DEVELOPING A SPATIAL DECISION SUPPORT SYSTEM FOR TIMBER SALE PLANNING ON A NATIONAL FOREST

by

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(ABSTRACT)

Resource planning on National Forests has become a complex and time consuming process. On the Jefferson National Forest (JNF), *"Opportunity Area Analysis"* (OAA) is used to implement the resource use mandates of the JNF Land and Resource Management Plan. Timber sale planning is an important component of the OAA process that requires the evaluation and analysis of large amounts of site-specific data and complex spatial relationships. Since geographic information systems (GIS) can manage spatial information efficiently, a prototype spatial decision support system (SDSS) was developed that integrates the data, GIS analysis routines, graphical map and tabular displays, and user interface utilities to interactively support the timber sale planning process.

The objectives of this research are: (1) to model the timber sale planning decision process, (2) develop the SDSS model, (3) demonstrate the use of SDSS on a case study area in the JNF, and (4) compare the SDSS approach to current manual methods for timber sale planning.

The SDSS model is structured to assist the planner in four areas: (1) identification of suitable stands for timber sale planning in the opportunity area, (2) evaluation and analysis of environmental and social objectives specific to each candidate stand, (3) economic analysis of the candidate stands, and (4) development of timber sale alternatives for a short term planning period. When compared to the manual methods currently used, the SDSS approach to timber sale planning provides faster access to current resource information, helps define and structure the timber sale planning process, allows flexibility in plan development, and assembles information for map production and report generation. Recommendations for future SDSS research are also discussed.

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CHAPTER 1 INTRODUCTION

Justification

Since the establishment of the United States National Forest System in 1891, forest planning has evolved from a few simple timber harvesting *rules of thumb* to a complex, bureaucratic, and time consuming multiresource analysis process. During the past eight decades of U.S. Forest Service stewardship, various legislative mandates have governed the focus and responsibilities of the agency. Specifically, the Multiple-Use Sustained-Yield Act of 1960, National Environmental Policy Act of 1969, and National Forest Management Act of 1976, initiated a shift in land management planning from traditional single resource administration to integrated interdisciplinary analysis of all natural resources and uses of the forest and range (Iverson and Alston, 1986).

To accommodate this changing environment, the Forest Service employed a *systems approach* in the development of computer-based models for resource planning. The Timber Resource Allocation Method (1971), Multiple Use-Sustained Yield Calculation Technique (1979), FORPLAN (FORest PLANning, 1979), and ultimately FORPLAN Version 2 (1982) gave resource planners a set of management tools for optimizing resource allocation decisions which addressed the changing forest planning process. These allocation models became increasingly complex as the planning process evolved to consider the whole spectrum of resource outputs.

Today, FORPLAN is utilized throughout the National Forest System for developing formal land and resource management plans as mandated by the National Forest Management Act. Criticisms directed at the FORPLAN model focus on its size and complexity and its inability to improve decision making at the local level. Many forest planners find it difficult to develop the input parameters and interpret the results of resource allocations, and in some cases, FORPLAN is being used to justify site specific actions beyond its design or capability (Sedjo, 1987). FORPLAN lacks the ability to address or represent the spatial components in site specific resource planning (Hof, 1987). Additional planning tools for site specific decision making are needed to supplement FORPLAN output and to help implement the directives of a land and resource management plan at the local ranger district level.

In the past ten years, significant advances in micro and mini-based computer hardware and software have given forest managers a new set of tools for making forest resource allocation and operational management decisions. Geographic information systems (GIS) are unique to this technology because of their ability to model and represent spatial problems graphically. As digital resource information becomes available for both public and private forest lands, integration of GIS and other spatial analysis models for the development of interactive multiresource planning aids is possible. Currently, the Forest Service is incorporating GIS into their organization through a process of technology evaluation at several National Forests (Yockey and Mead, 1989). With the completion of these controlled evaluations of GIS, it is possible that the Forest Service will have a GIS installed at each National Forest (Boulton, 1989).

Sessions (1987) identified the need for the development and evaluation of different types of linkages between FORPLAN type mathematical models and GIS. Since that time, little research has been done to address the GIS/FORPLAN connection to the timber sale planning and harvest planning process. Harvesting on National Forests continues to be a point of contention among the Forest Service, environmental groups, and forest-based industries. The need to demonstrate to the public *"how the planning process proceeds, how information is acquired and analyzed, how alternatives are developed and evaluated, and how trade-offs are made"* is evident (Wondolleck, 1988a, p. 19).

To bridge the gap between the FORPLAN forest-wide resource allocations, land and resource management plan implementation, and the development of site specific resource management alternatives, the Jefferson National Forest has adopted a manual system of multiresource evaluation called Opportunity Area Analysis (OAA). OAA requires a tremendous amount of site specific data to mitigate environmental and social concerns of forest practices and evaluate the silvicultural and economic effects of various management alternatives. A GIS-based approach to OAA can accelerate this complex area analysis process and help resource analysts and the public understand the spatial relationships between various forest management alternatives.

Today, GIS is used extensively in the management of natural resources. Unfortunately, this technology is complex and requires a significant amount of training and experience to fully understand and develop specific applications. This steep *"GIS learning curve"* has spurred the development of GIS-based applications that support the user in routine tasks such as map making and spatial database management to intricate decision making procedures that allow the resolution of complex spatial problems. For users that understand the variables in a problem domain, but lack the experience or time to learn a specific GIS software package, GIS-based decision support or a spatial decision support system (SDSS) can be designed and programmed to coordinate the data, spatial and non-spatial analysis routines, and graphical displays in a framework that replicates the user's problem solving style.

Timber sale planning on the Jefferson National Forest is an important component of the OAA process, and a problem that involves complex spatial relationships. A prototype SDSS designed to support timber sale planning could organize and structure the decision making process, demonstrate the utility of GIS-based decision support for evaluating spatial relationships, and help accelerate the development of timber harvesting alternatives.

Research Objectives

This research has four objectives.

(1) To model current USDA Forest Service methodology for making multiresource management decisions, and to integrate this methodology with an existing geographic information system (GIS) to create an interactive spatial decision support system (SDSS) for timber sale planning on the Jefferson National Forest.

(2) To develop a prototype SDSS for short term timber sale planning that considers the effects of harvesting on soil and water quality, visual and recreational use, fish and wildlife habitat, and the economics of harvesting a given planning or "opportunity" area.

(3) To apply the SDSS model to an opportunity area currently under environmental assessment by Forest Service personnel and generate a set of timber sale alternatives that reflect a variety of multiresource management objectives.

(4) To compare the results of the SDSS timber sale planning process to the current Forest Service Opportunity Area Environmental Review process.

CHAPTER 2 LITERATURE REVIEW

The purpose of this literature review is to examine relevant research which investigates the use of spatial decision support systems (SDSS), geographic information systems (GIS), and spatial analysis models for timber sale planning on the National Forests. To accomplish this task, this chapter is partitioned into four sections. The first section reviews the evolution of Forest Service land-use planning systems, discusses the short-comings of the most recent forest-level system (i.e. FORPLAN), and summarizes Forest Service analysis techniques for site specific planning. Section two defines geographic information systems and highlights the components and structures of geographic information systems. In section three, the concepts and components of a spatial decision support system (SDSS) are introduced followed by an assessment of geographic information and spatial decision support applications in forestry. The last section summarizes the review of literature and provides a set of recommendations that guide the development of the Spatial Decision Support System for Timber Sale Planning on the Jefferson National Forest.

Pre-GIS Land and Resource Planning: An Introduction

> *"National Forests are made for and owned by the people. They should also be managed by the people... This means that if National Forests are going to accomplish anything worth while the people must know all about them and must take a very active part in their management... There are many great interests on the National Forests which sometimes conflict a little. They must all be made to fit into one another so that the machine runs smoothly as a whole."* - Gifford Pinchot, Chief of the Division of Forestry, 1889-1905, and the Forest Service, 1905-1910 (USDA, 1907, p. 25).

Pinchot's foresight embodies the essential elements of multiple-use planning. To this day, his philosophies of wise use and protection to assure the *"greatest good for the greatest number of people in the long run"* has significantly influenced American Forest Policy and Management (Wondolleck, 1988b). Given the current state of Forest Service operations, it would be appropriate to question if he envisioned the consequences of multiresource management on forest planning. To understand the factors affecting the land and resource planning process, the first section outlines the evolution of Forest Service land-use planning systems, discusses the post-FORPLAN analysis dilemma, and reviews pre-GIS techniques and methods for implementing site specific forest plan directives.

Evolution of Forest Service Land-Use Planning Systems

The evolution of land-use planning systems on National Forests is represented by three distinct periods: conservation planning, environmental and multiple-use planning, and ultimately congressionally mandated planning. These three periods demonstrate the relationship between the expanding resource needs of society and the modernization of resource allocation techniques and mechanisms.

From 1910 to 1960, the traditions of utilitarian and protective planning were the basis of many early timber and range distribution methods. Pinchot's conservative approach required planners *"to prepare detailed inventories, monitor the condition of the reserves (forests), determine sustainable use levels, and exclude from use specific areas where necessary to protect the watersheds and other reserves"* (Wilkinson and Anderson, 1987, p. 23). To implement these guidelines, resource specialists employed two systems of resource planning -- *working circles* and *grazing allotments*.

The *grazing allotments* system determined the forage production capacity of certain forests and ranges and divided the lands among interested parties in a range management plan. Timber management plans for a *working circle*, area were based on the annual harvest volume necessary to support local forest-based industries. The tools of timber scheduling/planning were based on simple formulas. Area control or volume control calculations allocated the working circle annual cut by (1) fixing the area to be harvested each year, (2) establishing the volume to be removed annually, or (3) a combination of area and volume (Wilkinson and Anderson, 1987).

Until World War II, the management role of the Forest Service was primarily custodial. The marginal nature of the forests, low stumpage prices, and the lack of access roads to timber deterred private harvesting interests (Wondolleck, 1988b). However, the post-war economic expansion markedly increased the demand for public timber supplies and the Forest Service responded by expanding timber and road building programs. Though the concepts of multiple-use had been popularized in the 1930s, the resurgence of demand for non-commodity use of the National Forests in the 1950s clashed with the growth of timber harvesting. Concerns for social resources such as outdoor recreation, wildlife habitat, environmental amenities, and wilderness areas gained public attention in the 1960s.

The Multiple-Use Sustained Yield Act of 1960 and the National Environmental Policy Act of 1969 were the early directives that forced environmental and land-use planning. As Alston (1972) states, these acts sought to balance the use and management of all resources on National Forests. But, multiple-use unavoidably led to conflicts in resource allocation. New forest level analysis systems such as the Timber Resource Allocation Method, Timber RAM (Navon, 1971) and later the Multiple-Use Sustained Yield Calculation Technique, MUSYC (Johnson and Jones, 1979) were computerized linear programming (LP) models that attempted to optimize land-use goals and multiple-use constraints (Kent, 1980).

Congressionally mandated planning was initiated in 1974 by the Resources Planning Act (RPA) and further refined by the National Forest Management Act (NFMA) of 1976. Essentially, these acts required the Forest Service to undertake a comprehensive forest planning program establishing national long- and short-term goals for National Forest use and to develop a land and resource management plan for each national forest (Wilkinson and Anderson, 1987). With the knowledge gained developing and applying Timber RAM and MUSYC, the Forest Service developed the FORest PLANning Model, FORPLAN (Johnson, 1986), to integrate LP-based analysis of all land and water resources on a forest. In 1979, Douglas Leisz, Associate Forest Service Chief, designated FORPLAN *"the required tool of analysis"* for forest planning throughout the National Forest System (Iverson and Alston, 1986, p. 14).

The Post-FORPLAN Analysis Dilemma

During the first round of NFMA mandated forest plans, the Forest Service applied FORPLAN to a multitude of social, environmental, ecological, and economic situations. Both success and frustration were encountered in FORPLAN's implementation. Considerable knowledge regarding the model's abilities and short-comings was described by Hoekstra et al. (1987) and Bailey (1986). The primary problem areas identified by the users are the size and complexity of FORPLAN (Sedjo, 1987), the inability to process site-specific spatial analyses (Hof, 1987) and address *"spatial concerns"* (Baltic et al,1989), and the lack of model transparency or true understanding of critical factors and linkages determining the final solution (Beuter and Iverson, 1987).

Even though FORPLAN's shortcomings are significant, Sedjo (1987, p. 162) states that there is *"considerable support for the FORPLAN model, in concept, as an analytical tool"* if its role in the planning process could be limited to the resolution of long term issues. FORPLAN should provide a broad review of resource allocation goals for the whole forest while other site specific tools and spatial models ought to support *strategic* FORPLAN objectives in the short term and implementation stage.

Non-GIS Site Specific Plan Implementation Methods and Models

The standards and guidelines in a forest plan incorporate FORPLAN forest-wide resource use goals. To implement these plan objectives, several non-GIS Forest Service analysis methods and models have been designed to provide resource analysts with the ability to plan resource activities on a site specific basis.

The second generation of FORPLAN, FORPLAN Version 2 (Johnson et al, 1986), provides a flexible structure which allows strata-based analysis of an allocation or use zone. Capitalizing on the Version 2 model capabilities, Mitchell (1988), Phillips (1986), and Ryberg and Gilbert (1986), have tracked the economic and environmental effects of a harvest schedule for a specific planning area. The Integrated Resource Planning Model, IRPM, developed by Kirby and others (1980), is a tool designed to supplement FORPLAN. IRPM lends geographic meaning to the forest-wide timber management solution by identifying area specific projects inside the bounds of FORPLAN designated activity levels (Kehr, 1986). Both FORPLAN Version 2 and IRPM are based on linear programming techniques; therefore, they inherit the complexity associated with any LP-based model.

Beyond FORPLAN Version 1, FORPLAN Version 2 and IRPM, less complex computerized resource analysis techniques for long and short term area and project planning have been developed. To implement the strategic management goals of a forest plan, the Project Area Scheduling System, PASS (Tanke, 1987), permits the ordering of road building and harvesting activities on the forest. PASS assists Ranger District level personnel in analyzing the economics of various harvest schedules over a 50 year planning horizon. For project level analysis, the Computerized Assessment of Timber Sales, ComPATS (Hilliard, 1986), is an interactive FORTRAN program that weighs the relative attractiveness of various timber sale projects on a one to five year planning horizon. PASS and ComPATS represent significant efforts towards computerized decision support for the plan implementation process. Each system has an excellent user interface and has been readily accepted by the staff on each forest. However, the missing link is their inability to quantify geographic problems through spatial analysis and graphical represention of constraints and solutions.

Area Analysis, defined by Keller (1986), is a methodology designed to consider spatial constraints in resource allocation during the forest plan implementation stage. Keller outlines this process in seven steps: map prework, disaggregation of FORPLAN forest-wide results, verification of stand data, identification of candidate stands, mapping the solution, evaluation of effects, and monitoring for plan compliance. Area Analysis, a manual method of spatial analysis, is an effective approach to site specific planning and is becoming popular in Region 8 of the National Forest System.

In many of the above, the authors of each approach discuss the potential of integrating computer mapping and geographic information system technology into their analysis process. In the next generation of forest service planning, spatial resource information and GIS should play a pivotal role (Rains, 1987).

Geographic Information Systems

A geographic information system (GIS) integrates computer mapping, spatial analysis, and management information science (MIS) techniques. Geographic information systems provide *"a powerful set of tools for collecting, storing, retrieving at will, transforming, and displaying spatial data from the real world for a particular set of purposes"* (Burrough, 1986, p. 6). A pragmatic approach would describe the development of GIS as a convergence and synthesis of science and technology that blends fundamentals from the disciplines of cadastral and topographic mapping, thematic cartography, civil engineering, geography, mathematical studies of spatial variation, surveying and photogrammetry, land use planning, utility and transportation networks, remote sensing and image analysis, and computer science (Burrough, 1986).

Cowen (1988) categorizes the definition of GIS into four general approaches: the process-oriented approach, the application approach, the toolbox approach, and the database approach. Given the uncertainty and weakness of each approach, Cowen (p. 1554) contends *"that a GIS is best defined as a decision support system involving the integration of spatially referenced data in a problem solving* *environment."* While Berry (1986, p. 40) formally characterizes GIS as *"internally referenced, automated, spatial information systems . . . designed for data mapping, management, and analysis."*

Components of Geographic Information Systems

In functional terms, a GIS is a collection of computer hardware and software application modules organized in such a manner that allows the management of spatial and tabular data (Burrough, 1986). The major components of the hardware system include a digitizer, a central processing unit (CPU), data storage devices, backup storage devices, and output devices. Complementing the hardware is the software system which supports the data input and verification, data storage and database management, data output and presentation, data transformation and analysis, and interaction with the user (Burrough, 1986). A multitude of algorithms and structures designed to expedite processing of GIS functions can be found throughout literature and existing systems.

Building a GIS database is a tedious and evolutionary process requiring years of initial data capture and continual updating. It has been estimated that the cost of data entry and editing is over eighty percent of the total cost of purchasing, implementing, and operating a GIS (Blakeman, 1987). The benefit / cost relationship between data themes and map products typically is weighed to prioritize the types of data collected. Working with the Forest Service, Prisley et al. (1988) utilized linear programming techniques and benefit / cost information as a means of ranking data themes that accomplished specific product objectives.

An alternative source of relatively inexpensive spatial data can be purchased from US GeoData, a service of the U.S. Geological Survey (USGS). US GeoData sells a variety of digital map products, for example, Digital Elevation Models (X,Y,Z elevation points), Digital Line Graphs (i.e. roads, streams, railroads, etc.), and Land Use and Land Cover data. The characteristics, method of data production, and accuracy of 7.5

minute (1:24,000) 30 meter digital elevation models (DEMs) is discussed in the US GeoData circular by Elassal and Caruso (1983). In studies by Davis (1987) and Weih and Smith (1990), it is evident that a significant amount of variability not accountable to the terrain is present in DEMs. This inherent variability, which is often called *"noise"*, can be attributed to several factors: the method of data capture, location of study area on the quadrangle, and how well the DEM has been checked for data collection errors. Before any analysis or modeling with DEMs is done it is important to be aware of these limitations and their potential ramifications.

Structures of Geographic Information Systems - Raster Versus Vector Models

In the development of spatial data processing techniques, early methods of computer mapping were designed to manage X and Y coordinate data to which the user assigns labels or *"attributes"*. This extra information can be thought of as Z data. Linking the Z information discerns elements of unique form in the spatial database. Typically, these elements can be classified based on their form into points, lines, or areas. The linkage between these spatial elements and their corresponding non-spatial or tabular attributes distinguishes the information management capabilities of GIS from traditional computer mapping techniques.

To create a spatial database, the user enters points, lines, areas, and attributes using a digitizer and a keyboard. These four elements for a mapped area represent a single layer in the GIS database. These layers are also called themes, design files, or coverages. In a database, it is possible to have numerous distinct thematic layers. For example, a GIS designed to protect red spruce *(Picea rubens)* and balsam fir *(Abes balsamea)* from spruce budworm *(Choristoneura fumiferana)* infestations had forest covertypes, roads, budworm density, and forest susceptibility themes in the database (Erdle and Jordan, 1984). With this information, a user can combine maps (map overlay) and select the desired subset of geographic entities (spatial search) resulting in the creation of a budworm protection priority theme as shown in Figure

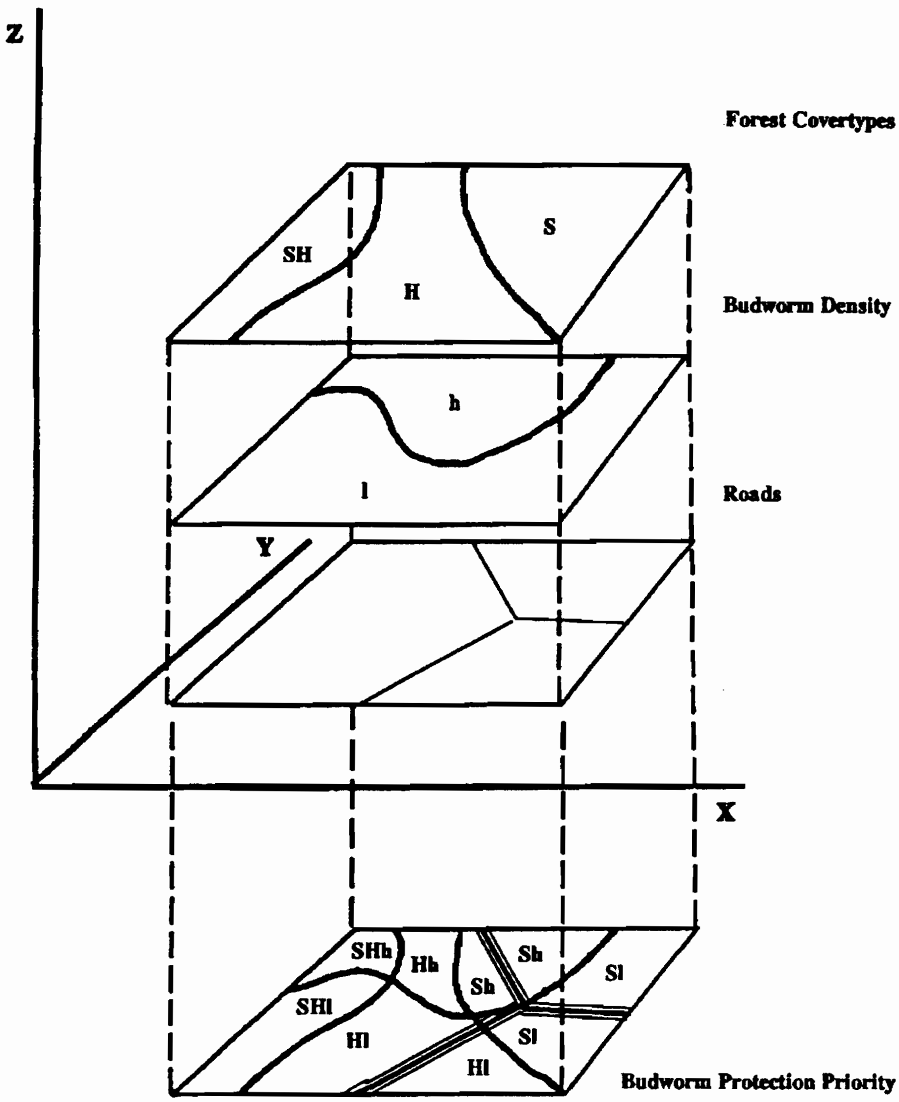

Figure 1. An Example of GIS Overlay and Spatial Search Functions

1. In the GIS toolbox, map overlay and spatial search enables the user to create new information from an existing database. This unique function furthermore separates GIS from other forms of digital analysis and computer mapping (Cowen, 1988).

The design and programming strategies of GIS diverge into two general data structures: raster and vector. The primary difference between raster and vector is the method of data storage. This difference has further implications for how a map element or spatial information is analyzed by the GIS software.

The raster data structure in its simplest form is an array or grid of cells. Referenced in matrix form by rows and columns, each cell represents a rectangular space on the map. A point is represented by a single cell, a line is a stream of cells, and an area is a conglomeration of cells as shown in Figure 2.2. The resolution, or scale of a raster data structure is determined by the cell size which is directly related to an area on the ground. Since only one thematic attribute can be assigned to each unit in a layer of data, information may be lost if a large cell size is used (Burrough, 1986). Precision can be a problem with raster data when map scale is varied. For example, a point with a large cell size can be located anywhere within the area represented by the cell. If map resolution is enhanced with a smaller cell size, the point may be located to an incorrect location. Certain important efficiencies are gained when processing raster information. Programming languages such as FORTRAN and C are well adapted to quickly handle spatial operations like map overlay and spatial searches. Since each cell is a discrete unit in an array of values, logical and boolean operations can easily address the appropriate locations and produce the desired information. Neighbor analysis of cells and analysis of continuous data (i.e. DEMs) within areas like a forest stand or soil type is relatively simple. Finally, raster map overlay routines are precise since the resolution of each cell representing a map entity is fixed.

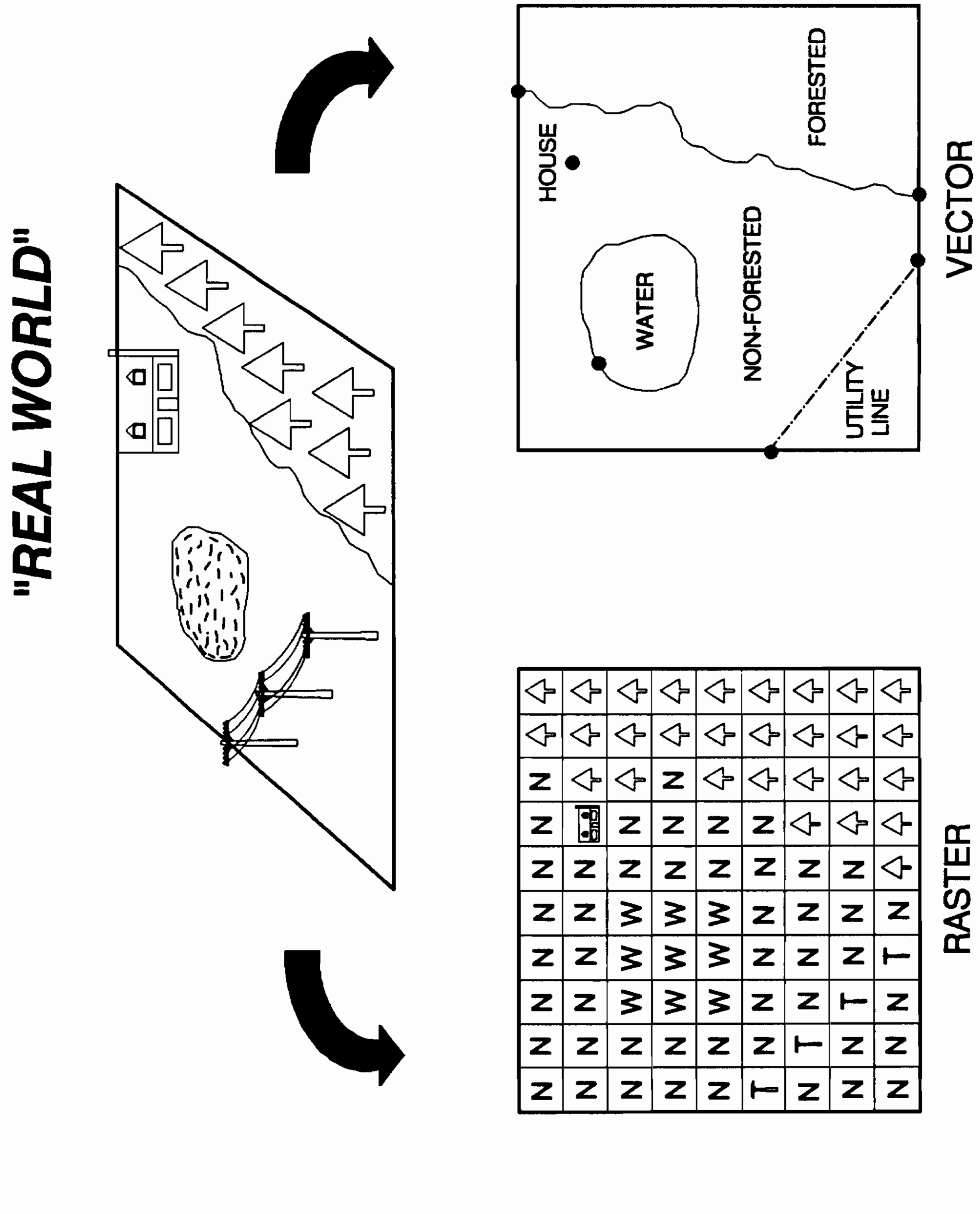

Figure 2. Raster and Vector Representations of Map Elements

Vector data structures contain arcs and nodes which are represented by points in a Cartesian (X, Y) coordinate system. By linking a series of points together, arcs are formed. Arcs are then connected to form either linear or polygonal *(area)* features. The junction of two or more distinct arcs is the location of a node. Thematic attributes are typically linked to points, lines, and polygons by a system of pointers to a map database system. The vector approach adjudicates the ground resolution and scale problem inherent in a raster system by locating points, lines, and boundaries (Figure 2) with digitized coordinates. Though algorithms in vector processing require complex attribute file structures and spatial analysis routines, vector operations more precisely represent the digitized information from maps. A vector system is the best method for network analysis where lines connecting elements have specific characteristics (i.e. utility lines, irrigation systems) or when presenting sharply defined lines and edges such as political boundaries or lines from a survey. However, in the case of an ambiguous or vague boundary like a forest stand or soil unit, a vector system implies too much accuracy for an element that is ill-defined (Maffini, 1987). The vector-based GIS compounds locational problems since spatial values, in particular area estimates, can be treated statistically (Prisley et al., 1989). When vector coverages or themes are joined (map overlay), the resultant coverage, shown in Figure 3, contains *sliver* polygons formed by joining near coincident polygons. *Sliver* problems are typically resolved by post-joining filtering routines in the software.

In the early years of computer mapping, there was a considerable rift regarding the *best* type of GIS. Today with advancements in computer hardware and software, both methods are recognized as valid techniques each with their respective advantages and limitations as compared in Table 1. Through the use of efficient vector to raster and raster to vector data conversion algorithms, it is possible to utilize the positive aspects of each system. Few prototype commercial systems exist to do this task (Sperry, 1988), though the demand for compact data structures, quick retrieval, and accurate and speedy analysis of geographic information should propel their development (Burrough, 1986).

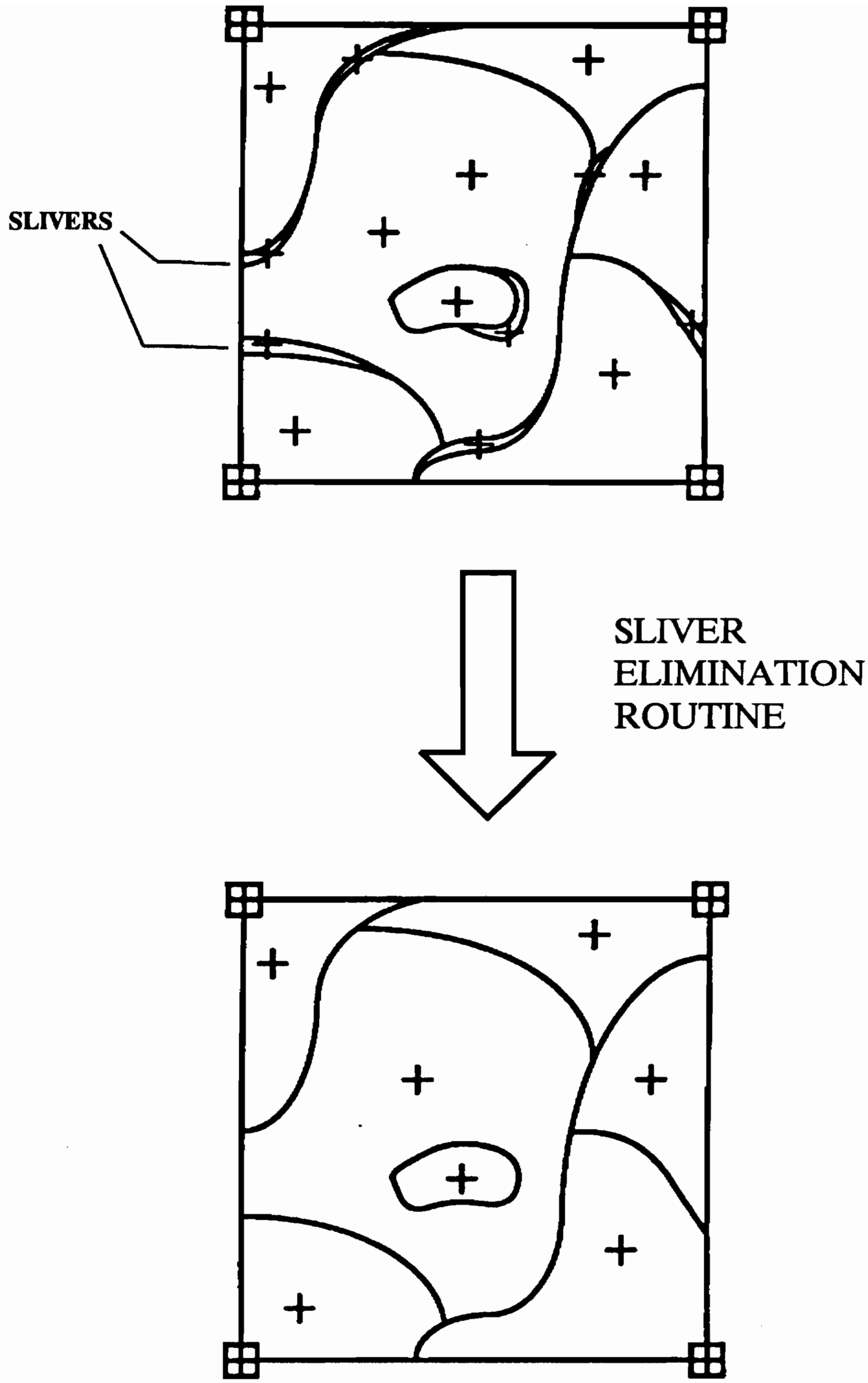

Figure 3. **Vector Map Overlay - Sliver Polygons Example**

Table 1. **Comparison of Vector and Raster Methods** (Burrough, 1986)

Vector Methods

Advantages

Good representation of phenomenological data structure.
Compact data structure.
Topology can be completely described with network linkages.
Accurate graphics.
Retrieval, updating, and generalization of graphics and attributes are possible.

Disadvantages

Complex data structure.
Combination of several vector polygon maps or polygon and raster maps creates difficulties.
Simulation is difficult because each unit has a different topological form.
Display and plotting can be expensive.
This technology is expensive, particularly for the more sophisticated software and hardware.
Spatial analysis and filtering within polygons are impossible.

