools for optimizing application efficiency of equipment on given sites, identifying those factors that most influence effectiveness of operations, and techniques to adapt systems to local conditions. Particular emphasis will be given to development of analysis tools for planning of harvesting operations on a stand level, identifying optimal setting and road locations, and real-time performance feedback systems for operators to tune system-level variables, such as skid distance and bundle size interactions in tree length logging.

Planning is a data intensive undertaking. Acquiring data for planning of forest operations is particularly difficult because of the dispersed, and often remote, location of the activities, and because the variables that need to be monitored are difficult to directly measure. Data acquisition systems and robust, task specific sensors will be developed to measure the performance of machinery in implementing management goals. The systems will be applied in long-term monitoring of key forest operation activities, something that has, until recently, been infeasible because of the expense of the alternative: field crews. Data acquisition systems will be developed to autonomously monitor performance of tree-length logging systems and site preparation activities. The data from these systems will provide a basis for development of models used in planning tools, and a durable record of activities that can be mined at some future date to investigate relationships that are not apparent at the present.

Planned accomplishments for the next 5 years:

1. Develop systems for monitoring productivity and environmental impacts of forest harvesting equipment.
2. Develop models relating site factors and productivity and environmental impacts of forest operations.
3. Use knowledge of landscape impacts on forest operations to enhance silvicultural planning and operational management.

4. Develop decision support tools which integrate discrete machines, activities, and operations to optimize efficiency and minimize impacts

11. Environmental Considerations

Most of the studies under this RWUD are expected to have little or no potential for soil movement, water quality degradation, or impact on sensitive resource values and are therefore categorically excluded from documentation in an EA or EIA as outlined in FSH 1909.15.31. Many studies are observational rather than manipulative, involving documentation of treatments and activities under the direction of other responsible resource officials such as private landowners or National Forests. Where environmental concerns exist, these will be evaluated within individual study plans, or by Environmental Assessments or Environmental Impact Statements prepared with and approved by cooperating District or Forest staffs.

12. Staffing Levels

The research outlined in the problem descriptions will require 6 scientists per year with an annual project budget of approximately $1.2M. An estimate of scientist years and budget per problem area is:

	Year 1		Year 2		Year 3		Year 4		Year 5	
Problem	SYs	$	SYs	$	SYs	$	SYs	$	SYs	$
1	1	250	1	250	1	250	1	250	1	250
2	2	350	2	350	2	350	2	350	2	350
3	1.5	250	1.5	250	1.5	250	1.5	250	1.5	250
4	1.5	350	1.5	350	1.5	350	1.5	350	1.5	350
Total	6.0	1200	6.0	1200	6.0	1200	6.0	1200	6.0	1200

Currently, Unit staffing includes 3 research engineers, 1 research soil scientist, 2 support engineers, 2 engineering technicians, 1 project secretary, 2 STEP engineering aides, and 2 SCSEP enrollees. In the course of research on national priorities in forest operations such as fuel reduction treatments, external funding will be developed to support an additional scientist. Additional funding will also be pursued to provide adequate field and technical support.