Raster Methods

Advantages

Simple data structures.
The overlay and combination of mapped data with remotely sensed data is easy.
Various kinds of spatial analysis are easy.
Simulation is easy because each spatial unit has the same size and shape.
The technology is cheap and is being energetically developed.

Disadvantages

Volumes of graphic data.
The use of large cell size to reduce data volumes means that phenomenologically recognizable structures can be lost and there can be a serious loss of information.
Crude raster maps are considerably less aesthetically pleasing than maps drawn with fine lines.
Network linkages are difficult to establish.
Projection transformations are time consuming unless special algorithms or hardware are used.

Spatial Decision Support Systems

In the 1960s and 1970s, the business data-processing community enhanced the analytical modeling and solution processing features of management information systems (MIS) through decision support techniques. Decision support system (DSS) theory integrates analytical modeling capabilities, database management systems and graphical display capabilities, to improve decision making processes in a structured or semi-structured problem environment. Examples of MIS/DSS can be found in Sprague and Carlson (1982), McCosh and Morton (1978), and Bonczek et al. (1981). Pre-GIS applications of computerized decision support in forestry are limited. Lembersky and Chi (1984) developed the *"decision simulator"* VISION for the optimal bucking of tree stems into logs. VISION consists of a database of typical stems, a dynamic programming model to determine the optimal bucking pattern for each log in the database, and a graphics interface for user support and reporting. The system has been applied to evaluate the effectiveness of present stem merchandising rules and to train loggers to cut or *"buck"* logs correctly.

The microcomputer-based OP-PLAN system developed by Robak and Prasad (1985) is a DSS for forest operations planning. This system supports district level decision making by selecting areas to be harvested given the fiber requirements of processing plants and which harvesting, road construction, and transportation systems are to be utilized. OP-PLAN represents a high level of DSS sophistication allowing users to quickly develop a non-graphical forestry operations plan.

In a parallel manner, the evolution of spatial decision support systems (SDSS) was motivated by the need for user decision support in analytical modeling and spatial problem solving interfaces with GIS. In the literature, the definitions of GIS, DSS, and SDSS often conflict and confuse the reader because each discipline encompasses characteristics of the other. Essentially, they are all similar, though the emergence of SDSS truly resembles a balance between GIS and DSS concepts. An excellent definition of SDSS is found in Densham and Goodchild (1989, p. 711) where they write *"to effectively support decision making for complex spatial problems, a SDSS normally is implemented for a limited problem domain; it integrates a variety of spatial and non-spatial data; it facilitates the use of analytical and statistical modeling; a graphical interface conveys information to decision makers"* in a framework that is similiar to the user's problem-solving style.

Armstrong et al. (1986) identify four key components of SDSS: a database management system; spatial and nonspatial analysis procedures; display and report generators; and a user interface. To the applications programmer, the modularity of these components permits engineering of analysis/decision processes. For the user, however, the system design is a series of decisions utilizing desired constraints and analysis techniques.

Applications of GIS and SDSS in Forestry

As with any new technology, applications-oriented research investigating its utility develops quickly. The following section brings together a selected group of papers which illustrate the progression of GIS / DSS / SDSS-based applications and research for the management of timber and other forest-related resources. Early studies exploring fundamental GIS operations produced simplified raster timber accessibility and harvest planning spatial models. Ferlow (1984) and Herrington and Koten (1988) developed a spatial methodology to evaluate regional timber harvest profitability. The Map Analysis Package, MAP, (Tomlin, 1983), a digital cartographic analysis software package developed at Yale University, was used to generate the maximum potential stumpage value of a tract by subtracting the skidding and transport costs from the mill delivered price of sawlogs and roundwood. Similiar research by Berry and Sailor (1981) spatially characterized the harvest and transportation costs for a *timbershed* (i.e. timber supply region) within the working circle of an existing or proposed forest products facility. Utilizing traditional GIS map overlay and spatial search routines, Mead and Rowland (1987) demonstrated how a GIS can select sand pine (*Pinus* *clausa*) stands for harvest under a complex set of stand (age, volume, stocking, etc.) and spatial (clearcut size, regeneration areas, height of adjacent stands, etc.) constraints.

More recent work by Osbourne (1989) builds on Herrington and Koten's models by integrating a forest growth and yield model to assess the temporal effects of stand growth on harvest profitability. Osbourne developed a system that linked three different analysis tools: the growth model FIBER 2.0 (Solomon et al. 1986) to project timber volumes; IDRISI, a GIS developed at Clark University (Eastman, 1988), for raster spatial analysis; and ARC/INFO for interactive display and query of results. By creating a fluent interface between the growth model, GIS raster analysis system, and interactive vector presentation system, Osbourne's methodology capitalized on the strengths of each tool.

Bobbe (1987) describes an ARC/INFO GIS project on the Tongass National Forest in Alaska designed to assist the development of timber harvest alternatives and evaluation of site specific economic and environmental effects. Five different harvesting alternatives were developed for the Tongass National Forest's Final Environmental Impact Statement (EIS). Each alternative emphasized a primary management objective (i.e. maximize economic return, minimize fisheries and wildlife impact). The range of alternatives developed were based on the spectrum of issues and concerns identified during the public involvement process. The data requirements for this project included forest types, stream classifications, wildlife area and point features, soil types, and logging systems / transportation themes. An economic analysis for the forest was performed for each alternative using timber values, and harvesting and transportation costs. Results from the economic analysis provided an economic ranking for comparison of alternatives. A site specific analysis of short and long term environmental effects identified environmentally sensitive areas where management guidelines and standards for mitigation are needed. The analysis also estimated the impact of implementing each alternative. Throughout the entire planning process, the GIS supported the data capture and verification process, analysis and selection of alternatives, and final reporting and EIS document support. Bobbe warns that creating a GIS database requires a significant initial investment of capital and time. However, he states that *"GIS has proved to be a valuable tool in the timber sale planning process"* (1987, p. 562).

Beyond the realm of timber management, a sample of other functional natural resource GIS applications include spatial analyses for fire prevention by Katsada (1989) and Bradshaw et al. (1987), pest management by Forrester and Vanderwall (1987), and wildlife by Mead et al. (1988) and Young et al. (1987). All of these functional applications demonstrate the utility and increasing use of GIS in the natural resources field.

To simplify the resource allocation procedure of a multi-objective management environment, Johnston (1987) designed a land management model for a Canadian timber company. A set of six submodels was constructed to weigh visual quality, landscape ecology, potential regeneration, fire management, wind management, and timber production and economics. To prepare management alternatives, objectives could be changed and quickly processed by the model. For each scenario, a timber harvesting suitability map was created by simulating the effects of each set of goals, and ultimately, the most suitable alternative could be selected. The Map Analysis Package (MAP), a system that uses a raster-based data structure, was the basis for all data analysis. Johnston encountered difficulties with MAP when combining the results of the six submodels into one final data layer. Because MAP only allows the assignment of integers to map cells, it was difficult to track which objective map had the most significant affect. A backtracking procedure that allowed the viewing of submodel results resolved this problem.

A survey of forest-based industries using GIS classified 18 companies in terms of how completely GIS and decision support were integrated within the company's operations (Reisinger, 1989, p. 171). Reisinger reports that *"relatively few companies. . . are using GIS as a tool for making operational and long range* *planning decisions"*. Among the companies with GIS facilities, only five have *fully integrated* GIS into their management information / decision support environment of daily operations. At Weyerhaeuser Company, Wakeley (1987, p. 455) states that for 25 years *"GIS and forest inventory have been inextricably linked"* providing an efficient and effective framework for collecting, storing, and distributing information throughout the organizational hierarchy. The Forest Information and Regeneration System (FIRS), developed entirely in-house, is Weyerhaeuser's central timber management information system for six million acres of fee land. FIRS supports forestry, woods operations, tactical, strategic, and long term planning. A similiar spatial resource information management philosophy is exemplified by Great Northern Paper Company in Maine (Wientzen, 1990). At Great Northern, GIS plays a pivotal role in the woodlands information/planning system and in the migration of data collection and decision support linkages to aid the forester in the field. In the heavily regulated forestry practices environment of California, Stumpf (1987) discusses Simpson Timber Company's experiences with GIS in developing a site specific harvest scheduling system. Simpson Timber currently uses GIS for determining the annual harvest levels, logging capacity and productivity rates, species mix of trees, harvesting systems, and erosion risks in a planning area.

Within the framework of a spatial decision support system, literature is limited to recently completed and on-going research. In cooperation with Great Northern Paper Company, Reisinger and Davis (1987) developed a prototype Harvest Planning Decision Support System (HPDSS) model. The four components of HPDSS include a database of spatial and nonspatial attributes, a library of operations research (OR)/decision models, a DSS software system and graphics interface, and the harvest planning analyst. The model base applies linear programming, minimum spanning tree, and integer programming techniques to optimize stand selection, stand access, and equipment selection. This system allows the planner to spatially delineate a planning area, specify the constraints bounding the problem domain, process the desired models, evaluate the initial solution, and then revise the constraints and rerun the models. After an iterative process directed and refined by the user, the proposed solution can be presented in a series of maps and tabular reports.

Current research at the School of Forestry, Northern Arizona University, by Covington et al. (1988) seeks to bridge the gap between strategic planning and implementation. The goal of the Terrestrial Ecosystem Analysis and Modeling System (TEAMS), a prototype spatial decision support system for multiresource evaluation, is to aid forest managers in developing site specific treatments for southwestern ponderosa pine. Through a series of control programs, TEAMS links several commercial PC-based software packages (i.e. R:Base 5000, CLOUT, ARC/INFO, LINDO, and CHART) and locally developed ecosystem simulation, linear programming, and benefit/cost models. The modular design of TEAMS and automated connections between modules eliminates the manual transfer of data freeing the user to focus on problem analysis. TEAMS has been used at both the undergraduate and graduate levels to teach multiresource management concepts and procedures.

Summary

Based on the finding of this literature review, several conclusions can be made that guide the development of a spatial decision support system for short term site specific timber sale planning on the Jefferson National Forest.

(1) Resource planning on National Forests is a complex process involving spatial relationships. Therefore, implementing the directives of a land and resource management plan warrants the inclusion of spatial considerations.

(2) Optimally, the selection of a geographic information system should facilitate spatial analysis in a raster environment and map query and presentation in a vector environment. However, few "hybrid" raster/vector systems exist, therefore to avoid time-consuming fundamental software development, all work will be done with a commercially available, state-of-the-art vector-based geographic information system.

(3) Several applications in forestry demonstrate the use of geographic information systems for harvest planning. But given the complexity of this technology, development of GIS-based applications requires a significant amount of experience and time. With the appropriate database management system, analysis procedures, display and report generators, and user interface, spatial decision support systems can translate the utility of GIS to the resource manager in the field.

(4) Through GIS spatial analyses and graphical and tabular displays, the SDSS environment should provide the resource analyst with an unambiguous perception of the forest plan implementation process, site specific analysis techniques, and spatial constraints bounding the end result.

(5) The spatial decision support system should support and closely replicate current planning procedures outlined in the Jefferson National Forest Land and Resource Management Plan and as refined by District level personnel. This will allow planning personnel to compare the manual approach and SDSS-generated area analysis alternatives.

CHAPTER 3 METHODS AND PROCEDURES

Introduction

This chapter discusses the methods and procedures for developing a prototype spatial decision support system (SDSS) for timber sale planning in a GIS environment. Four phases were undertaken to fulfill research objectives:

(1) Modeling and structuring the timber sale planning process for Opportunity Area Analysis;

(2) Assembling and programming the SDSS components to facilitate GIS-based timber sale planning. These components include a database, analytical and spatial modeling linkages, display and report generators, and user interface utilities;

(3) Processing a case study of a specific opportunity area using the prototype SDSS; and

(4) Comparing the use of SDSS to develop timber sale alternatives with the manual approach currently used for timber sale planning on the Jefferson National Forest.

Timber Sale Planning Process

The first phase of development of the spatial decision support system was to model current timber sale planning techniques used on the Jefferson National Forest. Defining the methodology and creating a model for timber sale planning was facilitated in two steps. The current Jefferson National Forest Land and Resource Management Plan was reviewed to gain a general understanding of the parameters influencing timber management. From this review, four decision steps were identified: (1) distinguishing suitable stands for timber management, (2) assessing the suitable stands for site specific constraints, (3) evaluating the economics of harvesting the suitable stands, and (4) developing harvest plans for the suitable stands based on the information developed in the previous steps. Then, in a meeting with Forest Service personnel, a description of the methods used for timber sale planning was obtained by asking timber sale administrators and other resource planners very specific questions regarding the current planning process. In this informal question / answer session, the criteria for stands suitable for timber management was determined, and the methods for evaluating site specific environmental and social constraints on the timber sale planning process were identified. The procedure for the economic analysis was outlined, and finally a routine for the development of timber harvesting alternatives was discerned. With this information, a series of flowcharts and tables were developed that illustrated the sequence of decisions and identified the specific information needed for each step in the decision process. A second meeting with the Forest Service reviewed these flowcharts and clarified and approved the process. During the development of the SDSS, frequent communications were maintained and when modeling problems were encountered, they were cooperatively resolved.

Spatial Decision Support System Development

With the timber sale planning process defined, a series of computer programs were developed to link the digital database, GIS spatial analysis routines, display and report generators, and user interface utilities. For this research, the digital database for the Clinch Ranger District on the Jefferson National Forest was supplied by the Forest Service and GIS software and hardware resident at VPI&SU were utilized for SDSS development. The user interface utilities were designed to manage the flow of information between the user and computer during the decision making process.

Digital Database

The Clinch Ranger District, located in southwestern Virginia, was the first district on the Jefferson National Forest (JNF) to have a complete digital database and necessary linkages to existing tabular databases (USDA, 1989). Availability of a digital database was a crucial factor for this project, since initial spatial database development is time consuming and expensive. The data layers for the Clinch Ranger District, shown in Table 2, are the result of an *"information needs analysis and the workload analysis"* completed by the Forest Service in January 1989. This process identified and prioritized the spatial and attribute data necessary to support the GIS products desired by the district. For more information on the Forest Service database development plan consult the GIS Implementation Plan for Region 8 (USDA, 1989). The digital data layers and digital elevation models for the Clinch area were obtained in September 1989. Since this database had not been used before, it was necessary to check the spatial and tabular data for errors. After an initial review of each layer of thematic information, it became apparent that several coverages had incomplete attribute files. Several months were spent linking road classifications, visual quality and recreation opportunity data, soils information, and stream classifications to the appropriate polygons, lines, and points in each coverage. It was also necessary to update the forest stand information to incorporate the attribute changes from the CISCII (Continuous Inventory of Stand Characteristics) Forest Service stand-level database system since the opportunity area used for the case study was re-inventoried in early 1990. Upon completion of the spatial database review and updates, all the data collection for the spatial decision support system was concluded.

Geographic Information System Selection

Since nation-wide GIS technology procurement by the Forest Service will not occur until 1991, the SDSS for timber sale planning was developed using a typical commercial GIS software and hardware configuration. The vector-based ARC/INFO Geographic Information System (Version 5.0) by Environmental Systems Research Institute of Redlands, California was selected to be the GIS toolbox for developing the SDSS since ARC/INFO is the primary software being evaluated by the Forest Service at various locations throughout the National Forest System. ARC/INFO software is maintained on a Digital Equipment Corporation (DEC) MicroVAX II mini-computer housed in Virginia Polytechnic Institute and State University's Department of Forestry, Center for Quantitative Studies in Natural Resources. The MicroVAX mini-computer supports a variety of color graphics screens (several IBM Personal Computers with GrafPoint TGRAF07 terminal emulation software and two Tektronix terminals), a CalComp 9100 digitizer, a CalComp 1044 plotter, and a Tektronix 4596 color graphics screen dump device.

Table 2. Clinch Ranger District Digital Database

Data Source	GIS Digital Coverage
Primary Base Series (PBS)	Quadrangles
	Streams
	Roads
	County Landlines
Tennessee Valley Authority *(contractor)*	Land Management Areas
	Land Management Points
	Utility Corridors
	Soils[1]
	Stands[2]
	Forest Service Compartments
	Forest Service Ownership Landlines
	Visual Quality Objectives & Recreation Opportunity Spectrum
	Wildlife Areas
	Wildlife Point Data
USGS	30 meter Digital Elevation Models

[1]linked with Jefferson National Forest Soils database.
[2]linked with CISCII (Continuous Inventory of Stand Characteristics) database.

User Interface / System Control

The prototype SDSS for timber sale planning is programmed in the ARC Macro Language (AML). AML is the interpretive computer language that permits the design of specialized applications in the ARC/INFO environment. AML provides full programming capabilities and a set of tools for linking ARC commands together to perform specific types of spatial and non-spatial analyses, database queries, or graphical and tabular displays. Another powerful feature of AML is the creation and use of screen menus for program control and communication with the user. AML was used to develop the linkages between the SDSS components. The SDSS user interface is a menu-driven system structured on timber sale planning heuristics that allows the resource planner to execute programs in AML. Each AML program queries the planner for the parameters needed for the selected decision process, quantifies the effects, and displays the results of the analysis. The modular design of the SDSS permitted the development of simple macros in early stages of system development. After becoming more familiar with the AML language syntax and the abilities and limitations of ARC/INFO, programming of intricate decision processes was possible.

SDSS Case Study

Of the ninety eight opportunity areas on the Jefferson National Forest, fourteen are found in the Clinch Ranger District. To facilitate a comparison between timber sale plans developed with the SDSS and plans developed using the manual approach, a case study area was selected from a group of opportunity areas currently under environmental assessment by the Forest Service. After a review of the Opportunity Area Analysis completion schedule, the participants of this research identified the Wallen Ridge Opportunity Area to be the most suitable study area. This opportunity area, shown in Figure 4, spans 3,925 hectares (9,700 acres) of which approximately sixty percent or 1,459 hectares (5,905 acres) is held in fee. The study area is located approximately ten kilometers (6.2 miles) south of the town of Big Stone Gap on Virginia State Route 23. It includes parts of Lee, Wise, and Scott counties that fall on the Big Stone Gap, Duffield, and Keokee 7.5 minute series USGS Topographic Quadrangles. In general, the terrain in the Wallen Ridge

Area, shown in a 3-D perspective in Figure 5 ranges from level and gently sloping to steeply sloping. In the study area, elevations range from 402 meters (1319 feet) to 956 meters (3136 feet). The forest in the study area is classified primarily as cove and upland hardwoods. Cove hardwood species include yellow popular (*Lirodendron tulipifera* L.), white oak (*Quercus alba* L.), and northern red oak (*Quercus rubra* L.). Species found in upland hardwoods include hickory (*Carya*), scarlet oak (*Quercus coccinea* Muenchh.), chestnut oak (*Quercus prinus* L.), white oak, and red oak. The present forest composition is displayed in Table 3.

After compiling and verifying the digital database for the Wallen Ridge Area, execution of the SDSS assisted the system user through the timber sale planning process. Using the issues and concerns identified during public involvement sessions and reported in the Wallen Ridge Opportunity Area Environmental Review (USDA, 1990), the opportunity area was evaluated using SDSS and a set of timber sale alternatives were developed to reflect these resource management objectives.

Table 3. Wallen Ridge Opportunity Area Present Forest Composition

Forest Type	# of Stands	Acres	Percent of total area (%)
Upland Hardwood	73	3,689.9	62.5
Cove Hardwood	34	1,901.0	32.2
Hardwood Pine	3	210.8	3.6
Pine	10	102.6	1.7
Totals	120	5,904.3	100.0

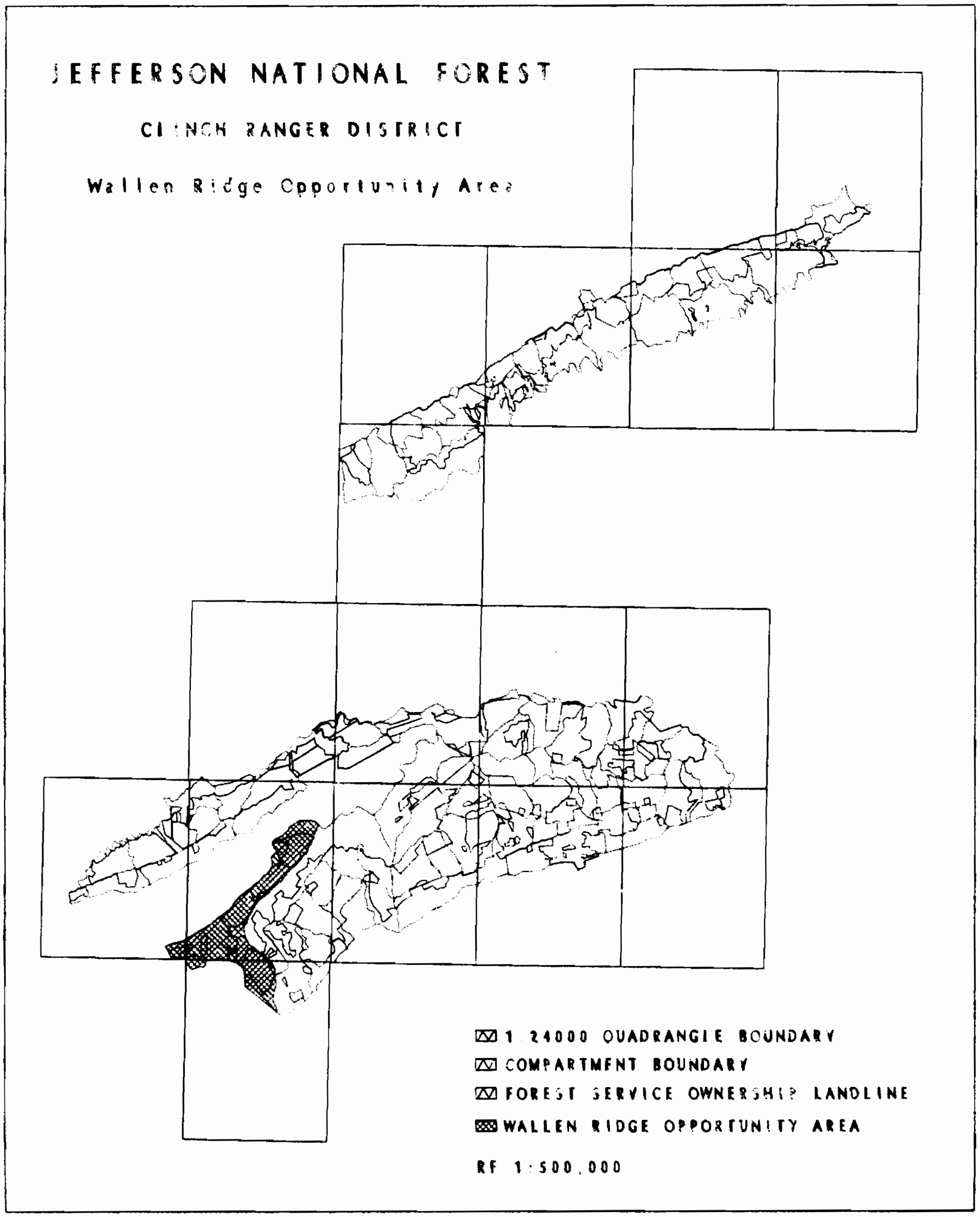

Figure 4. Wallen Ridge Opportunity Area, Clinch Ranger District

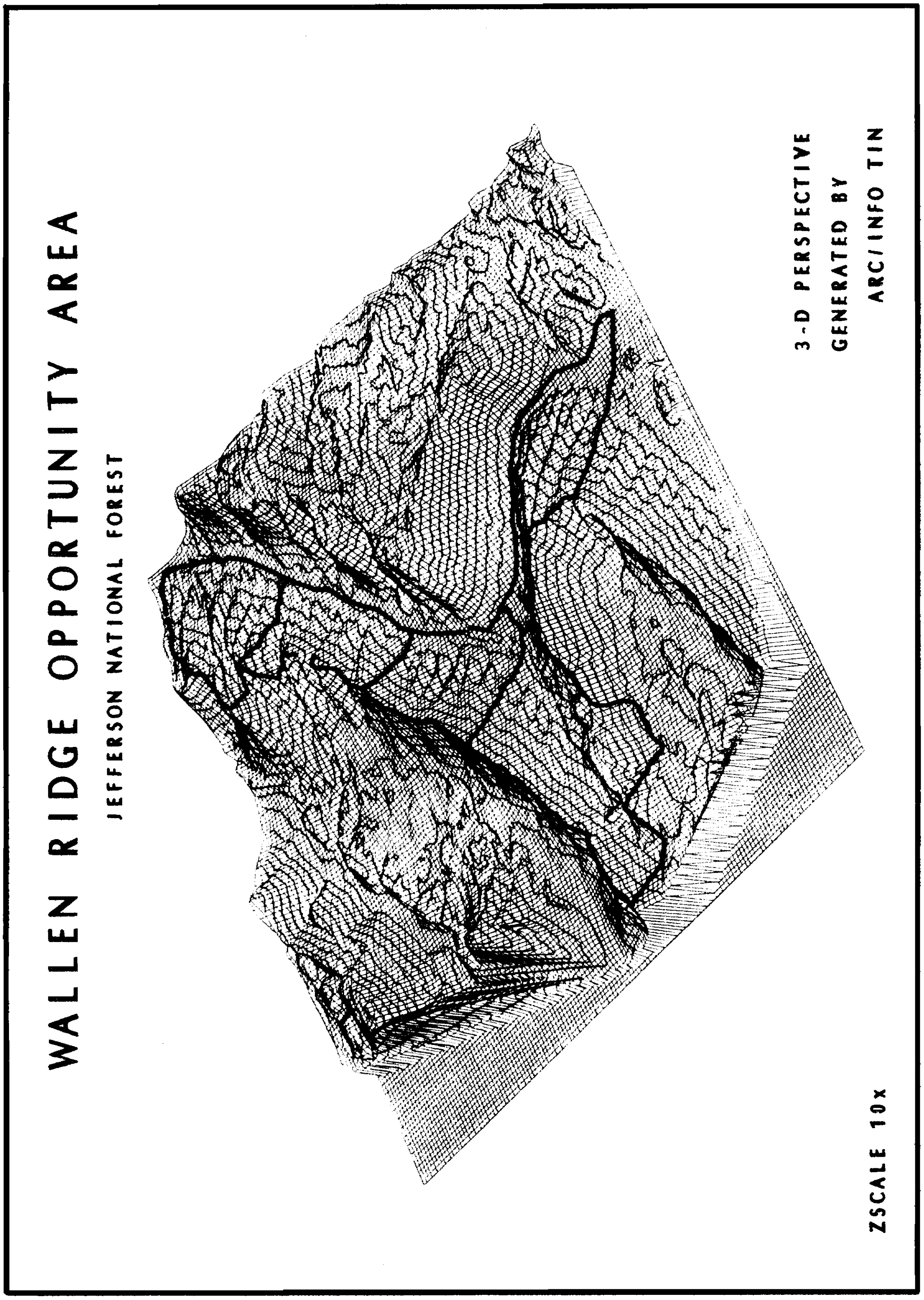

Figure 5. Three Dimensional Perspective of the Wallen Ridge Opportunity Area

Comparisons of SDSS and Manual Approaches

The use of spatial decision support for timber sale planning is the first attempt on the Jefferson National Forest to integrate GIS technology into the resource planning process. The SDSS is a prototype series of computer programs designed to enhance the resource planner's analysis abilities and possibly accelerate the timber sale planning process. Comparing the prototype SDSS results to the results developed using current manual techniques is the next logical step in refining the SDSS model. Differences between the analysis approaches are expected since the major emphasis of this research was on modeling the timber sale planning decision process and developing a prototype SDSS

. Comparisons at this time are made to identify the strengths and weaknesses of the prototype SDSS and to gain insight towards possible areas for future SDSS enhancements.

Comparisons between the approaches for generating timber sale alternatives include the following:

(1) Reviewing the data requirement of the timber sale planning process, and determining how the available spatial data in the SDSS facilitates adequate decision-making.

(2) Examining the differences at each step in the timber sale planning process between the SDSS and manual approaches, and investigating how the SDSS model effects the overall decision making process.

(3) Determining the time requirements for using the SDSS approach, and estimating the effects of time savings over current analysis methods used by the Forest Service.

CHAPTER 4 RESULTS AND DISCUSSION

Introduction

To describe the development of a prototype spatial decision support system (SDSS) for timber sale planning on a National Forest, this chapter is divided into four sections, each addressing one specific research objective. They include: (1) a description of the timber sale planning decision process, (2) a review of the SDSS model, (3) a demonstration of the use of SDSS on a case study area in the Jefferson National Forest (JNF), and (4) comparisons of the SDSS approach to current manual methods for timber sale planning on the JNF.

Timber Sale Planning Decision Process

After reviewing the Jefferson National Forest (JNF) Land and Resource Management Plan and meeting several times with JNF resource planning personnel, the present decision making process used for the timber sale planning component of Opportunity Area Analysis was identified. The purpose of this section is to briefly describe the current short term harvest planning practices used by timber sale administrators on the JNF. For discussion and modeling purposes, the decision process was structured into four steps:

(1) Identification of stands suitable for timber sale planning in the opportunity area;

(2) Evaluation and analysis of environmental and social constraints specific to each candidate stand;

(3) Economic analysis of the candidate stands; and

(4) Development of timber sale alternatives for a short term planning period.

Identification of Suitable Candidate Stands

The Land and Resource Management Plan (LRMP) for the Jefferson National Forest (1985b) partitions the forest into 10 management areas as shown in Table 4. A management prescription for each area specifies the general directions, standards, and guidelines for management practices and activities. The distribution of management areas in percent land area is depicted in Figure 6. Management Areas 7 and 8 comprise approximately eighty-five percent of the forest. The remaining fifteen percent of the forest, Management Areas 1, 2, 3, 4, 5, and 9, is reserved for recreation, wilderness and wilderness review, and unique and special quality areas.

Management Area 7 is managed for multiple-use emphasizing the development and maintenance of a healthy and vigorous forest capable of producing quality sawtimber and other forest products. On the JNF, approximately fifty percent of the total acreage is classified as Management Area 7 and is suitable for long term timber production. The directives for Management Area 8 provide for multiple-use with the emphasis on wildlife management, and forest stands in this area are designated unsuitable for timber production, though wildlife habitat and other resource needs may still require silvicultural treatments on a limited basis. Evaluating the factors that differentiate Management Area 7 from Management Area 8 is part of the first phase in the timber sale planning process. To identify stands suitable for timber management in the opportunity area, two levels of suitability are considered. Level I stand suitability classifies the forest stands as either Management Area 7 or Management Area 8 forestland based on site quality, slope, and stand access. Level II suitability determines which Level I suitable stands are potential candidates for timber sale planning during the current planning period.

Level I - Management Area 7 / Management Area 8 Classifications

To determine whether or not a stand is suitable for timber production, the timber sale administrator evaluates three parameters: site index, steepness of slope, and stand accessibility.

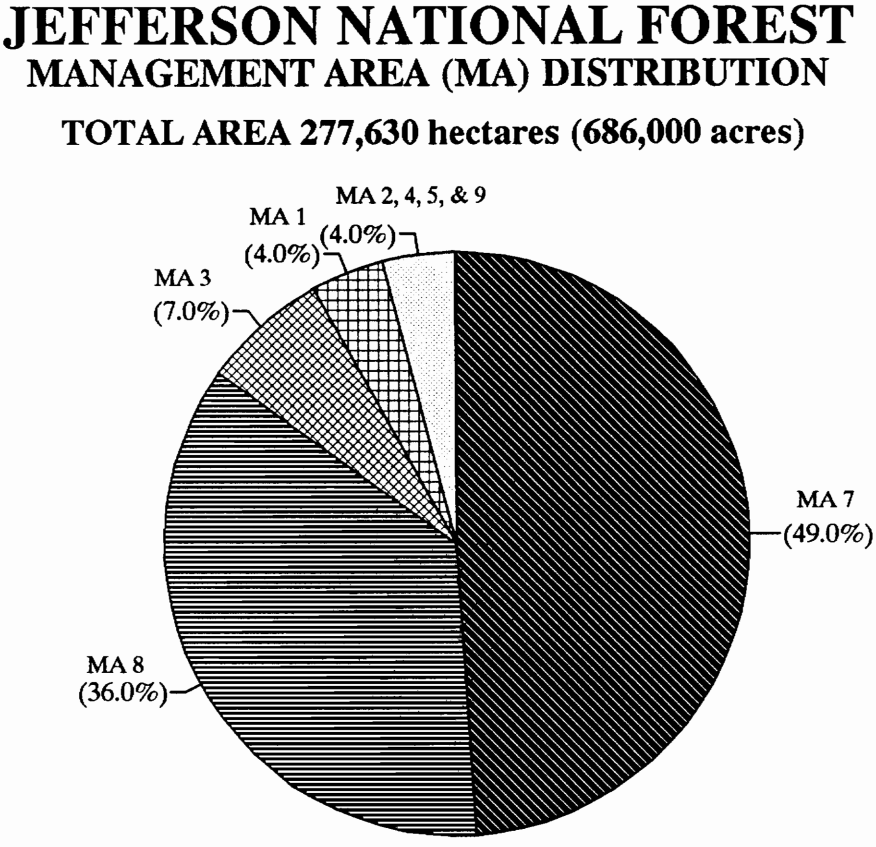

Figure 6. Pie Chart of Management Area Distribution for the Jefferson National Forest

Table 4. **Management Area Summary** (USDA, 1985b)

Mgt. Area	Description
1	The Appalachian Trail - 11,530 hectares (28,500 acres).
1a	Certain lands acquired by the National Park Service for the Appalachian Trail outside the Forest boundary.
2	All developed recreation sites - 1,490 hectares (3,680 acres).
3	Nine Wilderness Areas - 19,370 hectares (47,870 acres).
4	Two wilderness study areas - 4,130 hectares (10,200 acres).
5	Eight Areas of unique or special qualities identified in the Forest planning process - 2,950 hectares (7,300 acres).
6	Mount Rogers National Recreation Area - 46,820 hectares (115,700 acres). Portions of Management Areas 1, 2, 3, 5, 7, and 8 are within this area.
7	General Forest area identified for multi-resource management with emphasis on timber production and wildlife habitat - 137,400 hectares (339,600 acres).
8	General Forest area identified for multiple-use management with emphasis on wildlife habitats and other resource management - 101,215 hectares (250,100 acres).
9	White Rocks Semi-Primitive Recreation Area (3,030 acres).

Table 5. **Forest Service Suitability Guidelines for Forest Stands** (USDA, 1985b)

Status	Site Index[1]	Slope *(percent)*	Access
	> 50	35 <	roaded/unroaded
SUITABLE (Mgt. Area 7)	> 70	> 35	roaded/unroaded
	60	> 35	roaded
	40 <	--	--
UNSUITABLE (Mgt. Area 8)	50	> 35	roaded/unroaded
	60	> 35	unroaded

[1]Base Age 50 years

Site Index

Site index, an indicator of stand productivity, is a measure of site class based on the height of dominant trees in a stand at some index age (Smith, 1986). The index or base age for the Jefferson National Forest is 50 years. The site index for a stand is obtained from the Forest Service Continuous Inventory of Stand Characteristics (CISCII) stand-level attribute database. The timber sale administrator groups the stands according to the site index ranges specified in Table 5.

Slope

The average slope of a forest stand is the second factor that influences Management Area 7 / Management Area 8 classification. Five slope classes, listed in Tables 6, are based on stand suitability requirements found in Table 5 and harvesting equipment operability classes discussed in Level II analyses. Class 1 slopes are delineated to identify non-sloping or level areas for potential log collection and handling areas in harvesting operations. To the logger and forester, these areas are commonly known as *"landings"*. Classes 2 - 5 are used later in the decision process to determine logging system assignments. With the USGS 7.5 minute series topographic maps and personal knowledge from visits to specific sites in the opportunity area, the timber sale administrator assigns an average slope class to each stand evaluated.

Table 6. Slope Classification System for Evaluating Suitability

Slope Class	Range *(percent)*
1	0.0 - 2.0
2	2.0 - 35.0
3	35.0 - 50.0
4	50.0 - 100.0
5	greater than 100.0

Accessibility

Stand access is a function of distance from the existing network of Forest Service roads available for log and pulpwood transport operations. As stated in the forest plan's standards and guides (USDA, 1985b), all stands within a quarter mile (1320 feet) of a Forest Service road are considered accessible or *"roaded"*. Using this standard, a stand accessibility or *"road buffer"* distance is assigned to each road class (i.e. highways, lightduty roads, seasonal roads, unimproved roads) and a buffer corridor for each road is visualized. If a stand is only partially roaded (within the buffer corridor) the whole stand is considered accessible, otherwise it is regarded as inaccessible or *"unroaded"* and a new road will have to be designed and engineered to gain access if the stand is to be harvested.

Using the suitability criteria in Table 5, the planner evaluates all three parameters, site index, slope, and accessibility for each stand and assigns a suitability classification (Figure 7). All suitable stands are Management Area 7 stands. The unsuitable stands are classified as Management Area 8.

Level II - Candidate Stands for Timber Sale Planning

The next series of decisions in the process of identifying suitable candidate stands considers the appropriate logging systems and timber products objectives for each suitable stand meeting Level I criterion (Figure 8).

A partial list of factors influencing the selection of ground-based, advanced ground-based, or cable logging systems includes the length and percent of slope, soil properties, watershed characteristics, silvicultural treatment, logging system availability, economics, and other project specific concerns. At this point, however, the primary decision variables the planner uses are average stand slope and logging system availability; other factors affecting logging system selection are incorporated in later phases of the planning process. Traditional ground-based skidding systems are operable on stands with slopes averaging less than 35 percent. For slopes averaging between 35 percent and 50 percent, advanced ground-based (i.e. fast-

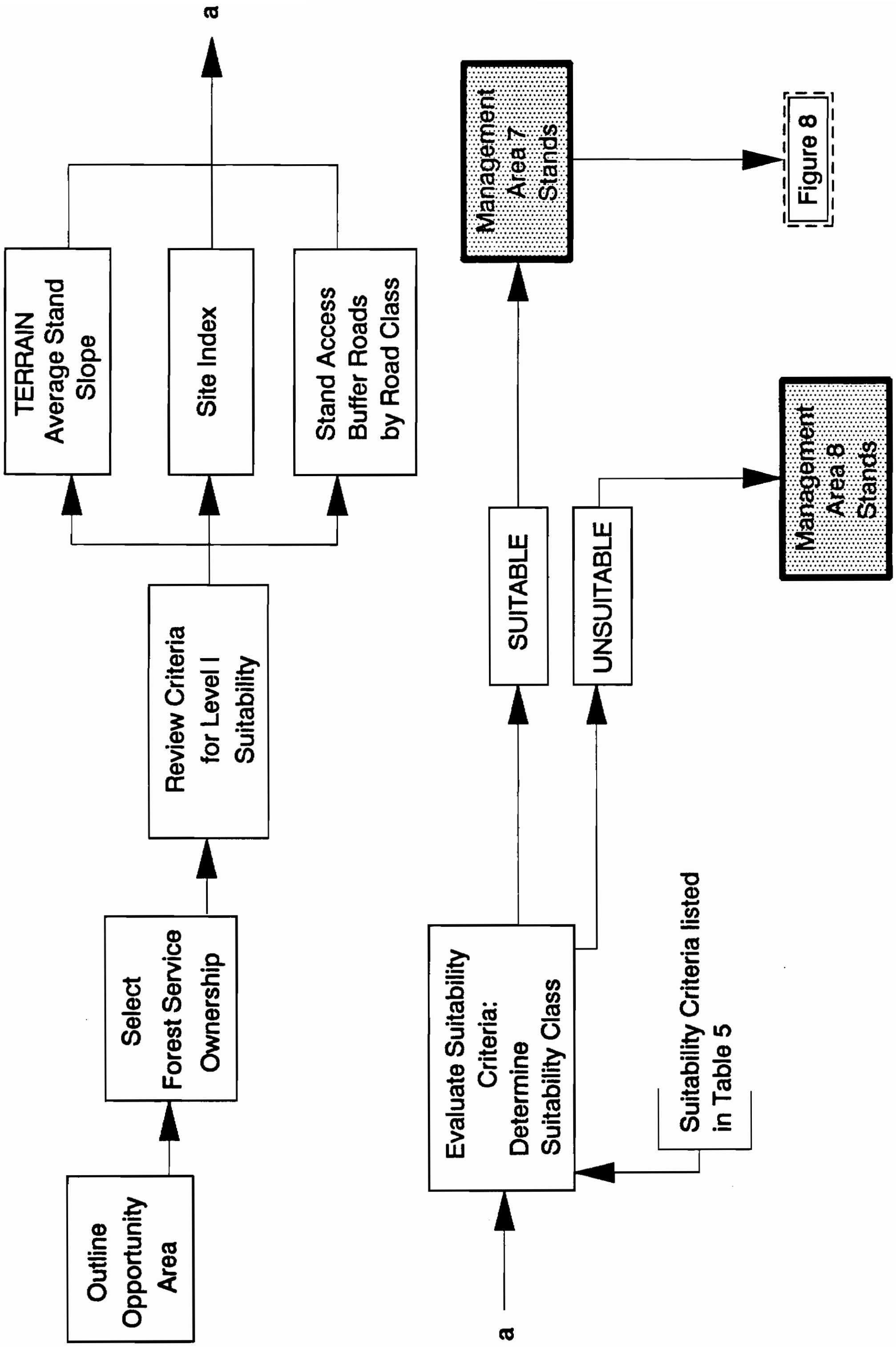

Figure 7. A Flowchart of Level I - Management Area 7 / Management Area 8 Classifications

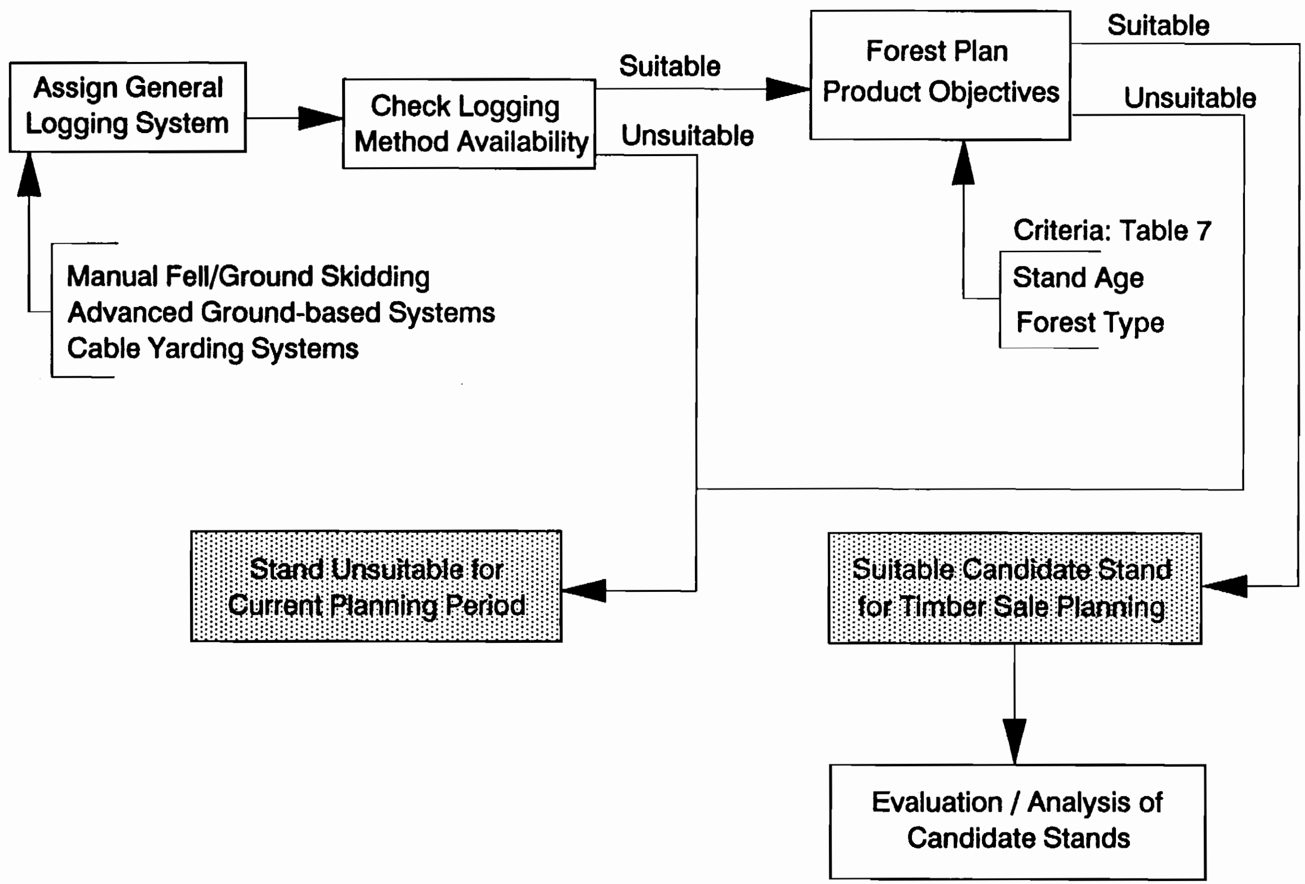

Figure 8. A Flowchart of Level II - Candidate Stands for Timber Sale Planning

tracked skidders or other specialized equipment), or cable logging systems may be employed. All stands with an average slope greater than 50 percent are designated to be harvested by cable yarding systems (USDA, 1985b). Using an average value for stand slope, one or more logging systems can be assigned to harvest each candidate stand. If any of the logging systems are unavailable, then those stands are classified as unsuitable for the current planning period.

The timber product objectives for Management Area 7 stands are to manage for quality sawtimber whenever possible. To meet this goal, the planner considers rotation age and diameter breast height (DBH) guidelines for cove hardwoods, upland hardwoods, white pine, hardwood pine-normal, and hardwood pine-low timber working groups that have been established. Determining whether or not a stand is a candidate for a timber sale is done by selecting stands that meet the forest stand type and rotation age criteria found in Table 7. Forest stand type and the stand age information are obtained from the CISCII stand database.

Table 7. Rotation Guidelines for Timber Working Groups on the Jefferson National Forest (USDA, 1985b)

Working Group	Rotation Range *(years)*	DBH *(inches)*
Cove hardwood	60 - 100	16 - 30
Upland hardwood	70 - 120	14 - 24
White pine	60 - 80	16 - 30
Hardwood pine-normal	70 - 100	11 - 17
Hardwood pine-low	70 - 100	9 - 13

After completing Level I and II suitability analyses, the timber sale administrator now has a set of stands satisfying all criteria for a potential timber sale area. These stands become candidates for further evaluation. All other stands are classified as unsuitable and are not considered in the next three decision procedures.

Evaluation and Analysis of the Candidate Stands

To evaluate the effects of social and environmental concerns associated with timber harvesting on National Forests, Forest Service resource planners are required to evaluate several site specific constraints that may influence the development of timber sale plans. This section will outline the procedures the timber sale planner employs in conjunction with a Forest Service interdisciplinary team of resource specialists. The candidate stands are evaluated for the following constraints:

(a) Recreation Opportunity Spectrum.

(b) Visual Quality Objectives.

(c) Wildlife featured species habitat.

(d) Best Management Practices (BMPs), riparian areas, and streamside management zones.

(e) Hazardous or unstable soils.

Recreation Opportunity Spectrum

The Recreation Opportunity Spectrum (ROS) delineates lands that reflect a variety of recreation experience opportunities, and are categorized into six classes -- primitive; semi-primitive non-motorized; semi-primitive motorized; roaded natural; rural; and urban. Each class is defined in terms of the degree to which it satisfies certain recreation experience needs, based on the extent to which the natural environment has been modified, the type of facilities provided, the degree of outdoor skills needed to enjoy the area, and the relative density of recreation use. Definitions for each class are summarized in Appendix A.

The purpose of this step in the evaluation process is to assign a ROS classification to each candidate stand. The timber sale administrator compares the ROS information in the opportunity area to the candidate stands and assigns the appropriate classifications to each stand (Figure 9). ROS classifications within a candidate stand may influence whether or not it will be harvested. For example, areas classified as rural or urban are unlikely areas for harvesting since the activities associated with timber harvesting may degrade the recreational experience in those areas.

Visual Quality Objectives

Visual quality objectives (VQOs) are used to qualify the public's concern for scenic quality as well as diversity of natural features. There are five classes of visual resource management goals: preservation; retention; partial retention; modification; and maximum modification. Except for preservation, each class describes a different degree of acceptable alteration in the natural landscape as defined in Appendix A. The degree of alteration is measured in terms of visual contrast with the surrounding natural landscape.

The decision process for evaluating VQO classifications, shown in Figure 9, is similar to the ROS procedure. By comparing the VQO information to the candidate stands, one or more VQO classes are assigned by the planner to each stand. VQO classifications within a stand may also influence how or whether or not a stand is harvested. Since VQOs define an acceptable degree of alteration in the natural landscape, the more restrictive visual management objectives typically require harvest planners to configure harvest patterns into the natural landscape. Since harvest planning and layout may take more time under these circumstances, it may be preferable to harvest timber in areas where visual quality goals are less critical.

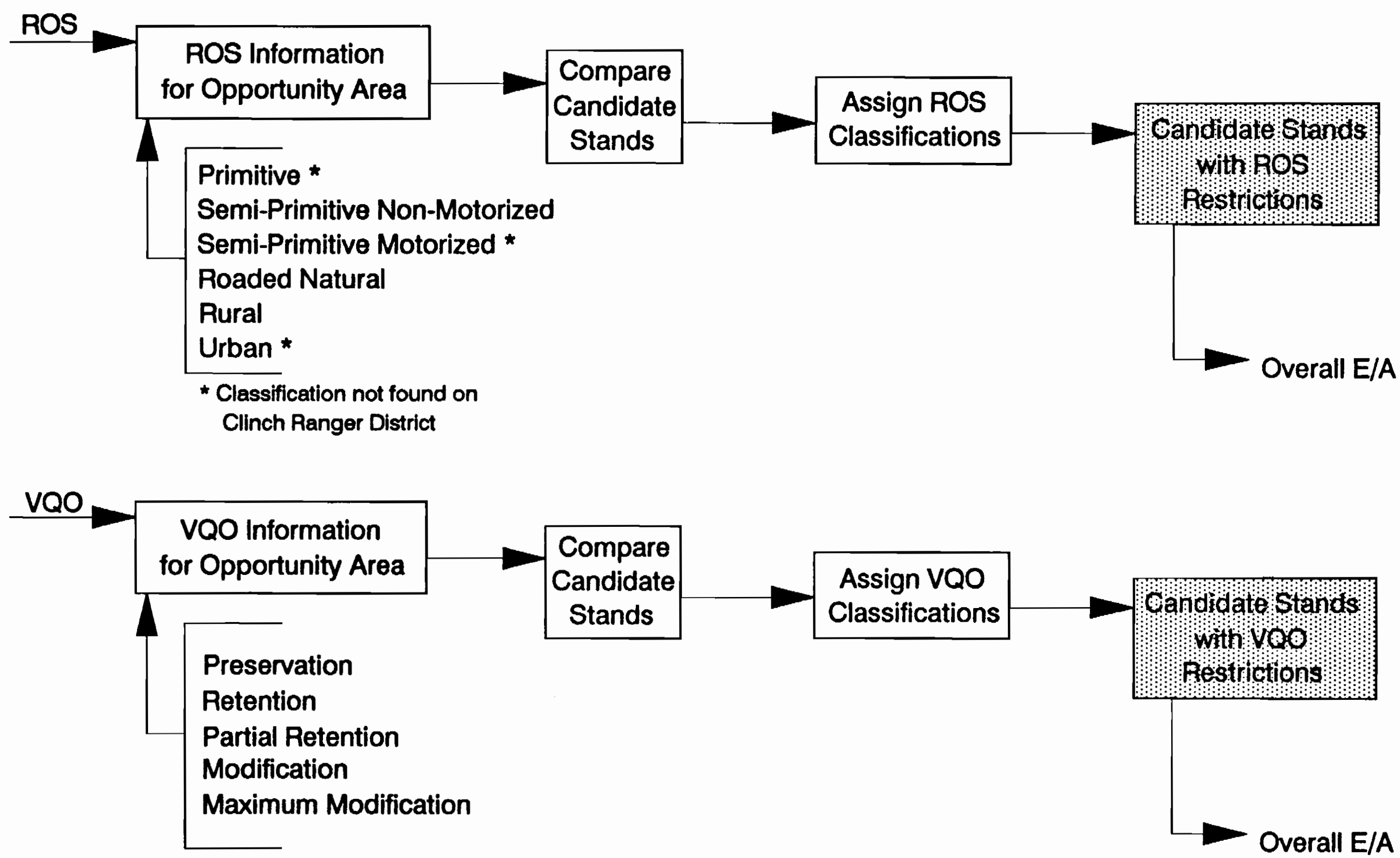

Figure 9. Recreation Opportunity Spectrum (ROS) and Visual Quality Objectives (VQO) Evaluation Process

Wildlife Featured Species Habitat

The wildlife featured species analysis evaluates the current habitat situation, desired habitat components, and proposed allowable changes in the forest age class distribution of each featured species zone in the opportunity area. It should be noted that this analysis is not stand specific and all stands, both Management Area 7 and 8, are included in the habitat evaluation. As outlined in Figure 10, the planner first determines the percent area of grass/forbes, 0 - 10 year (Management Area 7), 0 - 10 year (total), 40^{+} year, 100^{+} year, and coniferous components and the open road density (miles/acre) component in the current habitat zones. By comparing the current habitat components (in percent area) to the target forest age class and habitat distributions in Table 8, the allowable forest age class and type modifications for each wildlife feature species zone can be estimated for the opportunity area. By quantifying the bounds of allowable habitat change, the planner considers the effects of harvesting on wildlife habitat during the development of timber sale alternatives.

Table 8. Target Forest Age Class / Habitat Distribution for Three Featured Wildlife Species

Habitat Component	Featured Species[1]		
	White-Tailed Deer *(Odocoileus virginianus)*	Black Bear *(Ursus americanus)*	Wild Turkey *(Meleagris gallopavo)*
Grasses/Forbes	3 - 5	--	3 - 5
0 - 10 years (Suitable)	<= 12	<= 10	<= 10
0 - 10 years (Total)	3 - 12	0 - 5	3 - 10
40^{+} years	50 - 75	25 - 90	60 - 80
100^{+} years	--	25+	15 - 20
Coniferous	10 - 15	--	15
Open Road Density	1 mi. / 640 acres	1 mi. / 3840 acres	1 mi. / 1,280 acres

[1](percent habitat component)

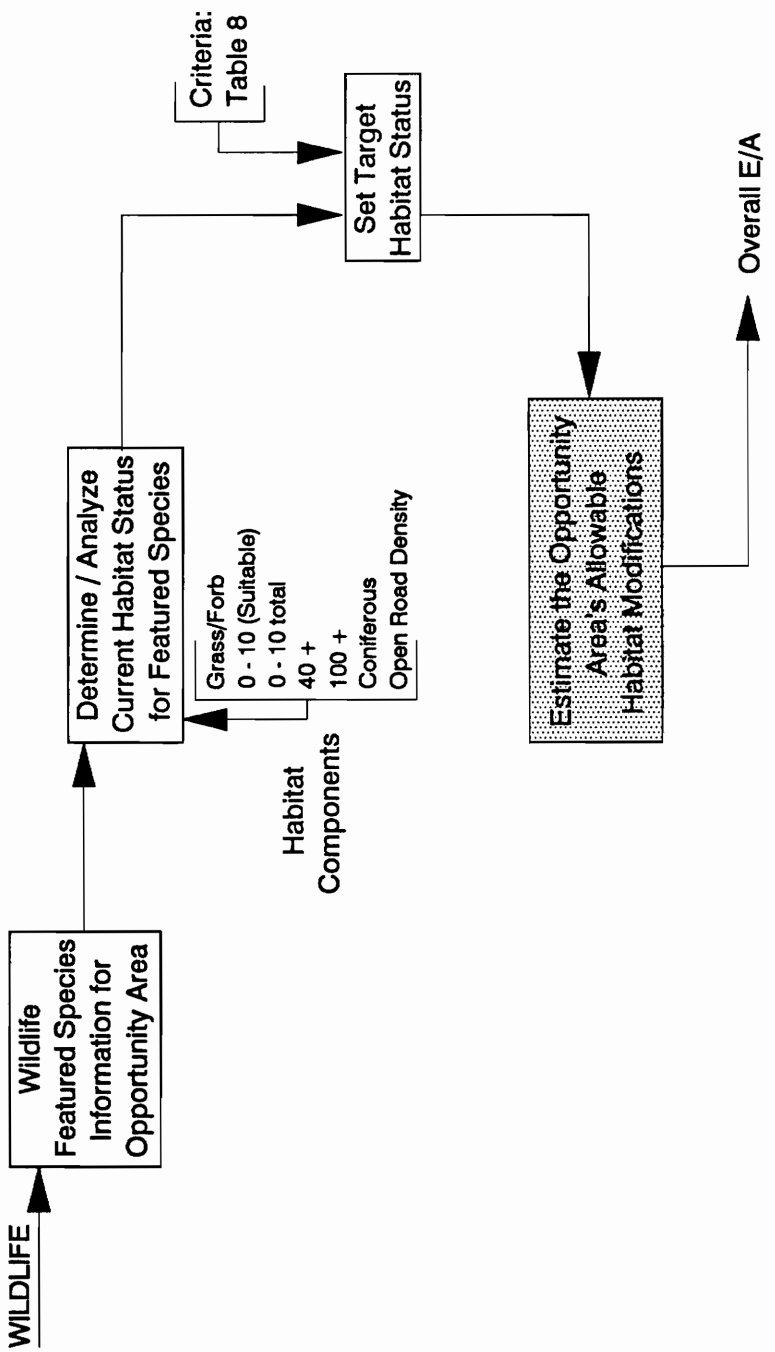

Figure 10. Wildlife Featured Species Habitat Evaluation Procedure

Best Management Practices

The best management practices (BMP's) for even-aged timber harvesting on the JNF specify the minimum water standards and guidelines for streamcourse protection. BMP's ameliorate the impacts of harvesting along stream and riparian areas by partially or totally excluding harvesting activities within a certain protection or buffer zone. As illustrated in Figure 11, the width of a buffer zone is based on the type of stream (perennial or intermittent), the presence of trout fisheries, and the type of harvesting system used. For each type of watercourse, a unique buffer distance is assigned by the planner and a stream buffer corridor is created. These buffer corridors are called streamside management zones (SMZ). In each SMZ, BMP restrictions stipulate that only the partial removal of trees or no harvesting can occur within a stream buffer corridor. These restrictions reduce the net area and timber volume available for harvesting. The sequence of steps the planner employs for evaluating BMP's is outlined in Figure 12.

Hazardous or Unstable Soils

Methods to consider the impacts of soil erosion and sedimentation from forest management activities are currently poorly defined. An evaluation of hazardous or unstable soils is included in this decision process framework because Forest Service planners thought that a GIS-based decision support approach could perhaps help quantify this problem. It was decided that a soils *"hazard rating"* method would be based on several of the soil type characteristics available from the JNF soils database. The decision process is illustrated in Figure 13. The procedure incorporates the following JNF soils database variables: surface texture, drainage class, road and equipment limitations, seedling mortality, erosion hazard, and development restriction characteristics for each soil type. The soils evaluation process assigns a soil hazard index to each soil type. Then, the timber sale planner compares the candidate stands to the soil types and determines an average soil hazard index for each stand. The soil hazard information will allow the planner to consider the risk of operating on a specific stand in relation to other stands in the opporunity area

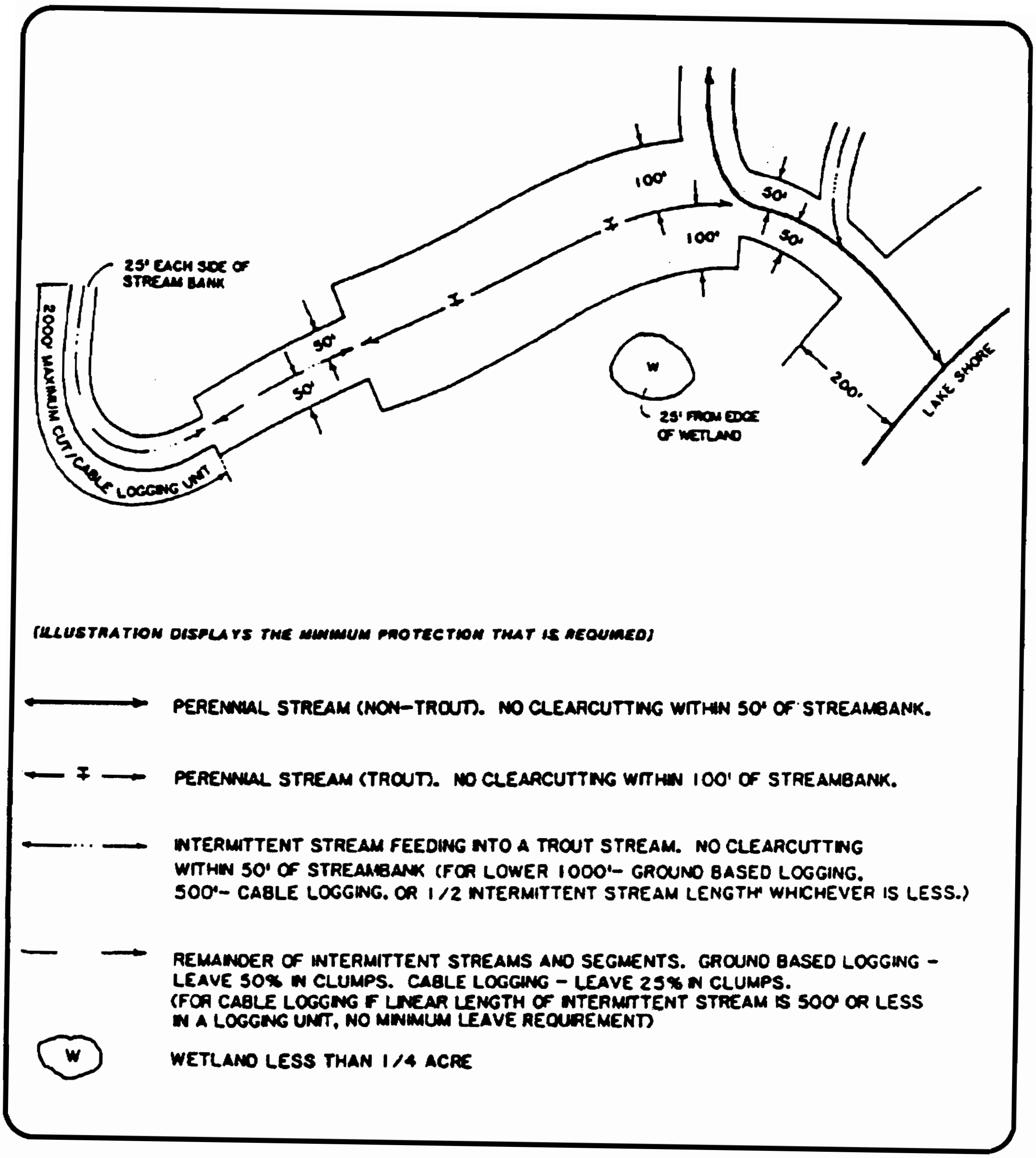

Figure 11. **Illustration of Water Standards and Guidelines for Streamcourse Protection under Even-Aged Timber Management Regimes** (USDA, 1985b)

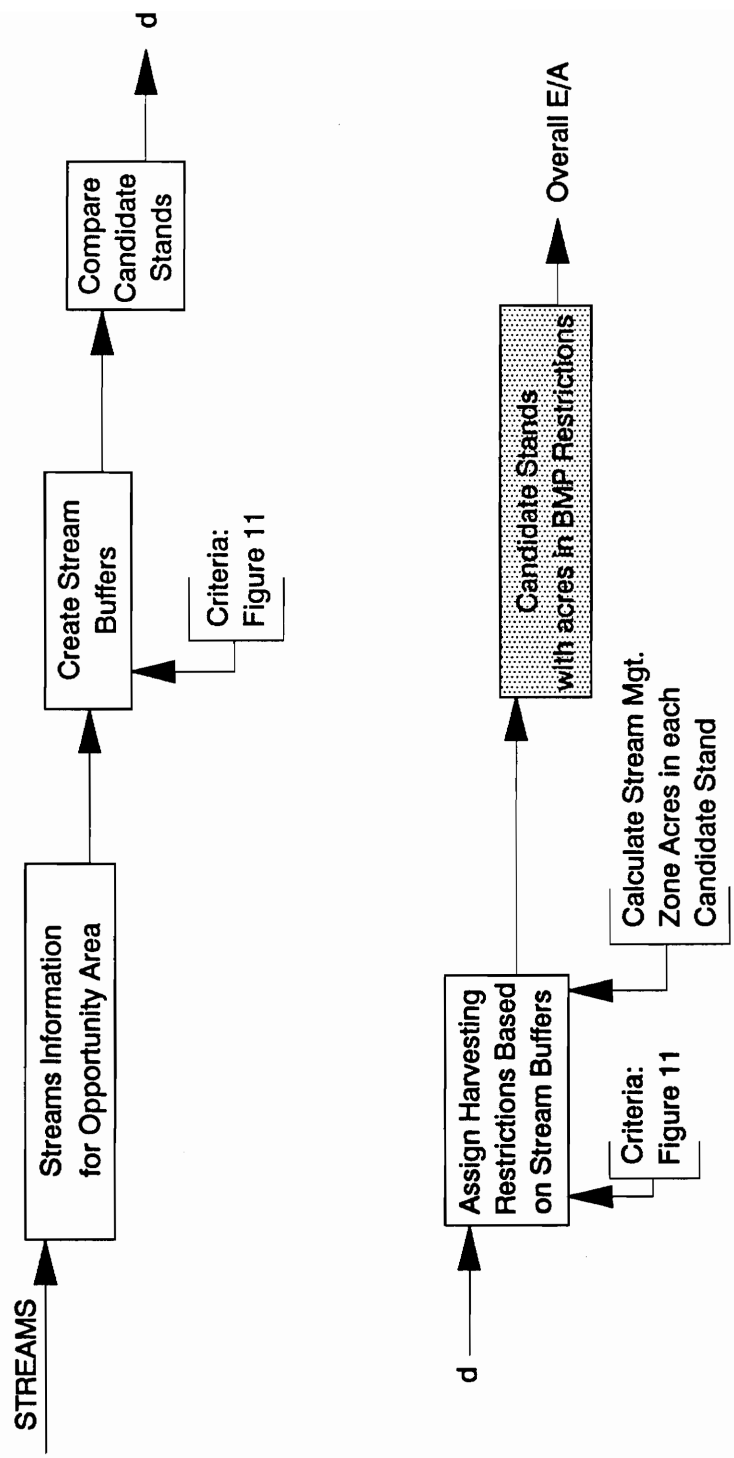

Figure 12. Best Management Practices / Streamside Management Zones Procedure

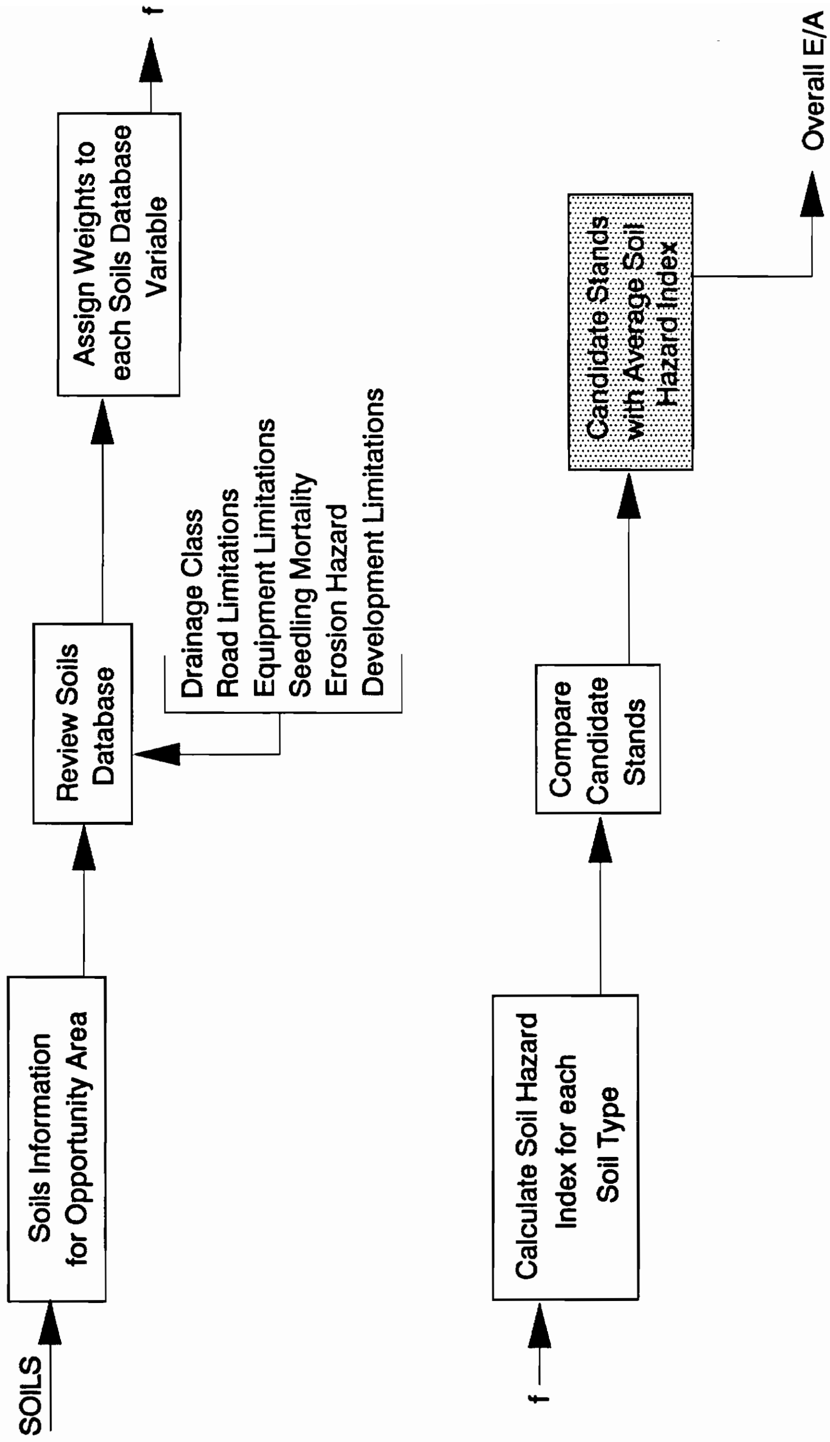

Figure 13. Hazardous or Unstable Soils Evaluation (Soil Hazard Index)

during the development of harvesting alternatives. The steps in the soil hazard rating process will be further developed in the SDSS model review.

Economic Analysis of Candidate Stands

The current Forest Service methods used to analyze the economics of timber harvesting are based on straight forward assumptions that do not account for differences in stand volume and value. Essentially, timber sale revenues for every stand are estimated by multiplying the same volume estimate (MBF/acre) and stumpage price (S/MBF). This revenue calculation assumes that the volume and species composition (hence the product values) of each stand is identical across the opportunity area. In discussions with timber sale administrators on the Jefferson National Forest, a method designed to differentiate stumpage values and harvesting costs was identified. For each candidate stand, the new approach estimates the timber volumes, determines the appraised value of the volume estimate, and includes district-wide fixed operating overhead costs. The procedure reports the total revenue per acre, total costs per acre, and net revenue per acre for harvesting each candidate stand.

Timber Volume Estimation

On the Clinch Ranger District, timber volume estimates are based on either historical forest stand volume data from previous Clinch District timber sales and/or from current information assembled by the planner. The historical volume database, listed in Appendix B, includes the tallied volumes by species groups (shown in Table 9) by forest type, stand condition class, and site index. Volumes are reported in thousand board feet (MBF) per acre for sawtimber and hundred cubic feet (CCF) or cunits per acre for pulp and roundwood. For each candidate stand, the timber sale administrator checks the historical database for the unique combination of forest type, stand condition class, and site index that matches a candidate stand's parameters. If a match cannot be found, a volume estimate from a stand of similiar characteristics is used or volume projections are specified by the planner. With the volume information for each species group assigned to each candidate stand, the planner can proceed to the next step in the economic analysis.

Table 9. Species Group Designations[1]

Group	Species
D - other hardwoods	Hickory, Blackgum
F	White Pine
P	Virginia Pine, Pitch Pine
E	Hemlock
A	Yellow Popular, Red Maple, Cucumber, Ash, Black Cherry, Basswood, Sugar Maple
C - mixed oak	Scarlet Oak, Chestnut Oak, Black Oak
G	White Oak
B	Northern Red Oak
001	softwood pulp and roundwood
004	hardwood pulp and roundwood

[1]Species groups ordered identically to Forest Service volume data.

Timber Value Estimation

The timber appraisal approach currently used by timber sale planners calculates an appraised timber value for each candidate stand by multiplying a current average price of stumpage (S/MBF) by a single volume estimate (MBF/acre) for all candidate stands. This timber valuation approach does not differentiate stands that may be more or less difficult to harvest. Factors such as temporary road construction, types of harvesting systems, wood transportion distances, and other site specific conditions should be considered because stumpage value is affected. An approach that accounts for the effects of stand location and operability conditions in the appraisal process was developed using an existing Forest Service harvesting cost adjustment procedure. In the GIS-based approach, this procedure will be applied to every candidate stand in the opportunity area.

After estimating the base stumpage value (average value of stumpage on the Ranger District) of each candidate stand, a series of cost adjustments (per MBF or CCF unit of wood handled) are calculated for each of the following: the type of harvesting system, woods to mill transportation, road maintenance, temporary road construction (i.e. landings, skid roads, access roads less than a quarter mile), and post-harvest seeding and fertilization of skid trails, skid roads, and temporary roads. With the harvesting cost adjustments factored into the base stumpage value of each candidate stand, a more realistic stumpage value that accounts site specific harvest and transport costs is then used to estimate total revenues. Equations and data requirements for each adjustment factor will be presented and discussed in the decision modeling section.

Overhead Costs

The last group of costs that affects harvest revenues are fixed overhead costs unique to each ranger district on the Jefferson National Forest. Fixed costs include harvest administration, timber planning and resource support, and general administration activities. Harvest administration includes the cost of Forest Service personnel and equipment needed to administer the commercial timber sale operations for one year. Timber planning and resource support includes the cost of Forest Service personnel and equipment for silvicultural examinations, NEPA document preparation (environmental impact assessment), timber sale planning and marking, other resource support, and reforestation activities. Since these costs are multi-year in nature, the costs are amortized and only a portion of these costs are applied to any given year. General administration includes Forest Service administrative costs for general support from the district and the JNF Supervisor's office in Roanoke, Virginia. The total overhead costs are subtracted from the appraised timber value per stand determined previously. Though overhead costs are district-wide and not stand specific, their addition helps reveal the actual net revenue per acre that will be generated after harvesting each candidate stand.

The economic analysis process, summarized in Figure 14, allows the planner to compare the sale value of various stands in terms of total revenue, total costs, and net revenue per acre. This analysis (and the model described later) makes no attempt to quantify the cost of rebuilding existing permanent roads and the cost of designing and engineering new roads to inaccessible stands.

Development of Timber Sale Alternatives

In the previous three decision steps, the timber sale planner has identified the stands suitable for timber sales, evaluated site specific environmental and social constraints affecting these stands, and quantified the economics of harvesting each stand. The last step in the timber sale planning process involves developing a set of timber sale alternatives that emphasize specific resource use objectives over the planning period. The end result of this procedure is a harvest schedule (i.e. list of stands to be harvested) based on the goals of each alternative.

The management objectives for an opportunity area are typically a function of the spectrum of issues and concerns identified during the public involvement process. The Forest Service interdisciplinary team approach involves evaluation by personnel of different resource management training and responsibilities. They assess the site specific stand-level information prepared in earlier analyses and design several timber sale alternatives that best reflect the public's interests.

Before developing a harvest schedule, the planner also considers the length of the timber sale planning period, the volume of timber to be harvested annually, the location and size of recent or planned harvests, and the effects of management activities on wildlife featured species habitat. For each alternative, the

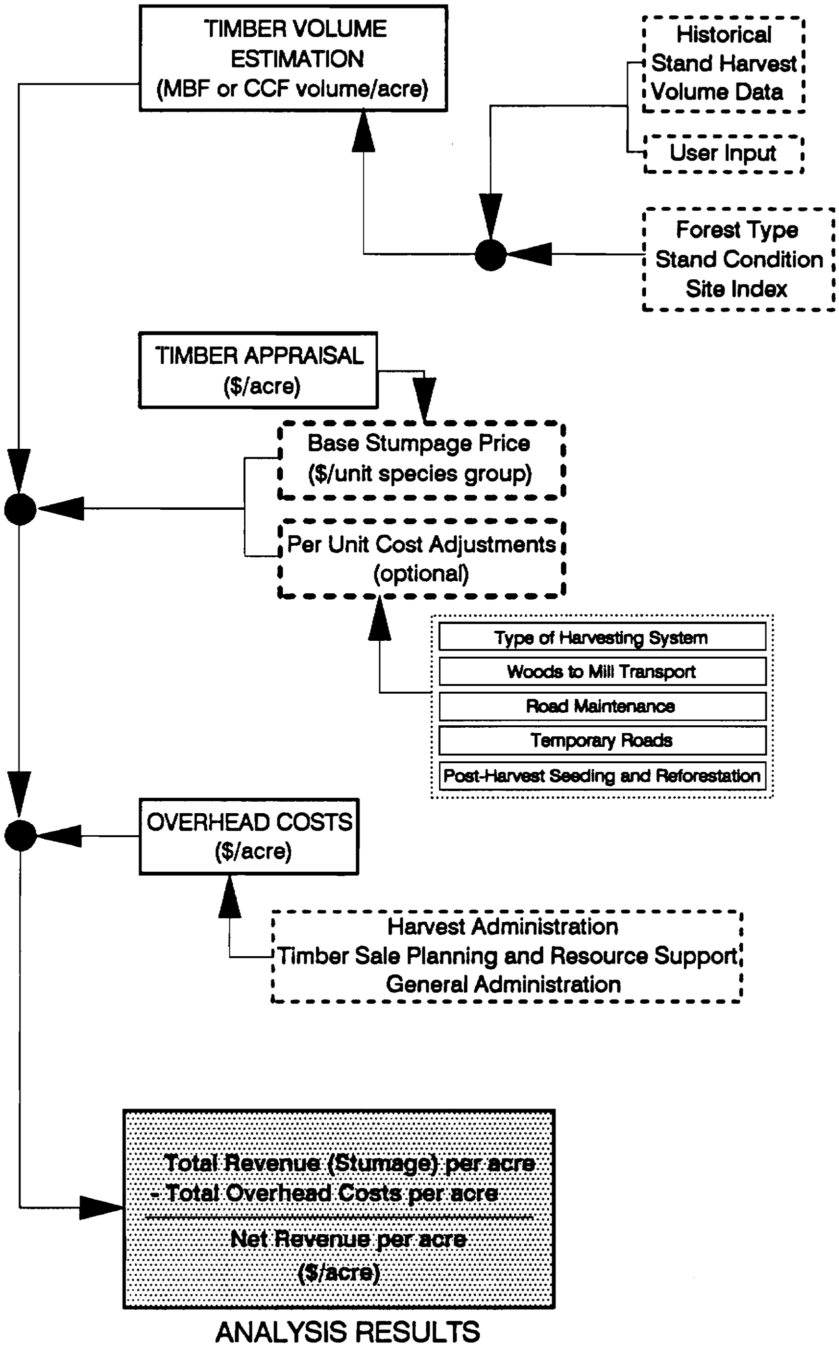

Figure 14. Decision Process for the Economic Analysis of the Candidate Stands

timber sale planner designates the number of years for the plan and the average annual timber harvest. An individual year's harvest can exceed the annual allowable cut average as long as the total timber volume removed remains within the total allowable cut for the planning period. When selecting stands to be harvested, the location and size of cut stands is a factor to be considered. Under current Forest Service guidelines, timber cannot be harvested within 330 feet of an adjacent stand less than 20 years in age. The harvest area is also limited to a maximum of 40 acres. Therefore, it is possible to have more than one harvest in a stand larger than 40 acres. To maintain the desirable distribution of stand age classes in the opportunity area, the projected habitat status for the featured wildlife species is checked at the end of the scheduling process.

The methodology for developing harvesting alternatives, shown in Figure 15, is a subjective and iterative process heavily dependent on the planning team's knowledge of the opportunity area's resource management objectives. Throughout this process, the timber sale administrator makes the scheduling decisions by reviewing site specific information and then specifying the acreage to be cut. The total impact of a timber sale plan is summarized manually for each opporunity area.

Once a set of timber sale alternatives are developed, maps displaying each alternative and tabular reports describing the stands to be harvested during the planning period are created to support the environmental review document for the opportunity area. This document is prepared for the public, so they can review, assess, and comment on the various short term resource management alternatives developed for the opportunity area.

In this section, the timber sale planning decision steps used by timber sale administrators on the Jefferson National Forest have been presented and discussed. This decision process, summarized in Figure 16, is the framework for the spatial decision support system model reviewed in the next section of this chapter.

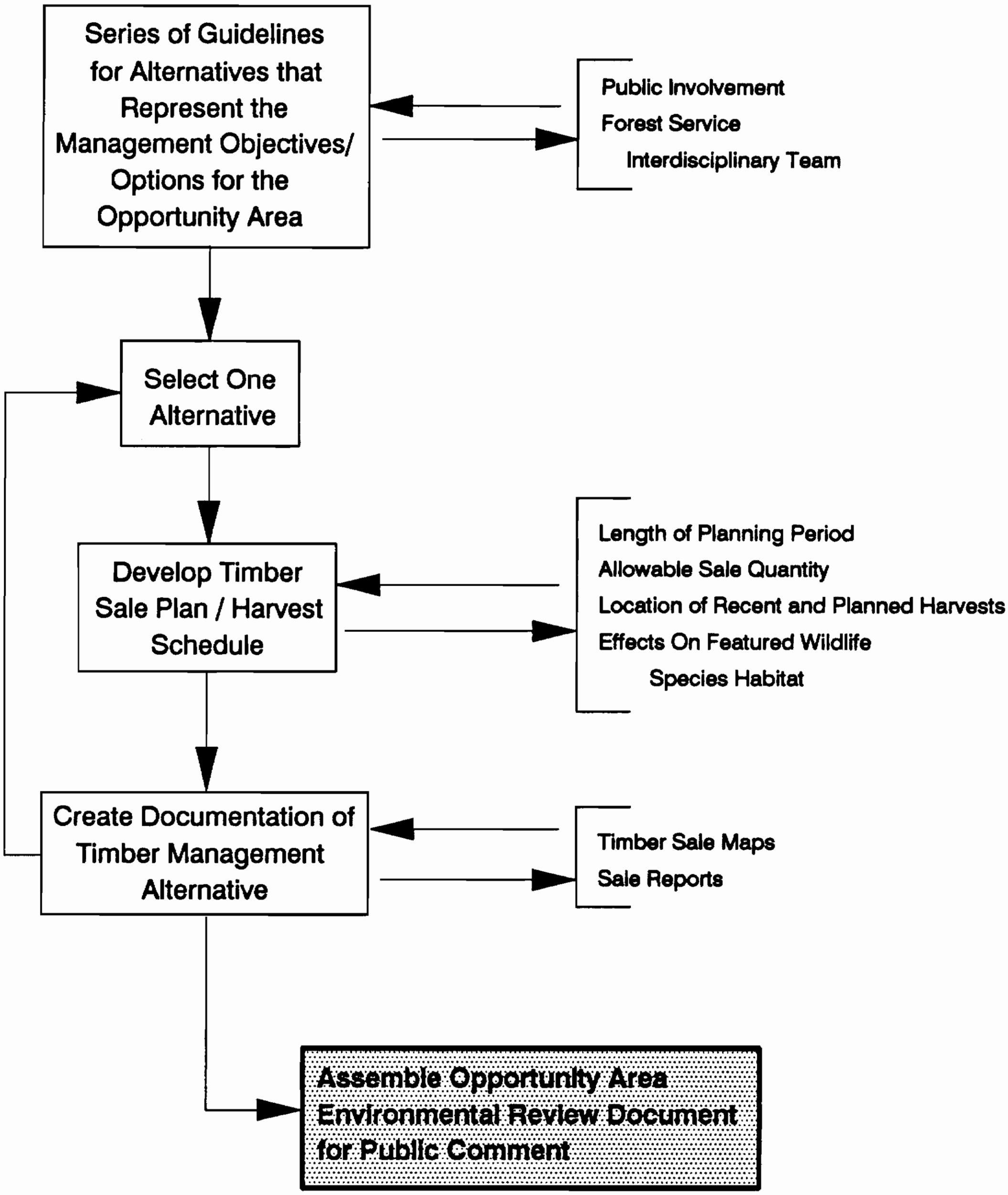

Figure 15. **Development of Timber Sale Alternatives Procedure**

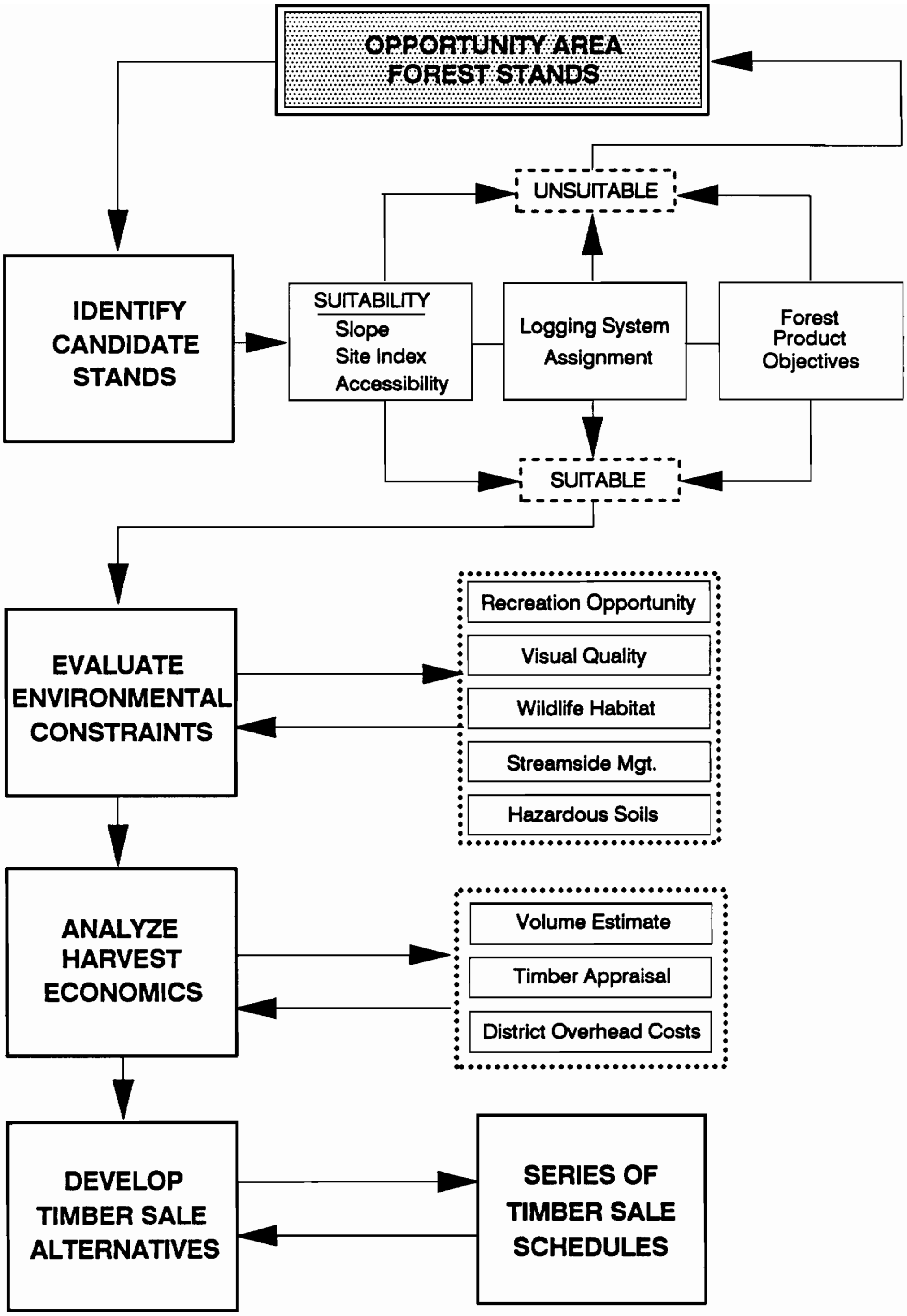

Figure 16. **Decision Methodology for the Prototype Spatial Decision System for Timber Sale Planning**

Spatial Decision Support System Model

The next step in the development of the spatial decision support system (SDSS) for timber sale planning models the timber sale planning decision process described in the previous section. The section describes the integration of timber sale planning decision procedures with a spatial and tabular database, spatial analysis techniques, and a fluent user interface in a ARC/INFO GIS environment. This section provides a brief review of the SDSS model design, ARC Macro Language (AML) operations, and assumptions made in developing the SDSS model.

The SDSS user interface is a hierarchical AML menu structure designed to control the decision making process. For this prototype SDSS, over eighty AML programs and thirty AML menus were developed to model the timber sale planning decision process. The first menu in the SDSS, shown in Figure 17, is the parent menu of all subsequent menus. The menu system is designed such that the planner selects successive menu operations from left to right using a series of pulldown menus. For each menu header, the planner should execute each operation in the order listed before proceeding to the next analysis to the right. Graphical support for communicating with the user is done on a single screen in ARC/INFO's ARCPLOT map display environment. The screen display is organized with the pulldown menus across the top of the screen, thematic information displayed in the center of the CRT monitor, a map legend is on the bottom right area, and an area for general analysis information (i.e. current analysis coverage, date and time, etc.) can be found in the upper right side of the screen. A sample screen of the SDSS working area is shown in Figure 18.

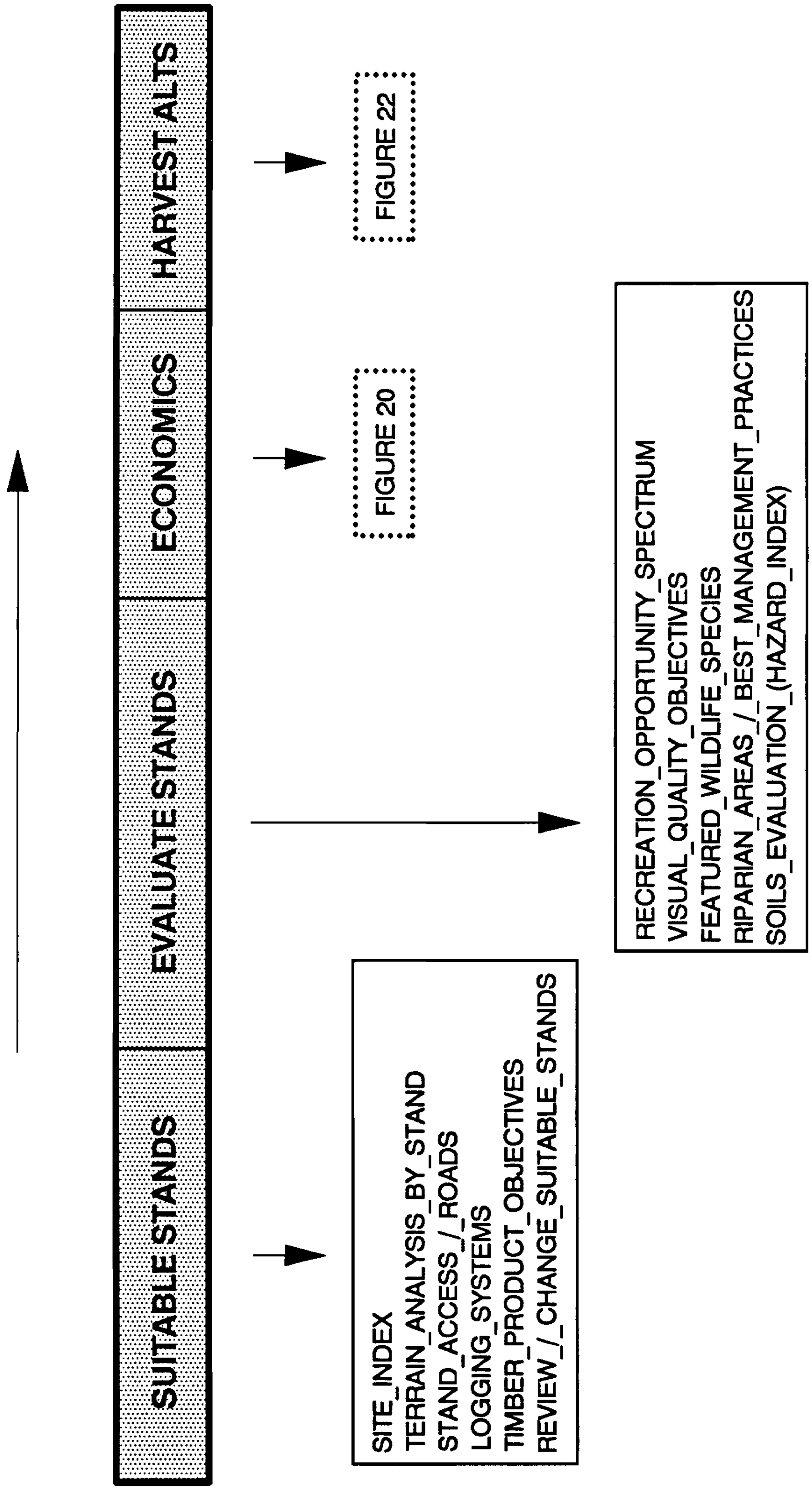

Figure 17. Spatial Decision Support System for Timber Sale Planning AML Menu for all Decision Support Procedures

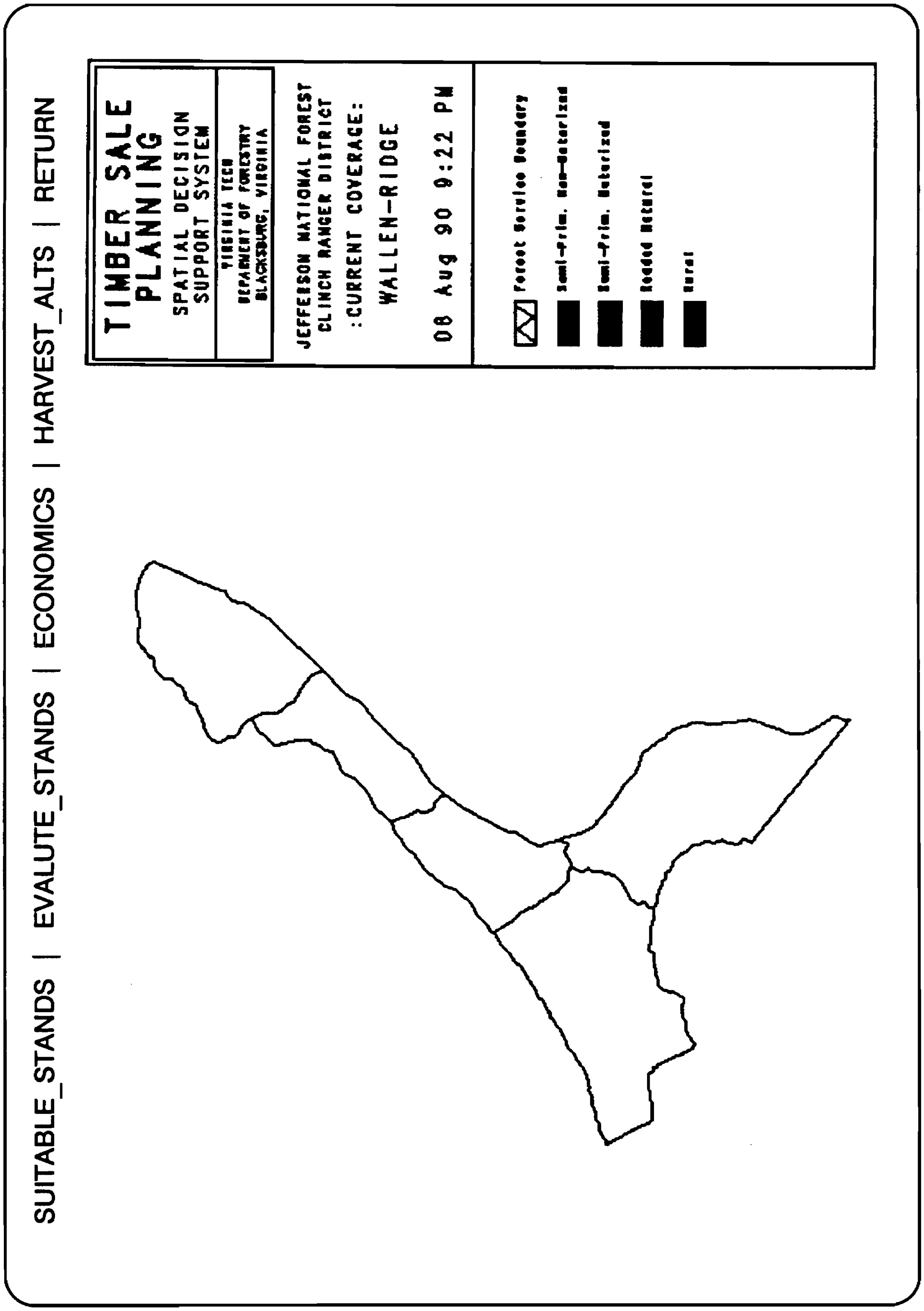

Figure 18. Sample Screen Display of the SDSS Working Area

The SDSS is designed to emulate the timber sale planning component of Opportunity Area Analysis by performing the following four interrelated site specific planning steps in a GIS environment:

(I) Identification of stands suitable for timber sale planning in the opportunity area;

(II) Evaluation and analysis of environmental and social constraints specific to each candidate stand;

(III) Economic analysis of the candidate stands; and

(IV) Development of timber sale alternatives for a short term planning period.

Each of the four operations is a separate decision module in the SDSS in which data input, spatial analyses, and graphical and tabular reporting are fully supported. These steps in the decision process are sequential and the results of each step are typically required as input to successive decisions.

To initiate the SDSS model, the planner submits the AML directive - &RUN - and the filename of the AML program - TIMBER - in ARC/INFO's ARCPLOT environment. The first input menu in the SDSS requires the planner to select an opportunity area for timber sale planning. Once this selection is complete, the planner can begin by executing each decision modules.

Module I - Identification of Suitable Candidate Stands

The "Identification of Suitable Candidate Stands" module determines the group of stands available for timber harvesting in the current planning period. This decision module evaluates Level I and Level II suitability parameters and assigns a suitability classifications to each stand on the opportunity area. The planner initiates Module I operations by selecting the SUITABLE_STAND header from the menu structure (Figure 17). Six sub-modules (listed below the SUITABLE_STAND header) are available for evaluating stand suitability. Sub-modules SITE_INDEX, TERRAIN_ANALYSIS_BY_STAND, and STAND_ ACCESS_/_ROADS are for Level I suitability and LOGGING_SYSTEMS and TIMBER_PRODUCT

OBJECTIVES are used to evaluate stands for Level II suitability. The last sub-module in this group, REVIEW/_CHANGE_SUITABLE_STANDS, is used to summarize suitability results.

Level I Suitability

Level I suitability evaluates the site index, terrain characteristics, and accessibility of each stand in the opportunity area for Management Area 7 or Management Area 8 classifications. The AML sub-modules programmed to support this analysis, SITE_INDEX, TERRAIN_ANALYSIS_BY_ STAND, and STAND_ ACCESS_/_ROADS, parallel the decision process described earlier.

SITE_INDEX

The site index of stands on the opportunity area can be displayed in one of three ways: by the forest plan standards and guides (Table 5), user specified ranges of site index, or discretely stand by stand. User specified site index categories are selected by the planner and displayed graphically. The AML program queries the forest stand coverage where site index information, a CISCII stand level attribute, has been linked to the stands.

TERRAIN_ANALYSIS_BY_STAND

Two methods of slope analysis were used: (1) a lattice or grid-based model; and (2) a triangulated irregular network (TIN) model to determine the terrain characteristics of each stand. The grid-based lattice approach, diagrammed in Figure 19, first generates a lattice file from digital elevation model (DEM) data. Then utilizing the LATTICEPOLY command in ARC/INFO's TIN software, the slope of each cell in the lattice altitude matrix is determined. After overlaying the forest stand coverage, a cell area-weighted average of slope for each stand is calculated as follows:

$$\text{Average Slope of Stand}_i = \text{Sum of } (\mathbf{S_{ij}} * \mathbf{A_{ij}}) / \text{Sum of } \mathbf{A_{ij}}$$

where: $\mathbf{S_{ij}}$ = Slope of cell or facet **j** within stand **i**

$\mathbf{A_{ij}}$ = Area of cell or facet **j** within stand **i**

To classify the slope values found within a stand, the slope values of adjacent cells are amalgamated to form polygons using the slope classification system presented in Table 6.

The second analysis technique, also shown in Figure 19, is based on the triangulated irregular network (TIN) model. This approach uses a continuous two dimensional surface of adjacent and nonoverlapping triangles developed from irregularly spaced points with x, y coordinates and z values (elevations). The TIN data structure includes topological information between points and their closest neighbors. The polygon attribute file for each TIN triangle *(facet)* contains its slope, aspect, and slope area. Unlike the fixed resolution of altitude matrices, the generation of a TIN keeps DEM points in areas of complex relief and generalizes points in areas of simple relief. In ARC/INFO's TIN software, the point generalization is specified by the user as a maximum allowable error range between z values in the output TIN and mesh points in the lattice file. A small z_tolerance produces a large number of facets in the output TIN. A minimum z_tolerance of 6.0 meters, determined by the ARC/INFO TIN software, generalized the digital elevation model data to produce the TIN coverage. After overlaying the stands coverage onto the TIN coverage, the average stand slope and the slope classes within a stand were calculated for each stand.

The ARC/INFO slope analysis procedures, diagrammed in Figure 19, are done before the planner initiates the SDSS model. In this sub-module, the results of the lattice and TIN models are compared by the planner. These comparisons are done to note the differences between the distribution of slope classes within a stand and the average stand slope and to decide which slope method results will be used in suitability classifications and later timber sale plannning decision (i.e. assignment of harvesting systems).

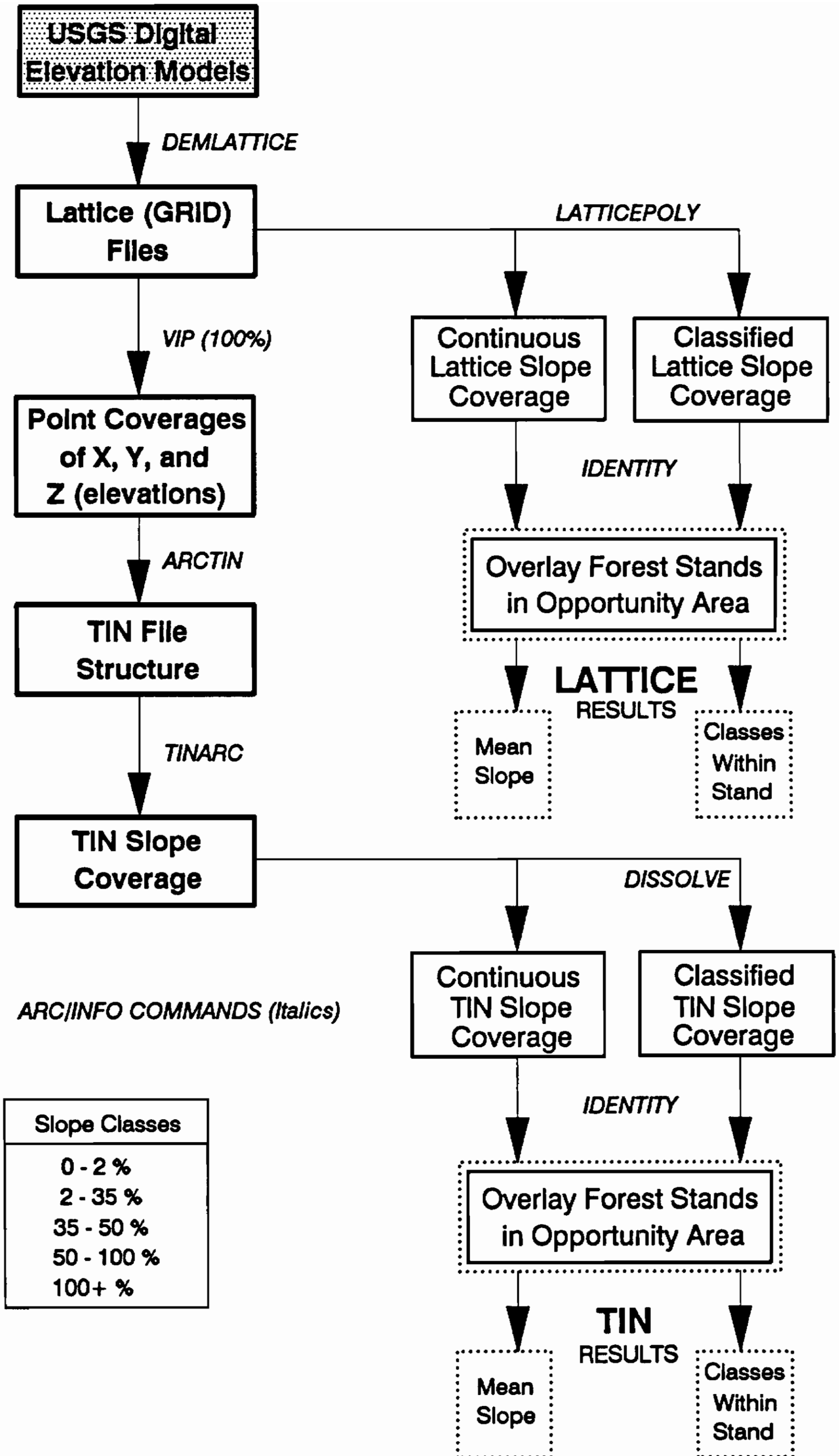

Figure 19. ARC/INFO Slope Analysis Procedures for Lattice and TIN Methods

The SDSS presents the lattice or TIN slope classes within each stand (selected by the user) in a color-coded graphic display. The average stand slope is also listed at the top of the screen.

STAND_ACCESS_/_ROADS

Access for timber management activities on the opportunity area is a function of the access or buffer corridor along Forest Service roads. Stand access classifications (either roaded or unroaded) are determined by querying the existing Forest Service road network in the opportunity area, defining the criteria for road buffer distances by road class (i.e. one-quarter mile), generating a road buffer coverage, and updating the access classification of each stand. Stand access classifications are presented to the user in a display of roads by road class, their buffer corridors, and stands and in a tabular screen listing of *"roaded"* and *"unroaded"* stands.

After executing the three Level I suitability SDSS sub-modules, the planner can evaluate Level I stand suitability based on the criteria given in Table 5. The sub-module REVIEW_/_CHANGE_SUITABLE_ STANDS allows the planner to view results of the suitability analysis, change the suitability of any stand, and write the final Level I suitability to the set of stands currently under analysis. The planner can change the suitablility of any stand to account for any anomalous stand access or average stand slope spatial analysis results or to incorporate the planner's knowledge of the site specific stand characteristics that influence management area classification.

Level II Suitability

Level II suitability further evaluates Level I suitable stands by considering the availability of logging systems and the timber product objectives of the current land and resource management plan. The assignment of logging systems is performed in sub-module LOGGING_SYSTEMS and then the timber product objectives are specified in sub-module TIMBER_ PRODUCT_OBJECTIVES.

LOGGING_SYSTEMS

The factors influencing the logging system assignment decision process are average stand slope and logging system availability. Either the triangular irregular network (TIN) or the grid-based lattice terrain analysis results can be selected to obtain average stand slope information. Three types of logging systems are typically employed on the Jefferson National Forest: ground-based systems on class 1 and 2 slopes (0 - 35%), advanced ground-based systems or cable logging systems on class 3 slopes (35 - 50%), and cable yarding systems on class 4 and 5 slopes (50%+). The assignment of logging systems entails selecting the TIN or lattice average slope results and specifying which logging systems are available for the current planning period. The results of this evaluation are presented to the planner in a thematic display and tabular report of logging systems assigned to each stand.

TIMBER_PRODUCT_OBJECTIVES

The timber product objectives for Management Area 7 specify the minimum rotation ages for the five timber working groups (upland hardwoods, cove hardwoods, white pine, hardwood pine - normal, and hardwood pine - low) on the Jefferson National Forest. The forest plan guidelines (Table 7) list suitable rotation age ranges for each working group of timber. The analysis procedure in this sub-module allows the planner to determine whether or not a stand is a candidate for timber sale planning by entering a rotation age for each timber working group listed on the SDSS input menu. (The JNF Land and Resource Management Plan standards are default values.) Then, the stands meeting the rotation age criteria are reselected from the stand coverage and displayed to the planner by working group.

Using the results of Level II analyses, the planner can identify the suitable candidate stands for timber sale planning during the current planning period. Sub-module REVIEW_/_CHANGE_SUITABLE_STANDS allows the planner to reselect candidate stands from the group of Level I suitable stands in the opportunity area if each stand meets the current timber product objectives and has been assigned a logging system. The suitability classification of each stand is presented to the planner in a graphical color-coded display and a tabular listing on the screen. This sub-module also permits the modification of stand suitability for any stand and the acceptance of final Level II suitability by the planner. Once a set of Level II suitable stands has been identified, these stands are candidates for timber sale planning in the next three decision modules.

Module II - Evaluation and Analysis of the Candidate Stands

Each candidate stand for timber sale planning is evaluated based on the following site specific environmental and social concerns: (a) effects on the Recreation Opportunity Spectrum, (b) effects on Visual Quality Objectives, (c) effects on wildlife featured species habitat, (d) best management practices (BMPs), riparian areas, and streamside management zones, and (e) areas with hazardous or unstable soils. Five SDSS sub-modules programmed to support this analysis are selected from the EVALUATE_STANDS header (Figure 17). They include:

(a) RECREATION_OPPORTUNITY_SPECTRUM

(b) VISUAL_QUALITY_OBJECTIVES

(c) FEATURED_WILDLIFE_SPECIES

(d) RIPARIAN_AREAS_/_BEST_MANAGEMENT_PRACTICES

(e) SOILS_EVALUATION_(HAZARD_INDEX)

RECREATION_OPPORTUNITY_SPECTRUM

The Recreation Opporunity Spectrum (ROS) is a land classification system that demarcates lands that contain a variety of potential recreational experiences. In this sub-module, the SDSS presents the opportunity area's ROS classifications in a color-coded graphical display and computes the acreage of each ROS class within a candidate stand by intersecting the ROS coverage with the candidate stand coverage. The distribution of ROS acres in each candidate stand is reported to the user in a tabular screen listing. To finish the ROS evaluation, the acreage values are appended to each candidate stand in the candidate stands coverage. The ROS information will be weighed during the development of timber sale alternatives.

VISUAL_QUALITY_OBJECTIVES

Visual Quality Objectives are a qualitative system of visual resource management used to qualify the public's concern for scenic beauty and natural diversity. Similiar to the ROS sub-module, the VQO analysis illustrates the distribution of VQO classes across the opportunity area in a color-coded graphical display and then calculates the acreage of one or more VQO class within each candidate stand by spatially overlaying the VQO coverage onto the candidate stands coverage. To complete this evaluation, the VQO acreage information is reported to the planner in a screen listing and appended to the candidate stands coverage. The harvesting modifications and restrictions associated with each VQO class are considered when developing timber sale alternatives.

FEATURED_WILDLIFE_SPECIES

The FEATURED_WILDLIFE_SPECIES sub-module allows the planner to ascertain the opportunity area's current habitat situation and estimate the allowable habitat changes. Habitat status is measured by the distribution of forest age classes and habitat types across the opportunity area. Following the decision methodology shown in Figure 10, this sub-module displays the current location of grasses/forbes, 0 - 10 year old stands (Management Area 7), 0 - 10 year (total), 40^{+} year, 100^{+} year, and coniferous habitat components. The acres in each habitat component and the open road density (total miles of Forest Service roads / total OA acreage) is reported to the planner in a tabular listing. From this analysis, the planner can estimate the allowable habitat and age class changes by comparing the distribution of habitat components in each feature species zone to the target forest age class and habitat distributions for the featured species (Table 8).

RIPARIAN_AREAS_/_BEST_MANAGEMENT_PRACTICES

The RIPARIAN_AREAS_/_BEST_MANAGEMENT_PRACTICES sub-module allows the planner to consider the effects of riparian and streamside management zones when developing harvest plans. The width of a stream buffer zone is dependent on the type of stream (perennial or intermittent) and the presence of trout fisheries, as described in the streamside management zone (SMZ) specifications in Figure 11. For each type of watercourse, the planner assigns a SMZ buffer width. Then, a stream buffer coverage is generated and presented in a graphical display containing the streams, their buffers, and the candidate stands. The calculation of SMZ acres impacted in each candidate stand is computed by overlaying the stream buffer coverage onto the candidate stands coverage. The SMZ acreage is appended to the candidate stands coverage and reported to the planner in a tabular screen listing. This acreage information provides an indication of the potential reduction in harvestable stand area and timber volumes due to BMP's.

SOILS_EVALUATION_(HAZARD_INDEX)

Since no established approach for soils evaluation is used on the Clinch Ranger District, a procedure for evaluating site specific soil erosion and sedimentation potential from resource management activities was developed. The SOILS_EVALUATION_(HAZARD_INDEX) sub-module classifies hazardous or unstable soil types by a hazard index. The soil hazard index is based on the variables in the JNF soils database which contains drainage class, road limitations, equipment limitations, seedling mortality, erosion hazard, and development restrictions for each soil type in the digital soils coverage. This sub-module first displays soil variables requested by the planner in a series of thematic maps. The values for each database parameter is an integer greater than one where a larger value indicates a less hazardous or *"better"* condition. The timber sale planner, knowing the characteristics of each soils type, assigns weights to each database variable, and the soil hazard index is calculated as follows:

$$\text{Hazard Index Value of Soil}_i = \text{Sum of } (\mathbf{W_p} * \mathbf{S_{ip}}) / \mathbf{R_p}$$

where $\mathbf{R_p}$ = range of values of soil parameter **p**

$\mathbf{S_{ip}}$ = value of parameter **p** for soil type **i**

$\mathbf{W_p}$ = user assigned weight for parameter **p**

Once the soil hazard index calculation is complete, all soil types are ranked from 1 to 6, where the higher hazard index value indicates a lower risk of soil related site impacts. Since the soil type boundaries are usually configured differently than the forest stand boundaries, spatial analyses intersecting the soils coverage and the candidate stands coverage may yield several soil types within a specific stand. The following equation weighs the area of each soil type within a stand and calculates an average soil hazard index.

$$\text{Average soil hazard index for Stand}_i = \text{Sum of } (\mathbf{H_{is}} * \mathbf{A_{is}}) \; / \; \text{Sum of } \mathbf{A_{is}}$$

where: $\mathbf{H_{is}}$ = Soil hazard index of soil type s within stand **i**

$\mathbf{A_{is}}$ = Area of soil type s within stand **i**

The final soil hazard index (1 - 6) of each candidate stand is appended to the candidate stands coverage and presented to the planner in a color-coded graphical display. A tabular report is also listed on the screen.

Module III - Economic Analysis of the Candidate Stands

The next main SDSS module, ECONOMICS, supports decision techniques programmed to estimate the timber volume, appraise the value of the volume estimate, and incorporate district-wide fixed operating overhead costs for each candidate stand. The objective of this analysis is to estimate the total revenue per acre, total costs per acre, and net revenue per acre for harvesting each candidate stand. The four SDSS economic sub-modules (displayed in Figure 20) include ESTIMATE_VOLUME, TIMBER_ APPRAISAL, OVERHEAD, and REVIEW_RESULTS.

ESTIMATE_VOLUME

AML routines for estimating timber volumes per acre by species group are arranged to be performed in 3 sequential steps as shown by the menu structure in Figure 21. The first step in this procedure, LINK_DATA, links the Clinch Ranger District historical stand volume data from previous Clinch District timber sales (Appendix B) to each candidate stand. This procedure searches the historical database for the unique combination of forest type, stand condition class, and site index that matches each candidate stand's attributes. The second step, UPDATE_VOLUME_ESTIMATES, has three options. The first option identifies those candidate stands with no historical volume data and allows the planner to enter current volume information. The second option updates the stands that already have volume estimates if a better volume estimate is available for a specific stand. The third options permits a quick check of the candidate stands to see which stands still have no volume information. Throughout this iterative update process, the SDSS provides the planner with screen displays that locate the current stand and tabular information listing the stand's characteristics (i.e. forest type, stand condition class, and site index) and its current volume estimate. Upon completion of the volume updates, the third step, WRITE_FINAL_ ESTIMATES, reports the candidate stands' final timber volumes in thousand board feet (MBF) per acre and hundred cubic feet or cunits (CCF) per acre for pulpwood and appends the final volumes to the candidate stands coverage. The planner now has an estimate of timber volume for each candidate stand.

TIMBER_APPRAISAL

The TIMBER_APPRAISAL sub-module is used to estimate the stumpage value of standing timber for each candidate stand. This sub-module is processed in two steps. First, the base stumpage value (average value of stumpage in the Clinch area) of the volume estimate is determined in the AML routine DETERMINE_BASE_STUMPAGE_VALUE_OF_VOLUME_ESTIMATES. The planner inputs the current stumpage prices for sawtimber ($/MBF) and pulpwood ($/CCF) by species group (Table 9). Then,

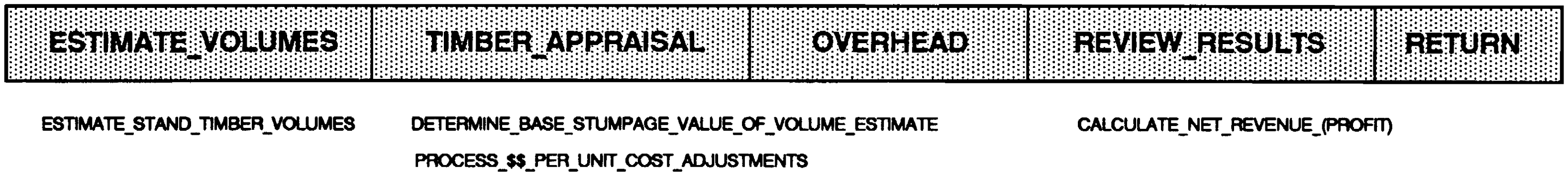

Figure 20. AML Menu for Module III - Economic Analysis of the Candidate Stands

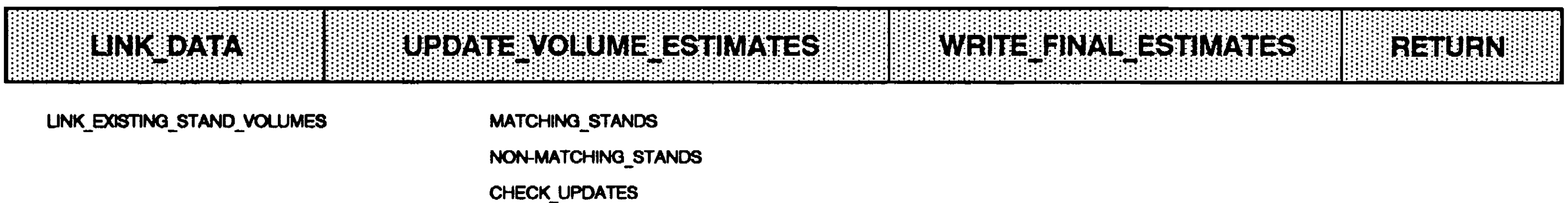

Figure 21. AML Menu for Economics Sub-Module - ESTIMATE_VOLUMES

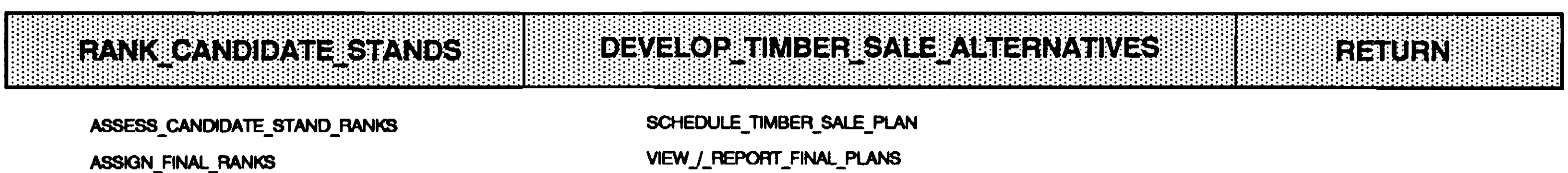

Figure 22. AML Menu for Module IV - Development of Timber Sale Alternatives

to calculate the total base value per acre for each candidate stand, the stumpage prices are multiplied by the appropriate stand volumes per acre:

Base stumpage value per Acre of Stand_i = Sum of $(\mathbf{MV_p} * \mathbf{V_{pi}})$

where: $\mathbf{MV_p}$ = Base stumpage value per unit volume for species group **p**

$\mathbf{V_{pi}}$ = Volume per acre of species group **p** in stand **i**

The results of the base stumpage value calculations are displayed in a tabular report to the planner. The candidate stands are summarized by their stand number, total sawtimber (MBF) and pulpwood (CCF) volume per acre, and total base stumpage value per acre.

A series of cost adjustments is factored into the base stumpage value per acre to determine the actual stumpage value of each candidate stand. The second AML routine PROCESS_$$_PER_UNIT_COST_ ADJUSTMENTS computes these cost adjustments. Cost adjustments for each stand are calculated for the type of harvesting system, woods to mill transportation, road maintenance, temporary road construction (i.e. landings, skid roads, and access roads less than a quarter mile), and post-harvest seeding and fertilization of skid trails and temporary roads. Each cost adjustment is quantified in terms of a cost per MBF and CCF unit of wood handled.

Cost adjustments for the type of harvesting system (ground-based, advanced ground-based, or cable systems) are input directly by the timber sale planner. The SDSS assigns the appropriate cost adjustments ($/MBF and $/CCF) to each candidate stand using the harvesting system assigned in Module I.

Cost adjustments for woods to mill transport are evaluated by first querying the planner for a sawtimber and pulpwood cost per unit-mile ($/unit*mile) haul factor. Then, as shown in the equation below, each factor is multiplied by the stand to mill distance for each candidate stand.

Haul Costs per Unit for $\text{Stand}_i = (\mathbf{HC_u} * \mathbf{D_i})$

where: $\mathbf{HC_u}$ = Cost per unit-mile for unit **u** ($/MBF or CCF * mile)

$\mathbf{D_i}$ = Stand **i** to sawmill or pulpmill distance (miles)

Cost adjustments for road maintenance are based on the total distance traveled on Forest Service roads. The SDSS prompts the planner to enter cost per unit-mile factors for sawtimber and pulpwood. The cost of road maintenance is estimated in the following equation using the access distance on Forest Service roads to each candidate stand and the cost factors specified by the planner.

Road maintenance costs per unit for $\text{Stand}_i = (\mathbf{RC_u} * \mathbf{FSD_i})$

where: $\mathbf{RC_u}$ = Cost per unit-mile for unit **u** ($/MBF or CCF * mile)

$\mathbf{FSD_i}$ = Access distance on Forest Service Roads to stand **i**

Cost adjustments for the construction of temporary roads are considered when a candidate stand has limited road access. In this adjustment procedure, the planner inputs an estimate of the average construction cost per mile for a temporary road and selects the stands requiring temporary roads. Then, stand by stand, the SDSS displays each selected candidate stand's location and current road access. The planner manually traces the temporary road into the stand with the graphics cursor (i.e. mouse). The SDSS computes the actual distance from the graphically traced distance and prompts the planner for approval. The cost of temporary roads is calculated as follows:

Temporary road costs per unit for $\text{Stand}_i = ((\mathbf{TRC} * \mathbf{TD_i}) / \mathbf{V_{iu}} * \mathbf{A_i}) * \mathbf{PV_{iu}}$

where: **TRC** = Average construction cost of temporary roads ($/mile)

$\mathbf{TD_i}$ = Temporary road distance for stand **i**

$\mathbf{V_{iu}}$ = Volume per acre of **u** (sawtimber {MBF} or pulpwood {CCF})

$\mathbf{A_i}$ = Acres in stand **i**

$\mathbf{PV_{iu}}$ = Percent of total volume in stand **i** of sawtimber or pulpwood

After processing each cost adjustment, the SDSS reports the cost per MBF and CCF of the activities, the total cost adjustments per unit, the volumes (sawtimber and pulpwood) per acre, and the total impact of cost adjustments per acre.

The last cost adjustment is for post-harvest seeding and fertilization of skid trails, log landings, and temporary roads. The SDSS queries the user for the per unit cost adjustments ($/MBF and $/CCF) and assigns them to each candidate stand.

Using the cost information and base stumpage value of each candidate stand, the adjusted total stumpage revenue per acre can be calculated by subtracting the total cost adjustments per acre from the base stumpage value per acre for each candidate stand. To complete the timber appraisal procedure in the SDSS, the base stumpage value per acre and the total cost adjustments per acre information is appended to the candidate stands coverage.

OVERHEAD

The last step in the economic analysis procedure incorporates the overhead costs associated with timber management activities on the Jefferson National Forest. These costs include harvest administration, timber planning and resource support, and general administration activities. The SDSS queries the planner for the average cost per acre of each activity using an input menu. The total overhead costs for timber management activities is calculated and appended to the candidate stands coverage

Module IV - Development of Timber Sale Alternatives

At this point, the timber sale planner has identified the stands suitable for timber sale planning in the current short term planning period (Module I), evaluated the effects of site specific environmental and social constraints (Module II), and quantified the economics of harvesting candidate stands in the opportunity area (Module III). Throughout these analyses, the results of each module were appended to the GIS attribute file of each stand in the candidate stands coverage. This information will now be used to assist the planner in harvest scheduling decisions made in the development of timber harvesting alternatives (Module IV).

The final SDSS menu selection, HARVEST_ALTS (Figure 17), is designed to (1) rank the candidate stands for various resource management objectives (sub-module RANK_CANDIDATE_STANDS) and (2) assist the timber sale administrator in the development of timber sale plans (sub-module DEVELOP_ TIMBER_SALE_ALTERNATIVES). The AML menu structure for this procedure is diagrammed in Figure 22.

RANK_CANDIDATE_STANDS

The prototype SDSS uses a ranking procedure, shown in Figure 23, to support harvest scheduling decisions. This ranking procedure is a two step process. In the AML routine ASSESS_CANDIDATE_ STAND_RANKS, the results of the Recreation Opportunity Spectrum, Visual Quality Objectives, Best Management Practices, and soils hazards analyses from Module II and Module III economic results are condensed into stand rankings. For each Module II result, the candidate stands are sorted such that the order in which stands will be harvested does not degrade the recreation opportunities, visual quality, or water quality of the opportunity area. The economic results are simply sorted by decreasing net revenue. At the present time, SDSS is capable of ranking the candidate stands based on the following five considerations. The following rules stipulate how the SDSS ranks the candidate stands:

<u>Recreation Opportunity Spectrum</u> - ROS classifications are used to order the candidate stands (1 . . .n) by the percent area in rural, roaded-natural, and/or semi-primitive classes in each stand.

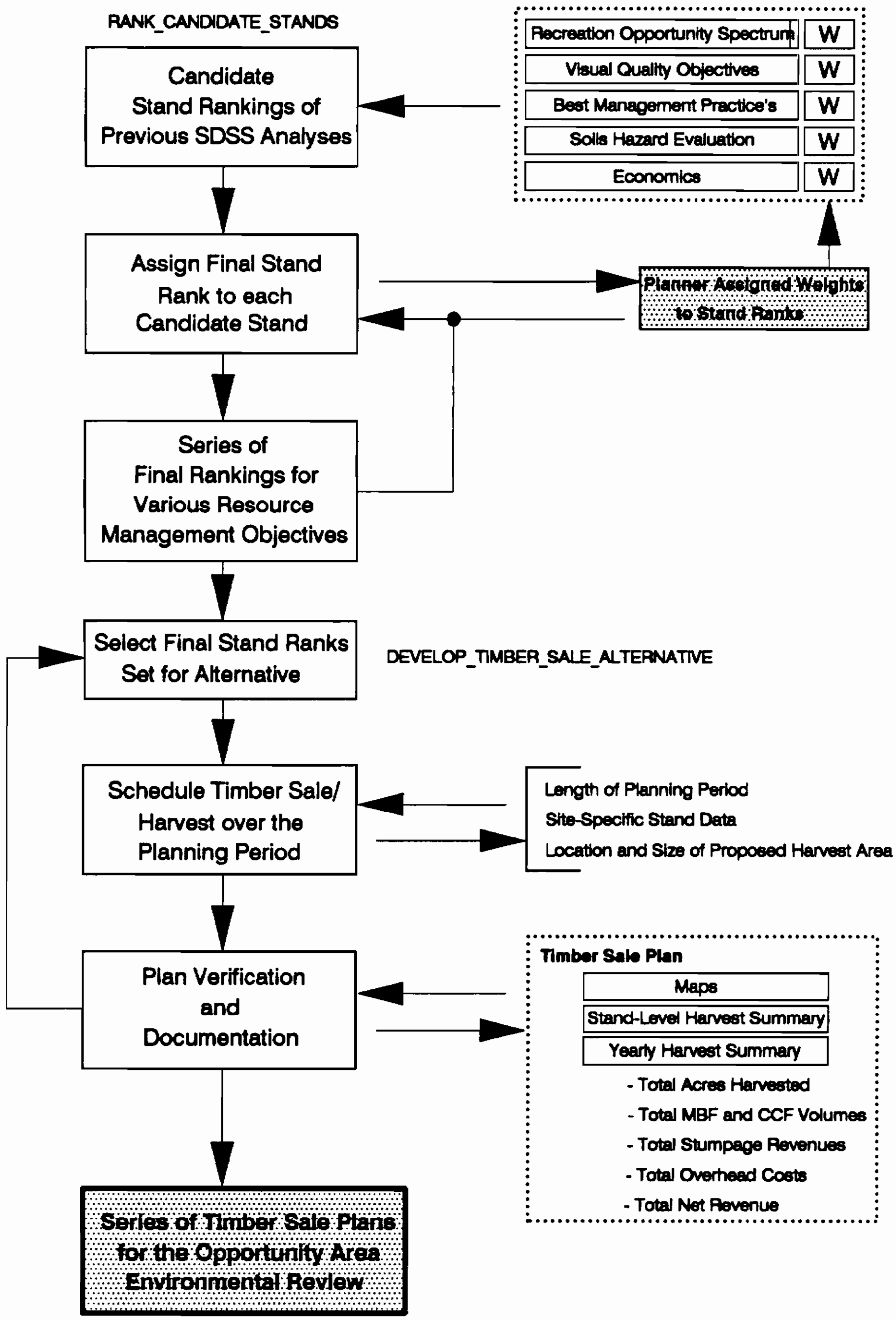

Figure 23. SDSS Procedure for Stand Harvest Scheduling / Planning

Visual Quality Objectives - VQO classisfications are used to order the candidate stands (1 . . .n) by the percent area in maximum modification, modification, partial retention, and/or retention classes in each stand.

Riparian Areas / Best Management Practices - Stand rankings are established by calculating the percent SMZ area in each candidate stand and sorting the stands (1 . . .n) from lowest to highest percent area.

Soils Evaluation (Soil Hazard Index) - Stand rankings are established by sorting the average soil hazard index. Stands are ordered (1 . . .n) from highest index (greatest risk) to lowest index.

Economics - Stand rankings are based on the potential net revenue per acre. The stands are ordered (1 . . .n) from high to low profitability.

The SDSS presents each set of ranks in a color-coded thematic map display and tabular report listing the candidate stands and their corresponding ranks.

The second part of the ranking analysis invokes the AML routine ASSIGN_FINAL_RANK in which a final candidate stand ranking is assigned based on the planner's interpretation of the opportunity area's resource management objectives. For each timber sale alternative, the planner assigns a weight to each stand rank. This rank weighting procedure is intended to reflect the alternative's management direction. For example, if the timber sale administrator planned to only harvest stands that maximized economic return, he/she would assign a weight of 1 to the stand's economic ranks and none (0) to the other four ranks. Hence, the final ranks of the candidate stands would be ordered by level of profitability. The final rank of a candidate stand is calculated as show below:

$$\text{Final Rank of Stand}_i = \text{Sum of } (\mathbf{W_p} * \mathbf{A_{ip}})$$

where: $\mathbf{W_p}$ = user assigned weight for stand rank attribute **p**

$\mathbf{A_{ip}}$ = rank of attribute **p** in Stand **i**

A series of management alternatives can be formulated using this iterative process. Once several final rankings for the candidate stands have been developed to represent various management objectives, the planner can begin the harvest scheduling process.

DEVELOP_TIMBER_SALE_ALTERNATIVES

The final set of AML routines in the SDSS model supports the scheduling of timber sale alternatives and reporting of final timber sale plans. Harvest scheduling is done using the AML routine SCHEDULE_ TIMBER_SALE_ALTERNATIVES. The first step in this process requires the planner to select one set of final candidate stand ranks from the group of alternatives developed in the previous step. The stand ranks will assist the planner in the selection of stands by ordering suitable stands to reflect the current resource management objectives. These final ranks are displayed by color-codings on the graphics monitor; stand numbers and final ranks are also listed. Then, to quantify the number of years in the current harvest plan, the timber sale administrator specifies the first and last year of the planning period. Stands will be scheduled for harvest during this planning period.

Harvest planning is done year by year. While scheduling the actual harvest plan, the timber sale administrator queries the suitable candidate stands available for harvest, reviews site specific stand characteristics (i.e. stand acres, stand condition class, site index, economics, rankings, etc.), decides which stands to harvest in the current planning year, directs the SDSS to select those stands, and assigns an acreage to be harvested in each stand. As harvest scheduling progresses, the SDSS summarizes the total acres harvested, the total sawtimber and pulpwood volume removed, the total stumpage revenue generated, the total overhead costs experienced, and the net revenue obtained. As yearly scheduling decisions are made, these totals are updated and displayed so the planner can compare these figure with the allowable cut desired in the current alternative.

After creating several timber sale alternatives, plan verification and documentation is done by the AML routine VIEW_/_REPORT_FINAL_PLANS. For each timber sale plan, the SDSS composes a map that includes opportunity area boundaries, Forest Service ownership boundaries, streams, roads by road classifications, and stands in the harvest plan by scheduled harvest date. The SDSS reports, in tabular forms, the following stand-level information: stand number, forest type, stand condition class, site index, year of harvest, road access, harvest system assignment, sawtimber and pulpwood volumes, revenue and cost figures, intermediate and final stand ranks, harvest acres, available acres, and total stand acres. The SDSS also summarizes the harvest plan by year in a report that includes the total acres harvested, total sawtimber and pulpwood volumes, total stumpage revenue, total overhead costs, and net revenue.

Wallen Ridge Opportunity Area Case Study

The Wallen Ridge Opportunity Area on the Jefferson National Forest was identified by the Forest Service as the most suitable area to compare timber sale plans developed by the prototype spatial decision support system (SDSS) with the plans developed using the manual approach. In this section, the prototype SDSS will be used to develop a set of timber sale alternatives for the Wallen Ridge Opportunity Area. The specification of input parameters for the case study and the results of each timber sale planning module are presented in the discussion below. Since most of the SDSS results are color-coded graphical screen displays, it is difficult to adequately portray or describe the spatial relationships revealed in this planning process. A few maps are presented in this section, but most of the results in the following discussion are summarized in tabular listings.

Module I Results - Identification of Suitable Candidate Stands

To identify a group of stands for timber sale planning in the current planning period, two levels of stand suitability were evaluated in the SDSS module SUITABLE_STAND (Figure 17). Level I suitability was evaluated by the timber sale administrator in sub-modules SITE_INDEX, TERRAIN_ANALYSIS_BY_STAND, and STAND_ACCESS_/_ROADS. Level II suitability was considered in sub-modules LOGGING_SYSTEMS and TIMBER_PRODUCT_OBJECTIVES.

Level I suitability evaluates the site index, average stand slope, and stand access requirements of each stand for Management Area 7 or Management Area 8 classification. The following sub-modules were used to evaluate the stands: SITE_INDEX, TERRAIN_ANALYSIS_BY_STAND, and STAND_ACCESS_/_

ROADS. The sub-module REVIEW_/_CHANGE_SUITABLE_STANDS was used to establish management area classifications.

The site index of stands in the opportunity area was grouped by the forest plan standards and guides found in Table 5. In Wallen Ridge, 110 stands, 96.6 percent of the opportunity area, have a site index of 70 or greater; 5 stands had a site index of 60 to 69; 1 stand was in the 50 to 59 group; and the remaining 4 stands had a site index less than 50. The grouping (summarized in Table 10) were displayed in a color-coded map on the SDSS screen so the planner could review the site index of stands across the opportunity area.

Two methods of terrain analysis were used to determine average stand slope and the slope classes (Table 6) within a stand: (1) a grid-based lattice model; and (2) a triangulated irregular network (TIN) model. Slope information for the Wallen Ridge area was pre-processed for the SDSS following the procedures in Figure 19. The number of stands in each slope class (by analysis technique) is listed in Table 11. Differences between the slope analysis methods occurred in the categorization of class 2 (2 - 35%) and class 3 (35 - 50%) average stand slopes. The results of the lattice model were consistently greater than the TIN model. The mean of the difference between the lattice and TIN average stand slope is 1.4% $\pm$ 1.12% for the 120 stands. For both analysis methods, 70 stands, 62.8 percent of the opportunity area, were classified as class 2 slopes; 17 stands (13.9%) are either class 2 or class 3 depending on the method selected; 32 (22.8%) stands are class 3 slopes; and only 1 stand is a class 4 slope as shown in Table 12.

The planner reviewed the slope information stand by stand. For each analysis technique, the slope classes within each stand were displayed and the average stand slope was reported by the SDSS. After this review, it was decided that the lattice results would be used for all subsequent timber sale planning decisions.

Table 10. **Distribution of Site Index for Stands in the Wallen Ridge Opportunity Area**

SITE INDEX RANGES	0 - 49	50 - 59	60 - 69	70+	Totals
# of Stands	4	1	5	110	120
Area (acres)	108.3	25.0	105.2	5666.5	5905
% of Total Area	1.8	0.4	1.8	96.0	100

Table 11. **Number of Stands by Slope Class for TIN and LATTICE Methods**

TERRAIN ANALYSIS TECHNIQUE	Number of Stands by Slope Class		
	2	3	4
TIN	87	32	1
LATTICE	70	49	1

Table 12. **Classifications of Average Stand Slope for both TIN and LATTICE Terrain Analysis for the Wallen Ridge Opportunity Area**

SLOPE CLASSES	2	2 or 3	3	4	Totals
# of Stands	70	17	32	1	120
Area (acres)	3705.3	822.1	1345.8	31.8	5905
% of Total Area	62.8	13.9	22.8	0.5	100

There are several reasons why the lattice average stand slope results were chosen for all subsequent SDSS decisions. The lattice method of determining slopes generalized the digital elevation model (DEM) data less than the TIN approach. This difference became apparent when the planner viewed the slope classes within stands across the opportunity area. Since the lattice average slope values were on average greater than the TIN values, timber sale planning decisions based upon this information will be more conservative since harvesting operations on steeper slopes is typically more expensive for the logging contractor and less profitable for the Forest Service (i.e. deflates stumpage value). Finally, the lattice terrain analysis techniques, a grid-based approach, is a better way of representing the Wallen Ridge DEM model since the data collection methods for USGS 1:24,000 DEMs in this area are also grid-based. Research investigating the use of the lattice and TIN analysis methods in ARC/INFO and digital elevation models is needed since terrain is an important factor in the timber sale planning process.

Access for timber management activities is a function of the access buffer zone along existing Forest Service roads in the Wallen Ridge area. A stand access distance of a quarter-mile (402.25 meters or 1320 feet) for lightduty paved, lightduty unpaved, seasonal use roads, and unimproved roads was used to generate the road buffer coverage. After overlaying the buffer coverage onto the forest stands coverage, the road buffer coverage was displayed to the planner and a report listing roaded and unroaded stands was produced by the SDSS. This report is summarized in Table 13. In Wallen Ridge, 117 stands, 99.4 percent of the area, were classified as *"roaded"* and 3 stands (0.6%) were *"unroaded"*.

Table 13. Stand Access Results for the Wallen Ridge Opportunity Area

STAND ACCESS	Roaded	Unroaded	Totals
# of Stands	117	3	120
Area (acres)	5869.8	35.2	5905
% of Total Area	99.4	0.6	100

After processing the three Level I suitability SDSS sub-modules, the necessary information for making Management Area 7 or 8 classification decisions was reviewed. The sub-module REVIEW_/_CHANGE_SUITABLE_STANDS evaluated the site index, average stand slope, and stand access of each stand in the opportunity area and classified its suitability for timber production following the criteria in Table 5. The final management area classifications, Figure 24, were displayed on the screen and listed in a report to the planner. This evaluation classified 116 stands, 98.2 percent of the area, as Management Area 7 and 4 stands (1.8%) as Management Area 8 (Table 14). The site idex, average stand slope (TIN and LATTICE), stand access, and final Level I suitability of each stand in the Wallen Ridge Opportunity Area is listed in Appendix C.

Table 14. Management Area Classifications for the Wallen Ridge Opportunity Area

LEVEL I SUITABILITY	-----Suitable----- (Management Area 7)	----Unsuitable---- (Management Area 8)	Totals
# of Stands	116	4	120
Area (acres)	5796.7	108.3	5905
% of Total Area	98.2	1.8	100

Level II suitability is evaluated to determine whether or not a Level I suitable stand is a candidate for the current timber sale planning period. The SDSS sub-module LOGGING_SYSTEMS was used to assign a logging system to each stand and then the forest plan product objectives were considered in sub-module TIMBER_PRODUCT_OBJECTIVES. The candidate stands for timber sale planning were identified in sub-module REVIEW_/_CHANGE_SUITABLE_STANDS.

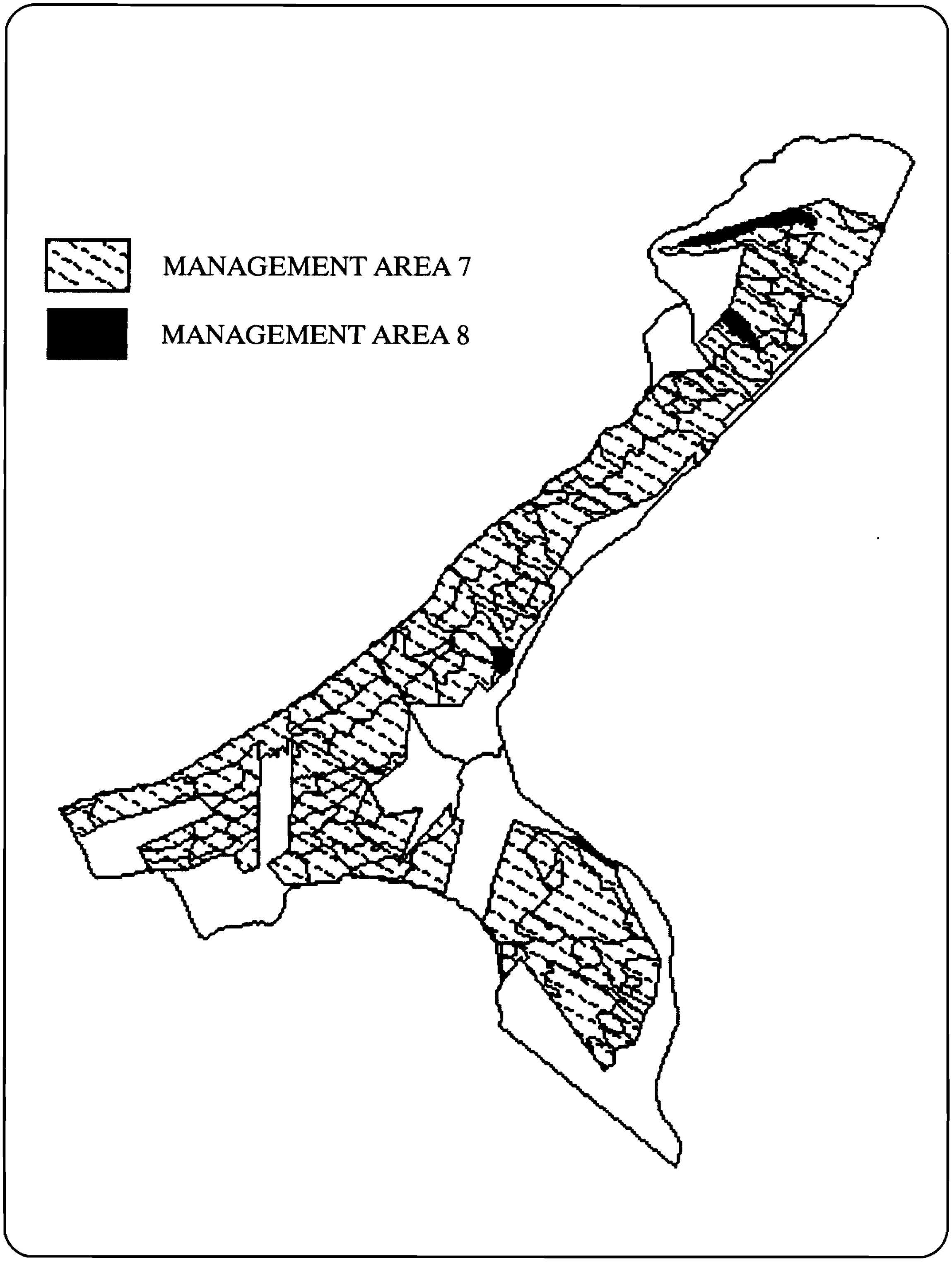

Figure 24. **Management Area 7 / Management Area 8 Forestland Classifications in the Wallen Ridge Opportunity Area**

The assignment of a logging system to a stand is dependent on (1) the availability of ground-based, advanced ground-based, and cable logging systems and (2) the average slope of the stand. At the moment, only ground-based and cable logging systems were considered *"available"* for timber harvesting on the Clinch Ranger District. Advanced ground-based systems were *"unavailable"*. Fortunately, this did not impact the suitability of stands at this point in the decision process since cable systems can be assigned to the same sites as advanced ground-based systems. Average stand slope is the only dependent variable in the assignment of logging systems. In Wallen Ridge, 70 stands were assigned ground-based systems and 50 stands were assigned cable systems using the average stand slope values from the lattice method. These system assignments were displayed on the screen and reported in a screen listing to the planner.

The forest plan product objectives for Management Area 7 specify the minimum rotation ages for the five timber working groups on the Jefferson National Forest. Following the forest plan guidelines for final harvest rotation ages in Table 7, 37 upland hardwood, 5 cove hardwood, 1 pine, 0 hardwood-pine normal, and 1 hardwood pine low were reselected from the Wallen Ridge stands coverage and displayed by working group. The number of stands, acreage, and percent of the total opportunity area for each timber working group is listed in Table 15.

To complete the suitable candidate stands evaluation, the sub-module REVIEW_/_CHANGE_ SUITABLE_STANDS assessed the results of the previous two analyses and identified 44 stands, 37.3 percent of the opportunity area, to be suitable candidate stands for timber sale planning. Since logging system availability was not a constraint for this opportunity area, the final harvest rotation ages for the five timber working groups was the primary parameter that delineated Management Area 7 stands for timber sale planning. The location of candidate stands, Figure 25, was displayed on the screen and a report (summarized in Table 16) listing the final Level II suitability of stands in the Wallen Ridge Opportunity Area was generated by the SDSS.

Table 15. Timber Working Groups for the Current Planning Period

TIMBER GROUP	Upland Hwds	Cove Hwds	Pine	Hwd-Pine Normal	Hwd-Pine Low	Totals
# of Stands	37	5	1	0	1	44
Area (acres)	1924.0	220.7	25.3	--	35.1	2205.1
% of Total Area	32.6	3.7	0.4	--	0.6	37.3

Table 16. Summary of Level II Suitability Evaluation for the Wallen Ridge Opportunity Area

LEVEL II SUITABILITY	Suitable	Unsuitable	Totals
# of Stands	44	76	120
Area (acres)	2205.1	3699.9	5905
% of Total Area	37.3	62.7	100

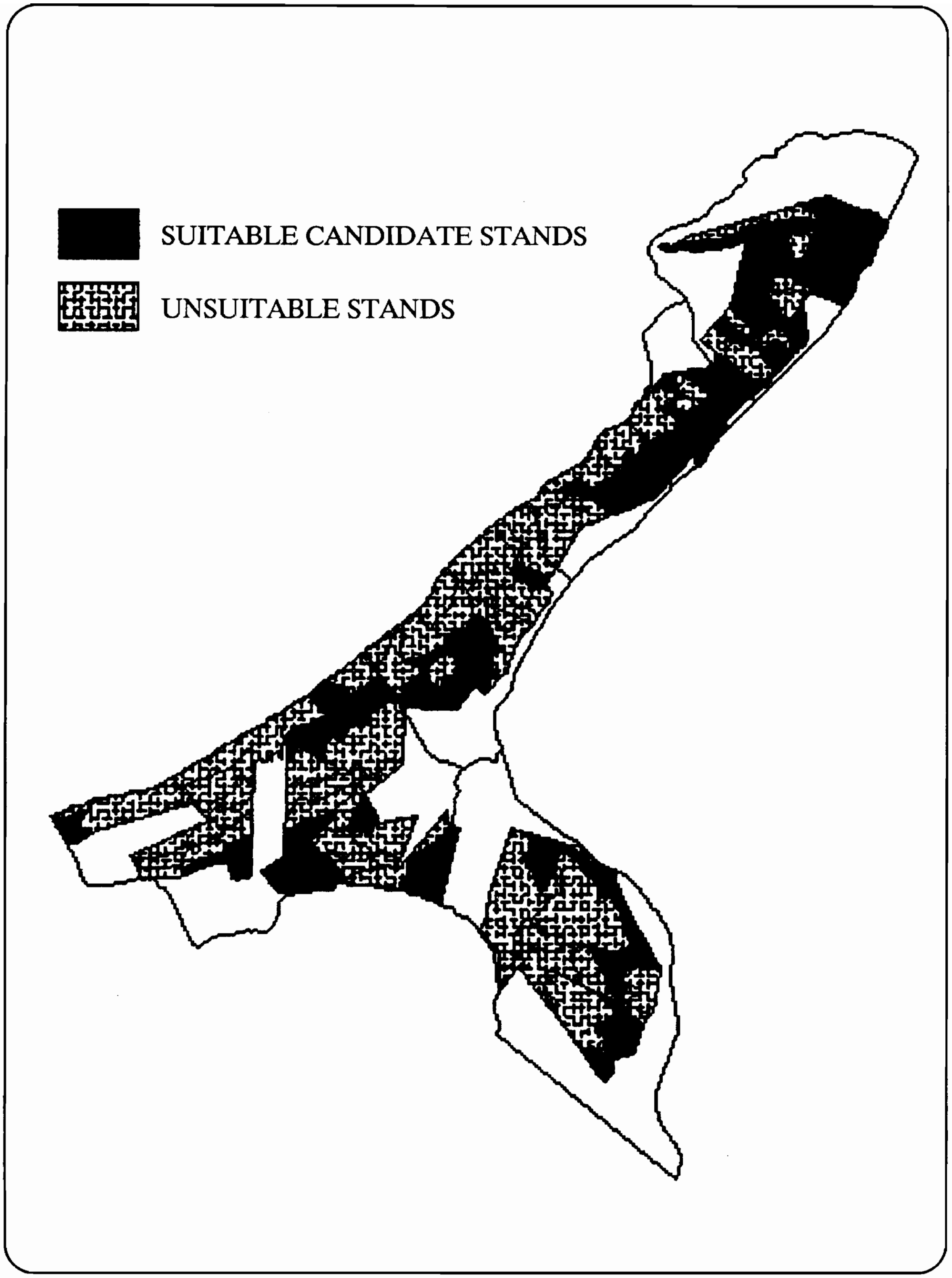

Figure 25. **Suitable Candidate Stands for the Current Planning Period in the Wallen Ridge Opportunity Area**

Module II Results - Evaluation and Analysis of Candidate Stands

The second series of analyses in the SDSS (listed below the EVALUATE_STANDS header on Figure 17) evaluated the candidate stands in the Wallen Ridge Opportunity Area for environmental and social constraints in the following sub-modules: RECREATION_OPPORTUNITY_SPECTRUM, VISUAL_QUALITY_OBJECTIVES, FEATURED_WILDLIFE_SPECIES, RIPARIAN_AREAS_/_BEST_MANAGEMENT_PRACTICES, and SOILS_EVALUATION_(HAZARD_INDEX).

Since the Recreation Opportunity Spectrum (ROS) classification for the Wallen Ridge Opportunity Area is *"roaded-natural"*, all 44 candidate stands have the same ROS class. A quantitative ranking (SDSS approach) of one candidate stand over another using ROS classifications was not possible since this variable is uniform across the opportunity area. The management guidelines of this classification allow dispersed recreation activities such as driving, hunting, firewood gathering, and hiking. The *"roaded-natural"* classification does not restrict timber harvesting.

Visual Quality Objective (VQO) classifications in the Wallen Ridge Opportunity Area include retention, partial retention, and modification classes. After overlaying the VQO coverage onto the candidate stands, the acreage of one or more VQO classes within each stand were calculated. The VQO classifications for the candidate stands were presented in a color-coded graphical display and a tabular report on the SDSS screen. This report (shown in Table 17) lists the acres of each VQO class by candidate stand. Approximately forty percent of the total area available for timber sale planning is in the *"retention"* VQO class. The remaining sixty percent of the area is equally divided between the *"partial retention"* and *"modification"* classifications.

Table 17. **Visual Quality Objective Classifications for the Candidate Stands in the Wallen Ridge Opportunity Area**

Stand Number	Visual Quality Objectives (acres) Retention	Partial Retention	Modification	None	Total Stand Acres
7507	24.5	0.0	0.0	0.3	24.8
7508	18.2	0.0	0.0	0.3	18.5
7509	17.1	0.0	0.0	0.0	17.1
7510	20.8	0.0	0.0	0.0	20.8
7511	19.1	0.0	0.1	0.0	19.2
7515	33.8	0.0	42.4	0.0	76.2
7516	19.2	0.0	0.0	0.0	19.2
7517	59.0	0.0	0.0	1.0	60.0
7521	0.0	105.4	0.0	1.5	106.9
7527	43.9	0.0	0.0	0.0	43.9
7602	0.0	27.6	0.0	0.2	27.9
7609	0.0	40.8	0.0	0.0	40.8
7611	0.0	116.0	0.0	0.0	116.0
7612	0.0	30.2	0.0	0.0	30.2
7620	0.0	36.2	0.0	0.0	36.2
7622	0.0	30.5	0.0	0.2	30.7
7627	0.0	59.2	0.0	0.3	59.4
7629	0.0	26.4	0.0	0.0	26.4
7630	0.0	45.1	0.0	0.0	45.1
7631	0.0	0.0	24.3	0.9	25.2
7632	0.0	24.1	6.9	0.8	31.8
7704	0.0	18.4	0.0	0.0	18.4
7712	20.5	0.0	0.0	0.0	20.5
7718	32.0	5.0	0.0	0.0	37.0
7721	83.3	0.0	0.0	0.6	83.9
7722	29.2	13.8	0.0	0.0	43.0
7724	28.6	16.8	0.0	0.1	45.5
7804	17.4	5.8	25.1	0.2	48.5
7807	110.8	0.0	86.0	1.4	198.2
7810	0.0	3.8	2.4	0.0	6.2
7813	0.0	27.0	5.8	0.0	32.8
7814	50.5	15.2	56.2	0.3	122.2
7901	9.1	0.0	19.9	0.3	29.3
7904	18.2	0.0	5.2	0.0	23.4
7906	16.6	0.0	59.5	0.3	76.4
7908	21.1	0.0	10.6	0.0	31.7
7909	13.5	0.0	10.7	0.0	24.2
7911	12.8	0.0	15.3	0.1	28.2
7912	42.2	0.0	0.0	0.5	42.7
7914	31.6	0.0	3.3	0.1	35.1
7915	4.2	0.0	10.4	0.0	14.6
7916	0.0	0.0	68.7	1.1	69.8
7919	63.6	0.0	208.2	0.2	271.9
7920	1.6	0.0	23.7	0.0	25.3
Totals	862.4	647.3	684.7	10.7	2205.1

White-tailed deer are currently the featured wildlife species for the entire Wallen Ridge Opportunity Area. The decision procedures in the sub-module FEATURED_WILDLIFE_SPECIES assisted the timber sale planner in analyzing the effects of timber harvesting on white-tailed deer habitat by displaying the total acreage and location of each habitat component. From this display, the planner estimates the allowable habitat and age class changes by comparing the current habitat situation to the optimal target habitat for deer as shown in Table 18. These comparisons indicate how timber harvesting could be used to enhance habitat for white-tailed deer on the opportunity area. In the development of timber sale alternatives, harvest plans that emphasize the importance of deer habitat should be patterned such that the grasses/forbes and coniferous components are increased, the 0 - 10 and 40$^+$ year areas are kept within present ranges, and the old growth (100$^+$ year) component is decreased. Finally, the construction of permanent roads should be limited since the open road density in Wallen Ridge is already high.

Table 18. Current Habitat Situation for the Wallen Ridge Opportunity Area and Target Habitat for White Tailed Deer

FEATURED WILDLIFE SPECIES ANALYSIS	-----------Current Habitat Situation--------- Area (acres)	Percent Area of OA ....(percent)......	---Target Habitat--- White-Tailed Deer ......(percent)......
Grasses/Forbes	60.5	1.0	3 - 5
0 - 10 years (Suitable)	656.3	11.1	<= 10
0 - 10 years (Total)	656.3	11.1	3 - 12
40$^+$ years	3921.6	66.4	50 - 75
100$^+$ years	282.4	4.8	0
Coniferous	122.7	2.0	10 - 15
Open Road Density	1 mi./ 550 acres	--	1 mi./ 640 acres

The effects of streamside management zones (SMZ) on the candidate stands were quantified in the RIPARIAN_AREAS_/_BEST_MANAGEMENT_PRACTICES sub-module. The forest plan standard SMZ widths described in Figure 11 were assigned to the streams in Wallen Ridge area. Then, a streams buffer coverage was generated by the SDSS and presented to the planner in a graphical display. After overlaying the buffer coverage onto the stands coverage, the SMZ acres in each candidate stand were calculated and reported in a tabular listing. This report is shown in Table 19. The distribution of SMZ acres among the candidate stands in the Wallen Ridge Opportunity Area is revealed in Figure 26.

The procedure for rating hazardous or unstable soils in the sub-module SOILS_EVALUATION_ (HAZARD_INDEX) classified the soils types in each candidate stand by a hazard index. The soils evaluation process required several steps. First, the planner reviewed a series of graphical displays that characterized the soil types by drainage class, road limitations, equipment limitations, seedling mortality, erosion hazard, and development restrictions. Then, the planner assigned weights to each variable. Road limitations, equipment limitations were assigned a weight of one. The other three variables were assigned a weight of zero. A hazard index value for each soil type was calculated using the equation discussed in the SDSS model section of this chapter. This calculation ranked the risk of harvesting timber on each soil type from 1 (high hazard) to 6 (low). Once the soil hazard index is assigned to each soil type, the soils coverage was intersected with the stands coverage and an average soil hazard index was calculated for each stand. The final average soil index of each candidate stand was presented to the planner in a color-coded graphical display on the screen. These results were also reported in a tabular listing (Table 20) of the candidate stands, soil hazard indexes, and stand acres. The distribution of soil hazard index values among the candidate stands is shown in Figure 27.

Table 19. Area of Candidate Stands in Streamside Management Zones

Streamside Management Zone (SMZ) Acres

Stand Number	SMZ Acres	Total Stand Acres	Percent of Stand
7507	3.9	24.8	15.7%
7508	1.7	18.5	9.2%
7509	3.0	17.1	17.5%
7510	0.3	20.8	1.4%
7511	5.1	19.2	26.6%
7515	8.9	76.2	11.7%
7516	1.4	19.2	7.3%
7517	6.7	60.0	11.2%
7521	5.0	106.9	4.7%
7527	6.2	43.9	14.1%
7602	0.0	27.9	0.0%
7609	0.0	40.8	0.0%
7611	7.9	116.0	6.8%
7612	2.8	30.2	9.3%
7620	0.1	36.2	0.3%
7622	0.0	30.7	0.0%
7627	0.9	59.4	1.5%
7629	0.0	26.4	0.0%
7630	0.0	45.1	0.0%
7631	0.0	25.2	0.0%
7632	0.0	31.8	0.0%
7704	0.0	18.4	0.0%
7712	4.0	20.5	19.5%
7718	3.8	37.0	10.3%
7721	5.1	83.9	6.1%
7722	6.4	43.0	14.9%
7724	4.6	45.5	10.1%
7804	7.5	48.5	15.5%
7807	16.5	198.2	8.3%
7810	1.1	6.2	17.7%
7813	6.0	32.8	18.3%
7814	12.6	122.2	10.3%
7901	2.7	29.3	9.2%
7904	5.1	23.4	21.8%
7906	4.8	76.4	6.3%
7908	4.7	31.7	14.8%
7909	3.2	24.2	13.2%
7911	0.0	28.2	0.0%
7912	4.0	42.7	9.4%
7914	3.0	35.1	8.5%
7915	0.0	14.6	0.0%
7916	4.0	69.8	5.7%
7919	17.8	271.9	6.5%
7920	5.0	25.3	19.8%
Mean SMZ area in Stands			8.7%
Totals	175.8	2205.1	

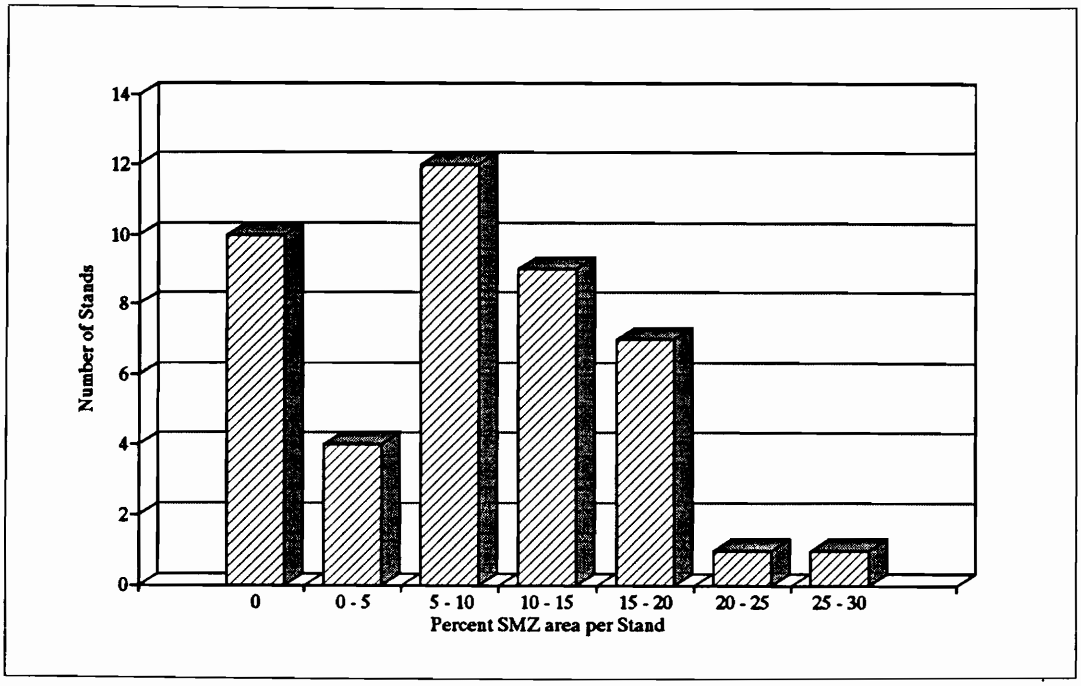

Figure 26. Distribution of Streamside Management Zones among the Candidate Stands

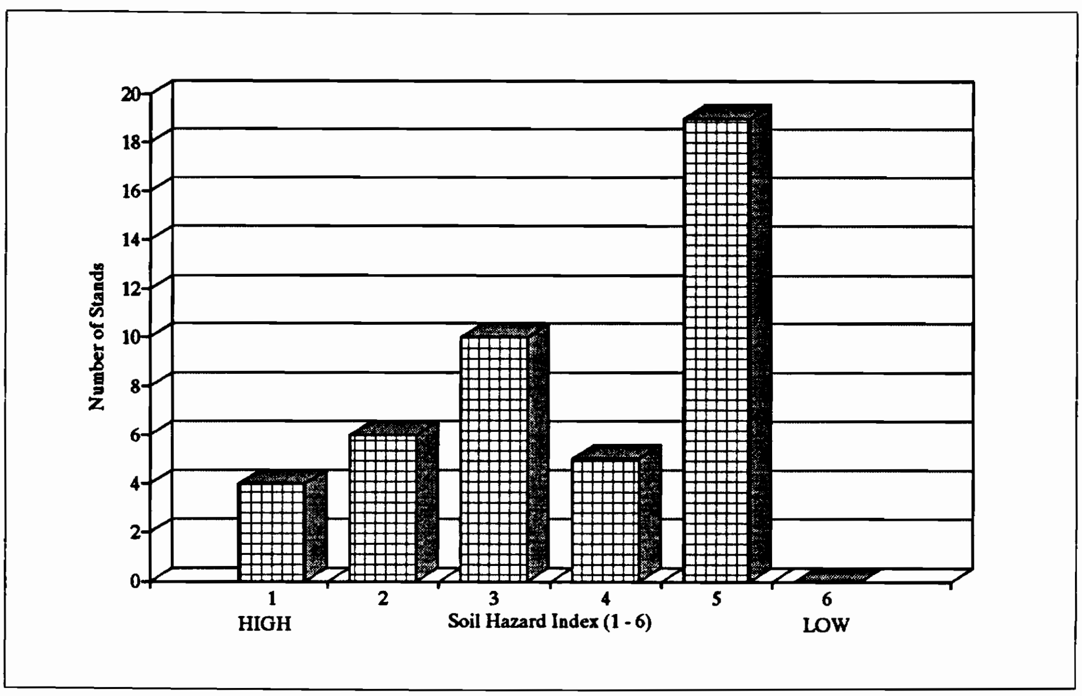

Figure 27. Distribution of Average Soil Hazard Index Values among the Candidate Stands

Table 20. Average Soil Hazard Index for the Candidate Stands

Soils Hazard Index

Stand Number	Soil Hazard Index	Total Stand Acres
7507	2.4	24.8
7508	3.8	18.5
7509	2.4	17.1
7510	3.2	20.8
7511	2.4	19.2
7515	3.0	76.2
7516	1.6	19.2
7517	3.6	60.0
7521	3.2	106.9
7527	3.0	43.9
7602	4.4	27.9
7609	5.2	40.8
7611	4.8	116.0
7612	4.8	30.2
7620	3.4	36.2
7622	4.2	30.7
7627	0.8	59.4
7629	2.4	26.4
7630	1.4	45.1
7631	4.2	25.2
7632	0.4	31.8
7704	5.0	18.4
7712	5.2	20.5
7718	5.2	37.0
7721	5.0	83.9
7722	5.0	43.0
7724	5.0	45.5
7804	2.6	48.5
7807	3.0	198.2
7810	5.2	6.2
7813	2.2	32.8
7814	3.2	122.2
7901	5.0	29.3
7904	5.2	23.4
7906	5.0	76.4
7908	5.2	31.7
7909	5.2	24.2
7911	5.2	28.2
7912	0.8	42.7
7914	2.6	35.1
7915	5.2	14.6
7916	2.8	69.8
7919	4.8	271.9
7920	5.2	25.3
Mean Index	3.7	
Total Acres		2205.1

Module III Results - Economic Analysis of the Candidate Stands

The third SDSS module, ECONOMICS, was processed to estimate the timber volumes, appraise the value of the volume estimates, and incorporate district-wide fixed operating overhead costs for each candidate stand. The results of this analysis are used to project the total revenue per acre, total costs per acre, and net revenue per acre for harvesting each candidate stand. The four SDSS sub-modules in the ECONOMICS module include ESTIMATE_VOLUME, TIMBER_APPRAISAL, OVERHEAD, and REVIEW_RESULTS.

The ESTIMATE_VOLUME sub-module is a three step procedure. First, historical stand volume data from previous timber sales on the Clinch Ranger District was linked to the candidate stands, and then, the volume information for each candidate stand was verified. The last step calculated the total sawtimber (MBF) and pulpwood (CCF) volumes per acre in each candidate stand. The final timber volume estimates were displayed in a tabular listing to the planner (shown in Table 21).

The TIMBER_APPRAISAL sub-module was used to estimate an adjusted stumpage value for each candidate stand. First, the base stumpage value ($/acre) of each stand was calculated by multiplying the stumpage prices of sawtimber ($/MBF) and pulpwood ($/CCF) by the appropriate stand volumes per acre. The stumpage prices (shown in Table 22) for each species group were selected from Timber-Mart South Reports on Average Stumpage Prices on the National Forests in Virginia (1st Quarter 1990, Volume 15 No. 1). It is important to note that stumpage prices are assumed to be fixed during the planning period since temporal effects of timber supply and demand are not included in this prototype model. After the SDSS computed the base stumpage values, a tabular listing on the screen reported the total volume and value per acre for sawtimber and pulpwood and the total base stumpage value per acre. This report is shown in Table 23.

Table 21. Final Timber Volume Estimates for the Candidate Stands

Timber Volume Estimates

Stand Number	Sawtimber MBF/Acre	Pulpwood CCF/Acre	Total Stand Acres
7507	6.9	9.9	24.8
7508	6.9	9.9	18.5
7509	4.7	8.9	17.1
7510	4.7	8.9	20.8
7511	7.1	10.6	19.2
7515	4.7	8.9	76.2
7516	4.7	8.9	19.2
7517	9.0	11.3	60.0
7521	4.8	11.0	106.9
7527	4.7	8.9	43.9
7602	4.7	8.9	27.9
7609	4.7	8.9	40.8
7611	4.7	8.9	116.0
7612	4.7	8.9	30.2
7620	4.7	8.9	36.2
7622	7.7	10.4	30.7
7627	4.8	11.0	59.4
7629	4.7	8.9	26.4
7630	8.8	14.3	45.1
7631	4.7	8.9	25.2
7632	4.0	4.3	31.8
7704	4.8	11.0	18.4
7712	4.8	11.0	20.5
7718	4.7	8.9	37.0
7721	4.7	8.9	83.9
7722	4.7	8.9	43.0
7724	4.7	8.9	45.5
7804	4.8	11.0	48.5
7807	4.7	8.9	198.2
7810	4.7	8.9	6.2
7813	4.8	11.0	32.8
7814	4.4	12.3	122.2
7901	4.8	11.0	29.3
7904	4.8	11.0	23.4
7906	4.7	8.9	76.4
7908	4.4	12.3	31.7
7909	4.5	12.5	24.2
7911	4.8	11.3	28.2
7912	7.6	13.4	42.7
7914	0.0	9.3	35.1
7915	4.7	8.9	14.6
7916	7.1	10.6	69.8
7919	4.8	11.0	271.9
7920	0.0	10.2	25.3
Mean	5.0	10.0	
Total Acres			2205.1

Table 22. Species Group Stumpage Prices for the Wallen Ridge Case Study

Group	Species	Stumpage Price[1]
D - other hardwoods	Hickory, Blackgum	$75 / MBF
F	White Pine	$51 / MBF
P	Virginia Pine, Pitch Pine	$51 / MBF
E	Hemlock	$21 / MBF
A	Yellow Popular, Red Maple, Cucumber, Ash, Black Cherry, Basswood, Sugar Maple	$98 / MBF
C - mixed oak	Scarlet Oak, Chestnut Oak, Black Oak	$120 / MBF
G	White Oak	$145 / MBF
B	Northern Red Oak	$190 / MBF
001	softwood pulp and roundwood	$5.50 / CCF
004	hardwood pulp and roundwood	$8.75 / CCF

[1]Stumpage Prices selected from Timber-Mart South Reports on Average Stumpage Prices on the National Forests in Virginia (1st Quarter 1990, Volume 15 No. 1)

The second step in this sub-module processed a series of cost adjustments to determine the actual total stumpage value per acre of each candidate. Cost adjustments for the type of harvesting system, woods to mill transportation, road maintenance, temporary road construction, and post-harvest seeding and fertilization were calculated. The equations describing each cost adjustment were discussed in the previous section. The cost adjustment input parameters (listed in Appendix D) for this case study were based on the cost factors applied in recent timber sales in the Wallen Ridge area. These input paramters were developed independently by the author and may not reflect actual Forest Service cost specifications for this opportunity area. The cost adjustment summary (Table 24) illustrates the impact of each cost adjustment on the base stumpage value per acre. For the candidate stands in Wallen Ridge, the total cost adjustments on averaged decreased the base stumpage values by $37.22 per acre in this example case study.

Table 23. Base Stumpage Value Report for the Candidate Stands

	Timber Volume Estimates			Base Stumpage Values		
Stand Number	Sawtimber MBF/Acre	Pulpwood CCF/Acre	Total Stand Acres	MBF $$/acre	CCF $$/acre	Total Base Value $$/acre
7507	6.9	9.9	24.8	$817	$88	$905
7508	6.9	9.9	18.5	$817	$88	$905
7509	4.7	8.9	17.1	$603	$80	$683
7510	4.7	8.9	20.8	$603	$80	$683
7511	7.1	10.6	19.2	$873	$95	$968
7515	4.7	8.9	76.2	$603	$80	$683
7516	4.7	8.9	19.2	$603	$80	$683
7517	9.0	11.3	60.0	$1,072	$102	$1,174
7521	4.8	11.0	106.9	$647	$99	$746
7527	4.7	8.9	43.9	$603	$80	$683
7602	4.7	8.9	27.9	$605	$80	$685
7609	4.7	8.9	40.8	$603	$80	$683
7611	4.7	8.9	116.0	$603	$80	$683
7612	4.7	8.9	30.2	$603	$80	$683
7620	4.7	8.9	36.2	$608	$80	$688
7622	7.7	10.4	30.7	$935	$94	$1,029
7627	4.8	11.0	59.4	$647	$99	$746
7629	4.7	8.9	26.4	$608	$80	$688
7630	8.8	14.3	45.1	$1,023	$129	$1,152
7631	4.7	8.9	25.2	$603	$80	$683
7632	4.0	4.3	31.8	$360	$38	$399
7704	4.8	11.0	18.4	$647	$99	$746
7712	4.8	11.0	20.5	$647	$99	$746
7718	4.7	8.9	37.0	$603	$80	$683
7721	4.7	8.9	83.9	$603	$80	$683
7722	4.7	8.9	43.0	$603	$80	$683
7724	4.7	8.9	45.5	$603	$80	$683
7804	4.8	11.0	48.5	$647	$99	$746
7807	4.7	8.9	198.2	$608	$80	$688
7810	4.7	8.9	6.2	$608	$80	$688
7813	4.8	11.0	32.8	$647	$99	$746
7814	4.4	12.3	122.2	$608	$111	$718
7901	4.8	11.0	29.3	$647	$99	$746
7904	4.8	11.0	23.4	$647	$99	$746
7906	4.7	8.9	76.4	$608	$80	$688
7908	4.4	12.3	31.7	$608	$111	$718
7909	4.5	12.5	24.2	$621	$113	$734
7911	4.8	11.3	28.2	$628	$102	$729
7912	7.6	13.4	42.7	$978	$121	$1,098
7914	0.0	9.3	35.1	$0	$61	$61
7915	4.7	8.9	14.6	$608	$80	$688
7916	7.1	10.6	69.8	$873	$95	$968
7919	4.8	11.0	271.9	$647	$99	$746
7920	0.0	10.2	25.3	$0	$68	$68
Mean	5.0	10.0		$639	$89	$728
Total Acres			2205.1			

Table 24. Summary of Cost Adjustments (per acre) for the Candidate Stands

Stand Number	Harvest System	Hauling	Road Maintenance	Temporary Roads	Seeding/ Fertilzation	Total Costs	Base Value	Adjusted Revenue
7507	$59.53	$51.41	($28.25)	$0.00	($14.45)	$68.24	$904.81	$836.57
7508	$0.00	$51.16	($26.77)	$0.00	($14.45)	$9.94	$904.81	$894.87
7509	$44.71	$41.52	($18.51)	$0.00	($11.22)	$56.50	$683.18	$626.68
7510	$44.71	$41.66	($19.34)	$0.00	($11.21)	$55.82	$683.18	$627.36
7511	$62.03	$53.23	($23.80)	$0.00	($15.13)	$76.33	$968.40	$892.07
7515	$0.00	$40.50	($12.80)	$0.00	($11.21)	$16.49	$683.18	$666.69
7516	$0.00	$40.19	($11.05)	$0.00	($11.21)	$17.93	$683.18	$665.25
7517	$0.00	$57.35	($9.92)	$0.00	($17.79)	$29.64	$1,173.50	$1,143.86
7521	$0.00	$47.40	($13.26)	$20.09	($12.75)	$41.48	$745.82	$704.34
7527	$44.71	$38.77	($2.98)	$0.00	($11.22)	$69.28	$683.18	$613.90
7602	$0.00	$45.56	($38.45)	$0.00	($11.26)	($4.15)	$685.22	$689.37
7609	$0.00	$41.36	($15.24)	$0.00	($11.21)	$14.91	$683.18	$668.27
7611	$0.00	$41.06	($13.55)	$0.00	($11.22)	$16.29	$683.18	$666.89
7612	$0.00	$41.77	($17.55)	$0.00	($11.22)	$13.00	$683.18	$670.18
7620	$44.82	$42.09	($19.09)	$0.00	($11.24)	$56.58	$688.20	$631.62
7622	$0.00	$53.58	($19.64)	$0.00	($15.70)	$18.24	$1,028.90	$1,010.66
7627	$49.72	$49.55	($22.00)	$0.00	($12.74)	$64.53	$745.82	$681.29
7629	$44.82	$42.29	($20.24)	$0.00	($11.24)	$55.63	$688.20	$632.57
7630	$79.20	$71.91	($39.45)	$23.83	($19.51)	$115.98	$1,151.70	$1,035.72
7631	$0.00	$43.10	($25.11)	$13.35	($11.21)	$20.13	$683.18	$663.05
7632	$31.60	$25.57	($17.48)	$0.00	($7.44)	$32.25	$398.60	$366.35
7704	$0.00	$47.62	($11.21)	$0.00	($12.74)	$23.67	$745.82	$722.15
7712	$0.00	$48.71	($17.27)	$0.00	($12.74)	$18.70	$745.82	$727.12
7718	$0.00	$40.50	($10.40)	$0.00	($11.22)	$18.88	$683.18	$664.30
7721	$0.00	$39.83	($6.62)	$0.00	($11.21)	$22.00	$683.18	$661.18
7722	$0.00	$40.26	($9.04)	$0.00	($11.21)	$20.01	$683.18	$663.17
7724	$0.00	$40.19	($8.69)	$0.00	($11.21)	$20.29	$683.18	$662.89
7804	$0.00	$48.20	($17.80)	$0.00	($12.74)	$17.66	$745.82	$728.16
7807	$0.00	$39.44	($10.21)	$0.00	($11.24)	$17.99	$688.20	$670.21
7810	$44.82	$38.90	($7.19)	$0.00	($11.23)	$65.30	$688.20	$622.90
7813	$49.72	$46.57	($8.71)	$0.00	($12.75)	$74.83	$745.82	$670.99
7814	$0.00	$49.70	($4.70)	$0.00	($13.10)	$31.90	$718.40	$686.50
7901	$0.00	$45.88	($4.84)	$0.00	($12.74)	$28.30	$745.82	$717.52
7904	$0.00	$46.32	($7.28)	$0.00	($12.74)	$26.30	$745.82	$719.52
7906	$0.00	$38.67	($7.03)	$14.11	($11.23)	$34.52	$688.20	$653.68
7908	$0.00	$49.84	($5.49)	$0.00	($13.10)	$31.25	$718.40	$687.15
7909	$0.00	$50.62	($4.09)	$0.00	($13.40)	$33.13	$733.75	$700.62
7911	$0.00	$47.58	($8.66)	$0.00	($12.95)	$25.97	$729.33	$703.36
7912	$70.50	$59.42	($13.54)	$0.00	($17.52)	$98.86	$1,098.40	$999.54
7914	$0.00	$33.33	($3.17)	$0.00	($6.04)	$24.12	$61.20	$37.08
7915	$0.00	$38.88	($8.23)	$0.00	($11.24)	$19.41	$688.20	$668.79
7916	$62.03	$48.92	($13.70)	$0.00	($15.13)	$82.12	$968.40	$886.28
7919	$0.00	$45.81	($4.41)	$0.00	($12.74)	$28.66	$745.82	$717.16
7920	$0.00	$36.88	($1.35)	$0.00	($6.63)	$28.90	$67.50	$38.60
					Mean	$37.22	$728.05	$690.83

**(All units are in $$/acre)
(Figures in parentheses represent negative numbers)

The last cost considered in the economics module incorporates the overhead costs associated with timber management on the Clinch Ranger District, Jefferson National Forest. These costs include harvest administration, timber planning and resource support, and general administration activities. In fiscal year 1988, overhead costs on the Clinch Ranger District averaged $125 per acre for harvest administration, $232 per acre for timber planning and resource support, and $199 per acre for general administration. These average values were used in this analysis. The total overhead cost for timber management activities, $556 per acre, was appended to the candidate stands coverage.

The results of the volume estimates, timber appraisal, and overhead accounting, were summarized in the final economics sub-module REVIEW_RESULTS. The base stumpage value, total cost adjustments, and overhead costs unique to each stand were reported to the planner in a tabular listing on the screen. This report can be found in Table 25.

Module IV Results - Development of Timber Sale Alternatives

In the final SDSS module, HARVEST_ALTS, the results of the previous three decision modules were combined to support the development of timber sale alternatives for the Wallen Ridge Opportunity Area. The candidate stands were ranked in the sub-module RANK_CANDIDATE_STANDS to reflect the issues and concerns identified during the public involvement process. Then, the SDSS sub-module DEVELOP_TIMBER_SALE_ALTERNATIVES was used to create a series of timber sale plans similiar to the management alternatives described in the Wallen Ridge Opportunity Area Environmental Review (USDA, 1990). The management alternatives are briefly outlined below:

Table 25. Summary Report of Module III Results - Economic Analysis of the Candidate Stands

Stand Number	Base Stumpage Value	Total Cost Adjustments	Total Overhead Cost	NET Revenue
7507	$904.81	($68.24)	($556.00)	$280.57
7508	$904.81	($9.94)	($556.00)	$338.87
7509	$683.18	($56.50)	($556.00)	$70.68
7510	$683.18	($55.82)	($556.00)	$71.36
7511	$968.40	($76.33)	($556.00)	$336.07
7515	$683.18	($16.49)	($556.00)	$110.69
7516	$683.18	($17.93)	($556.00)	$109.25
7517	$1,173.50	($29.64)	($556.00)	$587.86
7521	$745.82	($41.48)	($556.00)	$148.34
7527	$683.18	($69.28)	($556.00)	$57.90
7602	$685.22	$4.15	($556.00)	$133.37
7609	$683.18	($14.91)	($556.00)	$112.27
7611	$683.18	($16.29)	($556.00)	$110.89
7612	$683.18	($13.00)	($556.00)	$114.18
7620	$688.20	($56.58)	($556.00)	$75.62
7622	$1,028.90	($18.24)	($556.00)	$454.66
7627	$745.82	($64.53)	($556.00)	$125.29
7629	$688.20	($55.63)	($556.00)	$76.57
7630	$1,151.70	($115.98)	($556.00)	$479.72
7631	$683.18	($20.13)	($556.00)	$107.05
7632	$398.60	($32.25)	($556.00)	($189.65)
7704	$745.82	($23.67)	($556.00)	$166.15
7712	$745.82	($18.70)	($556.00)	$171.12
7718	$683.18	($18.88)	($556.00)	$108.30
7721	$683.18	($22.00)	($556.00)	$105.18
7722	$683.18	($20.01)	($556.00)	$107.17
7724	$683.18	($20.29)	($556.00)	$106.89
7804	$745.82	($17.66)	($556.00)	$172.16
7807	$688.20	($17.99)	($556.00)	$114.21
7810	$688.20	($65.30)	($556.00)	$66.90
7813	$745.82	($74.83)	($556.00)	$114.99
7814	$718.40	($31.90)	($556.00)	$130.50
7901	$745.82	($28.30)	($556.00)	$161.52
7904	$745.82	($26.30)	($556.00)	$163.52
7906	$688.20	($34.52)	($556.00)	$97.68
7908	$718.40	($31.25)	($556.00)	$131.15
7909	$733.75	($33.13)	($556.00)	$144.62
7911	$729.33	($25.97)	($556.00)	$147.36
7912	$1,098.40	($98.86)	($556.00)	$443.54
7914	$61.20	($24.12)	($556.00)	($518.92)
7915	$688.20	($19.41)	($556.00)	$112.79
7916	$968.40	($82.12)	($556.00)	$330.28
7919	$745.82	($28.66)	($556.00)	$161.16
7920	$67.50	($28.90)	($556.00)	($517.40)
Mean	$728.05	($37.22)	($556.00)	$134.83

**(all units are in $$/acre)
(Figures in parentheses represent negative numbers)

Alternative #1 - This alternative is the *"NO ACTION"* plan. Resource management activities are restricted to projects that ensure the public's health and safety and the protection of endangered and threatened species. No timber harvesting will occur in this alternative.

Alternative #2 - Timber harvesting is maximized under this alternative. Implementation of Best Management Practice's (BMP's) guidelines and soil limitations are also considered to be important. Visual Quality Objective (VQO) land classifications can be adjusted if necessary. Clearcut, group selection, and thinning are the silvicultural options under this alternative.

Alternative #3 - Timber harvesting is minimized under this alternative. VQOs will be strictly maintained by limiting the majority of harvesting activities to group selection and thinnings to mitigate visual impacts. BMP's and concerns for hazardous soils will also be considered. Clearcut, group selection, shelterwood, and thinning silvicultural options are allocated to stands suitable for timber production.

Alternative #4 - Timber harvesting is balanced between maximum and minimum levels under this alternative. VQOs, BMP's, and soil effects are considered more significant than the economics of timber harvesting. Clearcut, group selection, and thinning stand options are considered.

The SDSS model is currently designed to assist in the development of timber harvesting alternatives for stands requiring even-aged management (i.e. clearcut, group selection). At this time, the SDSS cannot quantify the economics of shelterwood and thinning harvest methods, but may be incorporated in system revisions beyond this research.

The SDSS stand ranking procedure (discussed in the previous section) was followed to establish the preferable order to harvest candidate stands for each alternative. The ranking procedure is a two step process. First, the appended attribute data from the Recreation Opportunity Spectrum, Visual Quality Objectives, Best Management Practices and Soil Evaluation analyses (Module II) and the net revenue information (Module III) was used to rank the candidate stands in the AML routine ACCESS_ CANDIDATE_STAND_RANKS. The rules by which the SDSS orders candidate stands were described in the SDSS model section of this chapter. The candidate stand rankings for Module II and III analyses were presented in a color-coded thematic map display and a summary table listing the candidate stands and their corresponding ranks (Table 26). Results from the Recreation Opportunity Spectrum (ROS) analysis were not ranked since the whole opportunity area has only one ROS classification, *"roaded-natural"*.

The AML routine ASSIGN_FINAL_RANKS used the numerical stand orderings from the previous routine to create several sets of final candidate stand rankings. For each set of final ranks, weights were assigned to each stand rank to represent an alternative's management direction. The SDSS calculated the final rank for each stand using these weights. The following sets of weighted objectives (Table 27) were selected to represent the four management alternatives for the Wallen Ridge Opportunity Area.

The ranking weights assigned were selected to represent the goals or objectives of each alternative. The utility and significance of the weighting process is discussed below. Under Alternative #1, timber harvesting will not occur. Therefore, no stand ranking was necessary. Under Alternative #2, timber harvesting is maximized for the opportunity area. The economics of timber harvesting and the effects of BMP's restriction and hazardous soil are equally considered. Visual quality is deemed flexible and assigned a weight of 0. Timber harvesting is minimized in Alternative #3 and restricted to areas that will not effect the visual and water quality of the area. The VQO classifications are prioritized over all

Table 26. Summary of Candidate Stand Rankings for the Wallen Ridge Opportunity Area

Candidate Stands Ranking Summary

Stand Number	NET Profit Rank	Visual Quality Objective Rank	Streamside Management Zone Rank	Soil Hazard Index Rank
7507	8	41	37	9
7508	5	43	25	22
7509	39	37	39	7
7510	38	38	12	17
7511	6	20	44	8
7515	28	8	31	14
7516	29	36	20	5
7517	1	44	30	21
7521	15	31	14	18
7527	41	35	33	16
7602	18	30	6	25
7609	26	27	4	37
7611	27	23	19	26
7612	24	24	24	27
7620	37	21	11	20
7622	3	29	5	24
7627	21	28	13	2
7629	36	25	10	10
7630	2	26	9	4
7631	32	2	8	23
7632	42	17	7	1
7704	11	22	3	32
7712	10	39	41	36
7718	30	34	28	44
7721	34	40	16	34
7722	31	33	35	31
7724	33	32	27	30
7804	9	10	36	11
7807	23	13	21	15
7810	40	14	38	43
7813	22	18	40	6
7814	20	11	29	19
7901	13	7	23	33
7904	12	16	43	41
7906	35	4	17	29
7908	19	15	34	42
7909	17	12	32	40
7911	16	9	2	35
7912	4	42	26	3
7914	44	19	22	12
7915	25	6	1	39
7916	7	1	15	13
7919	14	5	18	28
7920	43	3	42	38

other management goals. Water quality is ensured by weighting the streamside management zone practices and soils objectives. Harvest economics are not considered. The fourth management alternative (Alternative #4) represents a balance of timber management interests for the Wallen Ridge Opportunity Area. Consequently, VQOs, SMZ, and soil considerations are prioritized equally over harvest economics.

Table 27. Weight Assignments for Management Alternatives in the Wallen Ridge Opportunity Area

	ROS	ECON	VQO	SMZ	SOILS
Alternative #1	-	0	0	0	0
Alternative #2	-	1	0	1	1
Alternative #3	-	0	3	2	1
Alternative #4	-	1	2	2	2

The stand ranks for each management objective (i.e. economics, VQO, SMZ, and soils) and final ranks for Alternative #2 candidate stands are listed in Table 28.

The final sub-module, DEVELOP_TIMBER_SALE_ALTERNATIVES, was used to schedule and document three timber sale plans for the Wallen Ridge Opportunity Area. Stand selection and scheduling decisions were done in the AML routine SCHEDULE_TIMBER_SALE_ALTERNATIVES. For each alternative, the appropriate set of final ranks was selected, the rankings of each stand were displayed, and then the first (1991) and last (1993) year of the plan was specified.

At this point in the SDSS case study of the Wallen Ridge Opportunity Area, it is important to note that the selection of stands in each three year timber sale plan was based on the same stands chosen for clearcut and group selection harvest methods by the Forest Service Interdisciplinary Team (USDA, 1990). Though the

Table 28. **Wallen Ridge Opportunity Area Stand Ranks and Final Candidate Stand Ranks for Management Alternative #2**

Stand Number	NET Profit Rank	Visual Quality Objective Rank	Streamside Management Zone Rank	Soil Hazard Index Rank	FINAL Stand Rank	Weighted SUMMATION of Ranks
7630	2	26	9	4	1	15
7622	3	29	5	24	2	32
7912	4	42	26	3	3	33
7916	7	1	15	13	4	35
7627	21	28	13	2	5	36
7704	11	22	3	32	6	46
7521	15	31	14	18	7	47
7602	18	30	6	25	8	49
7632	42	17	7	1	9	50
7517	1	44	30	21	10	52
7508	5	43	25	22	11	52
7911	16	9	2	35	12	53
7516	29	36	20	5	13	54
7507	8	41	37	9	14	54
7804	9	10	36	11	15	56
7629	36	25	10	10	16	56
7511	6	20	44	8	17	58
7807	23	13	21	15	18	59
7919	14	5	18	28	19	60
7631	32	2	8	23	20	63
7915	25	6	1	39	21	65
7609	26	27	4	37	22	67
7510	38	38	12	17	23	67
7814	20	11	29	19	24	68
7813	22	18	40	6	25	68
7620	37	21	11	20	26	68
7901	13	7	23	33	27	69
7611	27	23	19	26	28	72
7515	28	8	31	14	29	73
7612	24	24	24	27	30	75
7914	44	19	22	12	31	78
7906	35	4	17	29	32	81
7721	34	40	16	34	33	84
7509	39	37	39	7	34	85
7712	10	39	41	36	35	87
7909	17	12	32	40	36	89
7724	33	32	27	30	37	90
7527	41	35	33	16	38	90
7908	19	15	34	42	39	95
7904	12	16	43	41	40	96
7722	31	33	35	31	41	97
7718	30	34	28	44	42	102
7810	40	14	38	43	43	121
7920	43	3	42	38	44	123

final stands rankings determined by the SDSS may indicate a different set of stands to harvest, the decision to select only the stands identified in the manual analysis was implemented so comparisons between the SDSS and manual approaches could be made. These comparisons will be discussed in the next section of this chapter.

The stands selected for harvest in each alternative, and a partial listing of SDSS scheduling stand-level statistics (i.e. cut acres, volumes, final rank) are presented in Tables 29 - 31. Under timber sale Alternative #2, 308 acres (11 stands) will be harvested in 1991 to 1993 yielding 1,507 thousand board feet (MBF) of sawtimber and 3,051 hundred cubic feet (CCF) of pulpwood. Timber harvest levels are decreased to 94 acres (4 stands) in Alternative #3 producing 410 MBF of sawtimber and 952 CCF of pulpwood. For the Alternative #4, 228 acres (8 stands) are selected for harvest. Sawtimber and pulpwood yields from this alternative are 1,043 MBF and 2,228 CCF.

The Forest Service's selection of stands was designed such that a similar group of stands were identified for harvest in each alternative. The 4 stands in alternative #3 and 8 stands in alternative #4 are subsets of the 11 stands specified in alternative #2. The final stand ranks (designed by the author) indicate that in each alternative, stands of high and low ranks were selected. Since the ranking process is organized to identify the best stand to harvest in the current plan, it clearly may not be optimal to harvest the stands in the exact order ranked. The temporal and other subjective aspects of harvest planning may be incorporated by the timber sale administrator. The stand ranking procedure developed in this research allows rudimentary comparisons between stands while harvest scheduling. The role of the SDSS was not to make stand selection decisions, but to structure and quantify the harvest scheduling process with graphical displays and tabular reports documenting each alternative so the planner can make the final decisions. Various mathematical programming techniques should be considered in successive SDSS versions to enhance the stand selection and harvest scheduling decision process.

Table 29. Wallen Ridge Opportunity Area - Alternative #2

Year	Stand Number	Final Rank	Harvested Acres	-------Volumes------- MBF	CCF
1991	7602	8	27.9	131.7	248.3
	7612	30	26.0	121.7	231.4
	7622	2	28.0	215.6	291.2
	7627	5	40.0	192.8	440.0
	7631	20	24.0	112.3	213.6
1992	7718	42	34.0	159.1	302.6
	7724	37	40.0	187.2	356.0
	7911	12	28.2	136.2	318.7
1993	7915	21	(2.0)	9.4	17.8
	7919	19	(50.0)	241.0	550.0
	7920	44	(8.0)	0.0	81.6
TOTALS		Clearcut	248.1	1256.6	2401.8
		Group Selection	(60.0)	250.4	649.4

Table 30. Wallen Ridge Opportunity Area - Alternative #3

Year	Stand Number	Final Rank	Harvested Acres	-------Volumes------- MBF	CCF
1991	7718	41	34.0	159.1	302.6
1992	-	-	-	-	-
1993	7915	3	(2.0)	9.4	17.8
	7919	7	(50.0)	241.0	550.0
	7920	13	(8.0)	0.0	81.6
TOTALS		Clearcut	34.0	159.1	302.6
		Group Selection	(60.0)	250.4	649.4

Table 31. **Wallen Ridge Opportunity Area - Alternative #4**

Year	Stand Number	Final Rank	Harvested Acres	-------Volumes------- MBF	CCF
1991	7602	18	27.9	131.7	248.3
	7612	29	26.0	121.7	231.4
	7627	5	40.0	192.8	440.0
1992	7718	44	34.0	159.1	302.6
	7724	38	40.0	187.2	356.0
1993	7915	8	(2.0)	9.4	17.8
	7919	7	(50.0)	241.0	550.0
	7920	36	(8.0)	0.0	81.9
TOTALS		Clearcut	167.9	792.5	1578.3
		Group Selection	(60.0)	250.4	649.4

Comparisons of SDSS and Manual Approaches

The fourth and final objective of this research was to compare the spatial decision support system (SDSS) timber sale planning approach to the current manual analysis/planning techniques used by timber sale administrators on the Clinch Ranger District, Jefferson National Forest. The timber sale alternatives generated by the Wallen Ridge Opportunity Area SDSS case study and the Forest Service Environmental Review of the Wallen Ridge Opportunity Area are compared in the discussion below and the strengths and weaknesses of the prototype SDSS are reviewed to gain insight towards possible areas for future SDSS enhancements. Differences between the SDSS analysis and the environmental review for the Wallen Ridge Opportunity Area were expected since each planning approach has limitations and is subject to the constraints designed by the planner, especially when analyzing the economics of various timber sale alternatives. Harvest scheduling in the SDSS case study was based on the stands selected in the manual process. This approach was implemented so meaningful comparisons between the planning methods could be discussed.

Data Requirements

The data requirements for each analysis were nearly identical in content. The forest stands, roads, streams, and other map-based information and tabular data (i.e. CISCII and the JNF soils database) that were used in the manual analysis were digitized and integrated with the appropriate tabular data to form a spatial database. This task was accomplished in part by the Forest Service Region-wide GIS Implementation plan and in part by the author. Other than the USGS Digital Elevation Model data for terrain analyses, no extra site specific data was collected for the SDSS. The Clinch Ranger District digital database is composed of the data layers listed in Table 2. This spatial and non-spatial data was required to perform either analysis.

In the manual approach, the paper map or tabular listing was the primary means of information access and storage. At each point in the timber sale planning process, the timber sale administrator manually compiled the necessary information to complete the analysis. The geographic information systems (GIS) capabilities of the SDSS fully automated the data storage and query processes. The SDSS organized the information needed for decision making as the planner executed each step of the analysis.

Module I Comparisons - Identification of Suitable Candidate Stands

The results of Management Area 7 / Management Area 8 classifications were the same for both the manual and SDSS approach. The Wallen Ridge Opportunity Area Environmental Review, the Forest Service documentation of the effects of alternative site specific projects (i.e. timber harvesting), does not differentiate *"candidate stands"* like the SDSS since the manual timber sale planning techniques consider a broader range of silvicultural options (i.e. thinnings, shelterwoods). Initial assumptions made in the development of the SDSS limited the selection of stands for timber sale planning to those stands meeting the forest plan product objectives and requiring final harvest (i.e. clearcut, group selection).

Module II Comparisons - Evaluation and Analysis of the Candidate Stands

The second series of analyses in the timber sale planning process evaluated and quantified the effects of environmental and social constraints on the stands in the opportunity area. The following comparisons were noted about each planning approach.

The Recreation Opportunity Spectrum classification of the Wallen Ridge Opportunity Area was entirely *"roaded-natural"*. The SDSS and manual analysis both documented the same fact. The broad distribution of Visual Quality Objective (VQO) classifications across the opportunity area was similiarly determined by each approach. The SDSS was able to enhance this analysis by numerically characterizing the VQO classifications (in acres per class) within each stand.

The results of analyzing the featured wildlife species current habitat status for white-tailed deer are nearly identical. This symmetry was expected since the forest age class, type, and road information in the database used by each approach are the same. The SDSS approach, however, can quickly determined the number of acres in each habitat component and the open road density in the opportunity area, thereby allowing the planner to spend more time estimating the allowable habitat changes and timber management direction for deer.

In the manual approach of estimating the effects of Best Management Practice's (BMP's), it is difficult to determine streamside management zone (SMZ) information for the whole opportunity area. In contrast, the SDSS approach computes the acres of SMZ in each stand. The impact of BMP's on the timber sale planning process were graphically presented and reported to the planner. The value of this information while developing a timber sale plan is significant since it indicates the potential acreage and timber volume reductions per stand if harvested.

No attempt was made in the manual analysis to quantify the effects of hazardous soils in planning. The *"soil hazard index"* procedure defined in this research allowed the planner to use the JNF soils database into the planning process. The significance of this data or interaction between soil characteristics was not fully explored. At this time, soils evaluation process in the SDSS is left to the planner to review and factor into the planning process.

Module III Comparisons - Economic Analysis of the Candidate Stands

One of the most notable differences between the manual approach and the SDSS planning techniques is how each method quantifies the economics of harvesting various stands on the opportunity area. A single stumpage price ($/MBF) and stand volume estimate (MBF/acre) was used to calculate stands values in the manual approach. Hence, all stands have the same value. This is not a realistic assumption. The SDSS model calculates stand values by linking volume information from previous timber sales on the Clinch Ranger District to estimate stand volumes and projects the value of products within each stand with a timber appraisal procedure that accounts for the value of different products and the effects of stand location, operability, and other site specific factors. This improved stand value appraisal capability is possible because of the computational efficiencies created by the SDSS. Overhead costs ($/acre) in the SDSS and environmental review document were comparably used to determine net revenue.

Module IV Comparisons - Development of Timber Sale Alternatives

The final phase in the timber sale planning process is the development of timber sale alternatives for the opportunity area. The Wallen Ridge Opportunity Area Environmental Review document (USDA, 1990) reported four management alternatives, the stands scheduled for harvest, and the estimated revenues and costs of each harvest plan alternative. The SDSS model assisted the planner in developing timber sale alternatives by ordering the selection of stands for harvest under each alternative using a candidate stands ranking procedure. Then, three 3 year timber sale plans were scheduled by selecting the stands designated for clearcut and group selection silvicultural options as described in the environmental review.

As shown in Tables 32 - 34, the volume per acre and stumpage prices assumptions in the manual approach and procedurally based stand value estimations in the SDSS model (price and cost assumptions designed

Table 32. Wallen Ridge Opportunity Area Alternative #2 - Harvest Plan Comparisons

Harvest Year		1991		1992		1993	
Plan		Forest Service	SDSS	Forest Service	SDSS	Forest Service	SDSS
# of Stands		5	5	3	3	3	3
Treated Acres		145.9	145.9	102.2	102.2	60.0	60.0
Volume	MBF	2188.5	774.1	1533.0	482.5	600.0	250.4
Estimate	CCF*	--	1424.5	--	977.3	--	649.4
Total (MBF)		2188.5	1871.0	1533.0	1235.0	600.0	750.0
MBF/acre		15.0	12.8	15.0	12.1	10.0	12.5
Revenue Estimate		$131,310	$108,121	$91,980	$68,936	$36,000	$37,505
Overhead Cost Estimate		($81,120)	($81,120)	($56,823)	($56,823)	($33,360)	($33,360)
NET Revenue		$50,190	$27,001	$35,157	$12,113	$2,640	$4,145
(per acre)		$344	$185	$344	$119	$44	$69

*Conversion Factor CCF to MBF International 1/4 rule: MBF = 0.77 * CCF
(Figures in parentheses represent negative numbers)

Table 33. Wallen Ridge Opportunity Area Alternative #3 - Harvest Plan Comparisons

Harvest Year		1991		1992		1993	
Plan		Forest Service	SDSS	Forest Service	SDSS	Forest Service	SDSS
# of Stands		1	1	0	0	3	3
Treated Acres		34.0	34.0	0.0	0.0	60.0	60.0
Volume	MBF	510.0	159.1			600.0	250.4
Estimate	CCF*	--	302.6			--	649.4
Total (MBF)		510.0	392.1	--	--	600.0	750.0
MBF/acre		15.0	11.5	--	--	10.0	12.5
Revenue Estimate		$30,600	$22,586	--	--	$36,000	$37,505
Overhead Cost Estimate		($18,904)	($18,904)	--	--	($33,360)	($33,360)
NET Revenue		$11,696	$3,682	--	--	$2,640	$4,145
(per acre)		$344	$108	--	--	$44	$69

*Conversion Factor CCF to MBF International 1/4 rule: MBF = 0.77 * CCF
(Figures in parentheses represent negative numbers)

Table 34. Wallen Ridge Opportunity Area Alternative #4 - Harvest Plan Comparisons

Harvest Year / Plan		1991 Forest Service	1991 SDSS	1992 Forest Service	1992 SDSS	1993 Forest Service	1993 SDSS
# of Stands		3	3	2	2	3	3
Treated Acres		93.9	93.9	74.0	74.0	60.0	60.0
Volume	MBF	1408.5	446.2	1110.0	346.3	600.0	250.4
Estimate	CCF*	--	919.7	--	658.6	--	649.4
Total (MBF)		1408.5	1154.4	1110.0	853.4	600.0	750.0
MBF/acre		15.0	12.3	15.0	11.5	10.0	12.5
Revenue Estimate		$84,510	$63,910	$66,600	$49,102	$36,000	$37,505
Overhead Cost Estimate		($52,208)	($52,208)	($41,144)	($41,144)	($33,360)	($33,360)
NET Revenue		$32,302	$11,702	$25,456	$7,958	$2,640	$4,145
(per acre)		$344	$125	$344	$108	$44	$69

*Conversion Factor CCF to MBF International 1/4 rule: MBF = 0.77 * CCF
(Figures in parentheses represent negative numbers)

by the author) caused significant differences in the net revenue calculations for each alternative. Net revenue figures for clearcutting in the first two years (1991,1992) of the plan lists $344/acre for the manual approach and $108/acre to $185/acre in the SDSS analysis. Group selection treatments in year 3 (1993) for all the alternatives estimate a net revenue per acre of $44 for the manual plan and $69 for the SDSS model. Net revenue figures are lower in years one and two since the SDSS volume estimate predicted a lower stand volume per acre and also accounted for site specific operating conditions and stand location. Net revenue figures are higher in year three for the SDSS plan because the SDSS cannot accurately account for the volume left in the stand after harvest under group selection harvest regimes.

SDSS Model Time Requirements / Other Notable Observations

It is difficult to estimate the time requirements of the SDSS approach as compared to the current manual timber sale planning techniques. To date, the Wallen Ridge Opportunity Area is the only example in which comparisons can be made.. Once the Wallen Ridge Opportunity Area spatial database was complete, approximately three hours were required to organize the site specific data for each stand and replicate one timber sale alternative identified in the environmental review. With the site specific information for each stand already processed, the remaining timber sale alternatives were quickly reproduced. The SDSS model replicated the alternatives, therefore, it is difficult to quantify the time utilized by the timber sale administrator in the analysis of various harvest options before the final alternatives were distinguished. Since the author worked independently from the Forest Service, it is impossible to document the complete time requirements of plan development. After demonstrations of the system and discussions with timber sale administrators, the general opinion expressed by Forest Service personnel was that the SDSS approach would accelerate and enhance the timber sale planning process. The amount of time required for plan development may not change, but the quality and quantity of information available and variety of timber sale alternatives would improve the entire planning process.

Once a series of timber sale alternatives were complete, the SDSS can produce high quality maps and a series of reports documenting each alternative. The time required to produce maps and reports manually is significantly greater than the automated reporting facilities incorporated into the SDSS.

Comparison Summary

The spatial decision support system for timber sale planning on the Jefferson National Forest is a prototype model that strengthens the development of timber harvest alternatives by providing faster access to current information for resource planning, defining and structuring the timber sale planning decision process, allowing flexibility and speed in the development of timber sale alternatives, and automating the harvest plan map production and report requirements. The comparison of the prototype SDSS model and manual decision making process revealed several areas where the model and the decision process being modeled needs to be enhanced. Fortunately, the system is designed with the necessary platform for refinements and successive versions.

CHAPTER 5 CONCLUSIONS

Research Overview

Resource planning on National Forests is a complex process involving spatial relationships. At the moment, geographic information systems (GIS) offer the best avenue for representing and interpreting these relationships. In recent years, GIS has been used for harvest planning by various research groups, organizations, and national forests. Given the complexity of GIS software, the development of GIS-based resource planning applications provides an efficient and understandable way to transfer benefits of this technology to the local district forester. Spatial decision support systems or structured GIS-based decision making is another planning tool available to the timber sale administrator. This approach to timber sale planning integrates the heuristics of the timber sale planning decision process and spatial (GIS) analysis methods and techniques in a framework similar to the planner's problem solving style. Essentially this research has demonstrated how SDSS can enhance, improve, and simplify the timber sale planning process on a National Forest.

Four objectives were established for this research. The first was to model and structure the current USDA Forest Service Opportunity Area Analysis methodology for making ranger district-level timber sale planning decisions on the Jefferson National Forest. The second objective was to develop a prototype spatial decision support system (SDSS) that would interactively support this decision making process. The third objective was to apply the SDSS model to an opportunity area currently under assessment by the Forest Service. The fourth and final objective was to compare the SDSS approach to the current manual methods for timber sale planning on the Jefferson National Forest. Based on the results of the research, several conclusions can be drawn regarding the benefits and limitations encountered in utilizing a spatial decision support system approach to the timber sale planning component of Opportunity Area Analysis.

The SDSS model for timber sale planning integrates both spatial and tabular databases, vector-based GIS analysis routines, graphical display and report generators, and user interface utilities to support the timber sale planning process. The SDSS decision model partitions the timber sale planning process into four steps: (1) identification of stands suitable for timber sale planning in the opportunity area; (2) evaluation and analysis of environmental and social objectives specific to each candidate stand; (3) economic analysis of the candidate stands; and (4) development of timber sale alternatives for the planning period. The SDSS model was used to develop a case study of the Wallen Ridge Opportunity Area located on the Clinch Ranger District in Southwestern Virginia for comparisons to the manual approach for timber sale planning. The comparisons revealed several areas where an SDSS approach significantly enhances the timber sale planner's ability to analyze various timber management alternatives.

Conclusions

The advantages and benefits of short term timber sale planning with the SDSS fall into the following four interrelated areas:

(1) *Provides faster access to current information for resource planning.* The SDSS provides the timber sale administrator and other resource analysts with a more efficient mechanism for querying, evaluating, and verifying the various site-specific data unique to the opportunity area. The primary role of GIS and SDSS in spatial resource information management is to eliminate the tedious and cumbersome manual methods for managing spatial information (i.e. mylar/paper maps, stand tables, etc.). The spatial overlays provided at each step in the decision process characterize the large amount of

information needed for evaluating each stand. With SDSS graphical and tabular display utilities, the planner also can identify areas where data are lacking and decision are being made without adequate resource information.

(2) *Helps to define, structure, and expedite the timber sale planning process.* The SDSS was designed to simulate the planning techniques used by experienced timber sale administrators. Therefore, the SDSS user interface is structured such that decisions are made in an environment similar to the planner's own problem solving style without the complexities of GIS software commands. This environment enhances the planner's understanding and interpretation of alternatives developed using SDSS. Additionally, more quality time can be spent by the planner developing comprehensive timber management alternatives since access to the spatial and attribute information and analysis modules at each decision point is facilitated by SDSS.

(3) *Allows flexibility in plan development.* The SDSS permits the timber sale administrator to incorporate personal knowledge and experience into the timber sale alternatives being developed. This is possible since the planner specifies the constraints, input parameters, and special cases at each decision point. *"Unknown"* factors invariably influence planning decisions, and the ability to include them results in a more realistic timber sale plan. The SDSS also makes it easier to modify and revise plan alternatives since the planner can refine the stand-level data by iteratively processing the stand suitability, environmental evaluation, harvest economics, or harvest scheduling modules in the SDSS.

(4) *Assembles information for map production and report generation.* Since harvesting and other forest resource decision are essentially spatial in nature, the graphical displays and maps, combined with tabular listings and reports, help demonstrate to the public and

resource managers the steps in the timber sale planning process, the information acquired and analyzed at each decision point, the harvest alternatives developed, and the trade-offs made for the resource management objectives emphasized in each alternative. The SDSS approach effectively addresses the needs of the timber sale administrator in compiling and presenting various timber sale alternatives to those parties concerned about the multiple resources available on the National Forests.

While the SDSS approach to timber sale planning has many advantages, several limitations in the prototype SDSS were encountered.

(1) *Data quality and quantity.* Spatial data acquisition is an evolutionary and expensive part of implementing a GIS in any land and resource management organization. Systems designed to support decision making in a GIS environment are only as good as the type and quality of the information available. The data must also be current if they are going to be the basis for accurate decision making. Significant time and effort was required to assemble and verify the GIS attribute and tabular data for the Wallen Ridge Opportunity Area before developing the SDSS. As the spatial databases for other ranger districts on the JNF become available, an equivalent amount of time and capital will be required to standardize the database, verify accuracy, and keep the information current. It will also be necessary to acquire and link complete attribute information (i.e. stream classifications, CISCII, soils, road classifications) to each spatial entity (i.e. point, line, or polygon). In the development of the prototype SDSS, the ARC Macro Language (AML) programming code assembled to perform specific timber sale planning analyses is designed following the INFO database variable format and data dictionary specific to the Clinch Ranger District. The reader should be cautioned that significant time will be

required to make the existing prototype SDSS compatible with other database designs in an ARC/INFO environment.

(2) *Vector-based GIS analysis.* The SDSS for timber sale planning was developed utilizing the vector-based ARC/INFO GIS environment. In the course of this research, the ARC/INFO georelational model provided a sufficient toolbox to organize and program the SDSS components. However, the inherent analysis limitations of vector-based systems should be considered in developing future applications. Certain spatial analyses in a raster-based GIS such as digital elevation model analysis and map overlay are less computationally intensive and conceptually less complex than vector routines. Attribute updating in a vector environment is also slow, thereby reducing the *"interactive"* aspects of SDSS. However, computer time processing requirements are directly related to specific hardware configurations. As GIS technology evolves, it is likely that software with full raster and vector data handling, transformation, and analysis capabilities will become available.

(3) *Applicability of prototype SDSS to other ranger districts.* One of the most notable limitations of the prototype system is that it was developed based on the decision process defined by a relatively small group of resource specialists on one National Forest. Specifically, the author worked closely with personnel from the Clinch Ranger District on the Jefferson National Forest. Though efforts were made to incorporate the procedures and constraints common to all areas on the Jefferson National Forest, activities unique to other ranger districts will have to be considered in successive versions of the SDSS prototype. Recommendations for refinements to the prototype SDSS and future extensions of the SDSS approach to resource planning are listed in the final section of this chapter.

Recommendations for Future Research

The prototype SDSS for timber sale planning was designed to complement, support, and improve current resource planning activities on the Jefferson National Forest. Efforts to date have concentrated on modeling the planning process and developing the SDSS framework, and further testing of the SDSS by Forest Service personnel is required to identify areas where the decision process can be improved. Based on the experience and insights gained and the observations made in completing the prototype SDSS, several recommendations can be made regarding the direction of future SDSS model revisions and research.

(1) Methods for quantifying and prioritizing the effects of environmental and social constraints on the forest stands in the opportunity area need to be developed. The impacts of Recreation Opportunity Spectrum and Visual Quality Objective classifications, Best Management Practice's, wildlife habitat needs, and soil hazards should be included in a semi-structured procedure that is less subjective and allows the planner to evaluate objectively these concerns.

(2) The present decision procedures in the SDSS economic analysis module need to be evaluated and refined by experienced timber sale planning personnel since the computer-based SDSS approach can support a more detailed analysis of harvest economics. If reliable stand age and volume information can be acquired, the economic analysis should be expanded beyond its present clearcut silvicultural regime to consider thinnings, shelterwoods, and other intermediate and final harvest options.

(3) In the present SDSS prototype, the final stand ranking procedure in the harvest scheduling SDSS module allowed objective comparisons between candidate stands. This

approach was adequate for current short term harvest scheduling procedures, but not for ranking stand-level information for longer planning periods (i.e. greater than three years). In future SDSS research, the data requirements and methods for integrating various mathematical programming techniques should be identified to optimize and complement the stand selection and harvest scheduling decision process.

(4) Finally, the temporal components influencing the short term harvest planning process should be considered since the prototype system is a deterministic model. The potential of incorporating growth and yield models, complex wildlife habitat capability analyses, and more detailed forest finance models into the existing SDSS platform should be explored in future SDSS research.

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APPENDIX A

DEFINITIONS

Recreation Opportunity Spectrum (ROS) Classifications:

Primitive - Area is characterized by an essentially unmodified natural environment of fairly large size. Interaction between users is very low and evidence of other users is minimal. The area is managed to be essentially free from evidence of human-induced restrictions and controls. Motorized use within the area is not permitted.

Semi-Primitive Non-Motorized - Area is characterized by a predominantly natural or natural-appearing environment of moderate to large size. Interaction between users is low, but there is often evidence of other users. The area is managed in such a way that minimum on-site controls and restrictions may be present but would be subtle. Motorized recreation is not permitted, but local roads used for other resource activities may be present on a limited basis. Use of such roads is restricted to minimize impact on recreation experience opportunities.

Semi-Primitive Motorized - Area is characterized by a predominantly natural appearing environments with moderate evidence of the sights and sounds of man. Such evidence usually harmonizes with the natural environment. Interaction between users may be moderate to high, with evidence of other users prevalent. Resource modifications and utilization practices are evident but harmonize with the natural environment. Conventional motorized use is allowed and incorporated into construction

Roaded Natural - A classification of the recreation opportunity spectrum (ROS) that characterizes a predominantly natural environment with evidence of some resource utilization.

Rural - A classification of the recreation opportunity spectrum (ROS) for areas characterized by a substantially modified natural environment.

Urban - A classification of the recreation opportunity spectrum (ROS) in which the natural setting is dominated by man-made structures and the sights and sounds of man predominate.

Visual Quality Objective (VQO) Classifications:

Preservation - This visual quality objective allows ecological changes only. Management activities, except for very low visual impact recreation facilities, are prohibited. This objective applies to Wilderness areas, primitive areas, other special classified areas, areas awaiting classification and some unique management units which do not justify special classification.

Retention - This visual quality objective provides for management activities which are not visually evident. Under Retention activities may only repeat form, line, color, and texture which are frequently found in the characteristic landscape. Changes in the qualities of size, amount, intensity, direction, pattern, etc., should not be evident. Duration of Visual Impact: Immediate reduction in form, line, color, and texture contrast in order to meet Retention should be accomplished either during the project or immediately after.

Partial Retention - Management activities remain visually subordinate to the characteristic landscape when managed according to the partial retention visual quality objective. Activities may repeat form, line, color, or texture common to the characteristic landscape, but changes in their qualities of size, amount, intensity, direction, pattern, etc., remain visually subordinate to the characteristic landscape. Activities may also introduce form, line, color, or texture which are found infrequently or not at all in the characteristic landscape, but they should remain subordinate to the visual strength of the characteristic landscape. Duration of Visual Impact: Reduction in form, line, color, and texture to meet partial retention should be accomplished as soon after project completion as possible or at a minimum within the first year.

Modification - Under the modification visual quality objective management activities may visually dominate the original characteristic landscape. However, activities of vegetative and land form alteration must borrow from naturally established form, line, color, or texture so completely and at such a scale that its visual characteristics are those of natural occurrences within the surrounding area or character type. Additional parts of these activities such as structures, roads, slash, root wads, etc., must remain visually subordinate to the proposed composition. Activities which are predominantly introduction of facilities such as buildings, signs, roads, etc., should borrow naturally established form, line, color, and texture so completely and at such a scale that its visual characteristics are compatible with the natural surroundings. Duration of Visual Impact: Reduction in form, line, color, and texture should be accomplished in the first year at a minimum should meet existing regional guidelines.

Maximum Modification - Management activities of vegetative and landform alterations may dominate the characteristic landscape. However, when viewed as background, the visual characteristics must be those of natural occurrences within surrounding area or character type. When viewed as foreground or middleground, they may not appear to completely borrow from naturally established form, line, color, or texture. Alterations may also be out of scale or contain detail which is incongruent with natural occurrences as seen in foreground or middleground. Introduction of additional parts of these activities such as structures, roads, slash, and root wads must remain visually subordinate to the proposed composition as viewed in the background. Duration of Visual Impact: Reduction of contrast should be accomplished within five years.

APPENDIX B

Clinch Ranger District Historical Timber Sale Stand Volume Database

Historical Timber Sale Database : Volume by Species Group

Forest Type	Stand Condition Class	Site Index	Acres Treated	Species Group (Sawtimber MBF/acre) D	F	P	E	A	C	G	B	Total MBF	Roundwood (CCF/acre) SWD	HWD	Total CCF
15	8	50	34	0.00	2.30	1.80	0.00	0.00	0.50	0.20	0.00	4.80	0.80	6.10	6.90
39	11	50	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.30	2.80	10.10
42	6	60	15	0.10	4.90	0.00	0.00	0.00	0.10	0.10	0.00	5.20	0.90	3.10	4.00
42	8	60	39	0.20	2.10	0.40	0.10	0.40	1.10	0.20	0.20	4.70	0.30	5.90	6.20
45	6	60	35	0.30	2.50	0.80	0.00	0.00	0.90	0.50	0.00	5.00	0.80	5.70	6.50
45	8	60	57	0.10	1.00	1.40	0.10	0.10	0.80	0.20	0.00	3.70	0.20	5.20	5.40
48	7	50	26	0.00	0.00	2.80	0.00	0.00	0.30	0.10	0.00	3.20	1.00	4.00	5.00
53	3	60	37	0.20	0.00	0.00	0.00	0.20	1.20	0.60	0.20	2.40	3.80	5.40	9.20
53	3	70	38	0.10	0.00	0.00	0.00	1.20	0.80	0.20	0.80	3.10	5.00	7.20	12.20
53	5	70	38	0.10	0.00	0.00	0.00	0.30	2.50	0.10	0.10	3.10	6.70	8.80	15.50
53	8	50	40	0.00	0.00	0.00	0.00	0.00	0.60	0.20	0.00	0.80	0.10	7.30	7.40
53	8	60	23	0.20	0.00	0.60	0.00	0.00	1.00	0.30	0.10	2.20	0.20	6.50	6.70
53	8	70	131	0.40	0.00	0.08	0.00	0.20	2.30	1.10	0.60	4.68	0.10	8.20	8.30
53	8	80	34	0.20	0.00	0.00	0.00	0.30	4.00	0.10	0.80	5.40	0.00	9.40	9.40
53	10	60	46	0.10	1.20	0.90	0.00	0.10	1.00	0.60	0.10	4.00	0.10	4.20	4.30
53	10	70	183	0.50	0.03	0.00	0.00	0.80	2.10	0.50	0.90	4.83	0.00	11.30	11.30
53	10	80	363	0.90	0.07	0.01	0.00	1.00	1.00	0.60	1.10	4.68	0.10	8.80	8.90
53	10	90	265	0.90	0.00	0.01	0.00	2.80	1.80	0.50	0.90	6.91	0.30	9.60	9.90
53	11	70	33	0.30	0.00	0.00	0.00	0.40	2.10	0.60	1.00	4.40	0.00	12.30	12.30
53	12	50	35	0.00	0.20	0.10	0.00	0.00	0.20	0.10	0.00	0.60	0.00	7.90	7.90
53	12	60	38	0.20	0.00	0.00	0.00	0.30	0.50	0.30	0.40	1.70	0.00	6.50	6.50
53	12	70	90	0.50	0.00	0.00	0.00	0.20	2.70	0.80	0.50	4.70	0.00	8.90	8.90
53	12	80	363	0.40	0.00	0.02	0.00	1.00	1.70	0.60	1.10	4.82	0.00	11.00	11.00
53	12	90	122	0.40	0.00	0.00	0.00	3.20	2.00	0.20	1.30	7.10	0.00	10.60	10.60
55	11	80	40	0.40	0.00	0.00	0.00	0.90	0.50	0.40	2.10	4.30	0.00	12.60	12.60
56	10	80	172	0.60	0.10	0.00	0.10	4.60	1.70	0.30	1.60	9.00	0.00	11.30	11.30
56	10	90	37	0.20	0.00	0.00	0.00	0.90	0.80	0.50	1.80	4.20	0.00	8.40	8.40
56	10	100	105	1.00	0.00	0.00	0.00	4.10	0.30	0.20	1.10	6.70	0.00	10.80	10.80

Historical Timber Sale Database : Volume by Species Group

Forest Type	Stand Condition Class	Site Index	Acres Treated	D	F	P	E	A	C	G	B	Total MBF	SWD	HWD	Total CCF
				Species Group (Sawtimber MBF/acre)									Roundwood (CCF/acre)		
56	12	70	63	0.40	0.00	0.00	0.00	3.30	1.70	0.40	1.80	7.60	0.00	13.40	13.40
56	12	80	25	1.00	0.00	0.00	0.00	3.40	2.80	1.00	0.60	8.80	0.00	14.30	14.30
56	12	90	179	0.50	0.00	0.00	0.00	2.80	1.10	0.30	0.90	5.60	0.00	10.70	10.70
56	12	100	92	0.50	0.00	0.00	0.00	4.50	0.80	0.10	1.60	7.50	0.00	10.40	10.40
53	7	50	11	0.40	0.00	1.90	0.00	0.90	0.50	0.40	0.00	4.10	0.50	6.50	7.00
53	7	60	87	0.20	0.90	0.80	0.00	0.20	2.00	0.60	0.10	4.80	0.70	10.50	11.20
53	7	70	67	0.20	0.60	1.00	0.00	0.30	1.50	0.30	0.10	4.00	2.10	5.80	7.90

APPENDIX C

Level I Suitability Analyses Report

Stand Number	Site Index	Average Stand Slope TIN Method	LATTICE Method	Stand Access	Stand Acres	Level I Suitability
7501	75	32.4%	34.7%	roaded	15.5	Suitable
7502	75	30.6%	29.8%	unroaded	10.3	Suitable
7503	94	28.7%	30.5%	roaded	43.1	Suitable
7504	94	29.5%	31.3%	roaded	83.3	Suitable
7505	94	27.1%	29.0%	roaded	31.4	Suitable
7506	85	31.9%	33.7%	roaded	153.6	Suitable
7507	94	36.2%	35.8%	roaded	24.8	Suitable
7508	94	28.5%	30.3%	roaded	18.5	Suitable
7509	85	39.0%	39.0%	roaded	17.1	Suitable
7510	85	36.6%	38.9%	roaded	20.8	Suitable
7511	94	43.1%	42.3%	roaded	19.2	Suitable
7512	75	36.2%	38.6%	roaded	38.8	Suitable
7513	85	40.3%	39.2%	roaded	11.6	Suitable
7514	85	32.9%	34.9%	roaded	54.6	Suitable
7515	85	33.5%	35.4%	roaded	76.2	Suitable
7516	85	33.6%	35.5%	roaded	19.2	Suitable
7517	85	28.8%	32.2%	roaded	60.0	Suitable
7518	85	32.3%	34.0%	roaded	248.6	Suitable
7519	85	34.9%	36.0%	roaded	16.8	Suitable
7520	85	33.3%	34.8%	roaded	213.2	Suitable
7521	85	34.5%	36.4%	roaded	106.9	Suitable
7522	9	17.8%	21.4%	roaded	7.1	Unsuitable
7527	85	36.7%	38.3%	roaded	43.9	Suitable
7601	81	44.0%	43.1%	roaded	11.9	Suitable
7602	81	31.1%	32.0%	roaded	27.9	Suitable
7603	71	34.2%	35.1%	roaded	128.5	Suitable
7604	91	39.6%	40.8%	roaded	130.3	Suitable
7605	91	28.4%	30.3%	roaded	54.5	Suitable
7606	91	22.1%	23.6%	roaded	44.8	Suitable
7607	91	30.6%	31.9%	roaded	21.1	Suitable
7608	81	32.4%	34.1%	roaded	46.2	Suitable
7609	81	31.9%	33.6%	roaded	40.8	Suitable
7610	81	33.6%	35.3%	roaded	53.0	Suitable
7611	81	31.0%	32.0%	roaded	116.0	Suitable
7612	81	27.2%	29.6%	roaded	30.2	Suitable
7613	83	28.7%	30.0%	roaded	60.2	Suitable
7614	71	30.6%	32.3%	roaded	173.8	Suitable
7615	61	31.6%	31.2%	roaded	8.3	Suitable
7616	111	21.7%	22.5%	roaded	12.9	Suitable
7617	111	27.9%	29.4%	roaded	47.2	Suitable
7618	111	38.7%	40.7%	roaded	25.1	Suitable
7619	81	28.6%	30.0%	roaded	60.0	Suitable
7620	72	36.3%	37.7%	roaded	36.2	Suitable
7621	111	35.6%	36.4%	roaded	34.6	Suitable
7622	111	30.1%	32.4%	roaded	30.7	Suitable
7623	83	45.8%	46.8%	roaded	73.2	Suitable
7624	91	39.6%	41.8%	roaded	53.3	Suitable
7625	91	46.1%	45.7%	roaded	48.0	Suitable
7626	91	31.8%	32.8%	roaded	27.3	Suitable
7627	81	41.6%	42.4%	roaded	59.4	Suitable
7628	111	41.3%	43.1%	roaded	47.9	Suitable
7629	72	43.0%	43.9%	roaded	26.4	Suitable
7630	81	36.8%	38.8%	roaded	45.1	Suitable
7631	81	26.7%	28.8%	roaded	25.2	Suitable
7632	62	43.1%	41.3%	roaded	31.8	Suitable
7633	101	32.4%	35.1%	roaded	28.4	Suitable
7634	101	31.3%	33.1%	roaded	33.8	Suitable
7635	101	28.6%	29.9%	roaded	28.8	Suitable
7636	101	40.8%	44.7%	roaded	34.1	Suitable
7637	101	60.5%	60.7%	roaded	31.2	Suitable
7638	101	36.0%	37.9%	roaded	29.9	Suitable
7639	101	34.3%	33.5%	roaded	21.5	Suitable
7701	82	34.2%	35.9%	roaded	20.7	Suitable
7702	71	30.9%	32.2%	roaded	68.6	Suitable
7703	82	28.5%	29.4%	roaded	68.2	Suitable
7704	82	30.4%	33.6%	roaded	18.4	Suitable

Stand Number	Site Index	Average Stand Slope TIN Method	LATTICE Method	Stand Access	Stand Acres	Level I Suitability
7705	71	33.2%	35.9%	roaded	54.5	Suitable
7706	71	35.0%	36.5%	roaded	53.1	Suitable
7707	71	35.2%	37.6%	roaded	52.5	Suitable
7708	71	32.7%	34.6%	roaded	145.3	Suitable
7709	63	40.1%	40.3%	roaded	15.0	Suitable
7710	71	32.9%	34.6%	roaded	6.0	Suitable
7711	83	28.8%	29.5%	roaded	40.8	Suitable
7712	83	29.7%	31.4%	roaded	20.5	Suitable
7713	83	27.5%	30.2%	roaded	27.2	Suitable
7714	93	22.1%	22.4%	roaded	21.9	Suitable
7715	83	31.6%	31.6%	roaded	31.0	Suitable
7716	83	27.0%	28.0%	roaded	56.9	Suitable
7717	63	22.2%	25.4%	roaded	15.0	Suitable
7718	83	32.2%	33.6%	roaded	37.0	Suitable
7719	43	24.1%	25.7%	unroaded	19.7	Unsuitable
7720	73	20.4%	21.5%	unroaded	5.2	Suitable
7721	83	29.5%	31.2%	roaded	83.9	Suitable
7722	83	30.6%	32.1%	roaded	43.0	Suitable
7723	83	28.9%	31.0%	roaded	32.3	Suitable
7724	83	26.7%	27.3%	roaded	45.5	Suitable
7801	71	33.2%	36.7%	roaded	18.4	Suitable
7802	82	35.1%	36.3%	roaded	112.0	Suitable
7803	71	36.2%	37.9%	roaded	17.9	Suitable
7804	81	34.4%	35.6%	roaded	48.5	Suitable
7805	72	35.9%	38.0%	roaded	69.3	Suitable
7806	71	35.7%	37.0%	roaded	64.2	Suitable
7807	72	29.3%	30.3%	roaded	198.2	Suitable
7808	72	33.7%	36.0%	roaded	64.5	Suitable
7809	72	34.7%	38.0%	roaded	16.8	Suitable
7810	71	41.1%	39.2%	roaded	6.2	Suitable
7811	83	31.1%	34.9%	roaded	14.0	Suitable
7812	83	31.9%	33.7%	roaded	27.0	Suitable
7813	81	37.0%	35.9%	roaded	32.8	Suitable
7814	71	30.2%	31.5%	roaded	122.2	Suitable
7901	82	26.4%	27.9%	roaded	29.3	Suitable
7902	74	27.1%	28.6%	roaded	53.9	Suitable
7903	56	30.4%	31.4%	roaded	25.0	Suitable
7904	85	34.0%	32.5%	roaded	23.4	Suitable
7905	46	33.9%	35.8%	roaded	22.3	Unsuitable
7906	75	29.6%	30.5%	roaded	76.4	Suitable
7907	74	26.8%	27.9%	roaded	20.7	Suitable
7908	75	23.2%	25.6%	roaded	31.7	Suitable
7909	85	24.0%	25.5%	roaded	24.2	Suitable
7910	75	25.7%	27.9%	roaded	36.0	Suitable
7911	75	23.0%	25.7%	roaded	28.2	Suitable
7912	75	45.2%	45.3%	roaded	42.7	Suitable
7913	85	31.8%	33.1%	roaded	19.9	Suitable
7914	65	34.1%	36.1%	roaded	35.1	Suitable
7915	75	20.2%	23.9%	roaded	14.6	Suitable
7916	95	36.3%	36.4%	roaded	69.8	Suitable
7917	46	34.0%	35.3%	roaded	59.2	Unsuitable
7918	84	24.1%	24.9%	roaded	26.9	Suitable
7919	84	23.6%	25.5%	roaded	271.9	Suitable
7920	95	23.8%	24.6%	roaded	25.3	Suitable

APPENDIX D

Cost Adjustment Factors used in the TIMBER_APPRAISAL Sub-module

Cost Adjustment Factors used in the TIMBER_APPRAISAL Sub-module

	Sawtimber (MBF)	**Pulpwood** (CCF)
Harvesting System		
Ground-Based Skidding	0.00	0.00
($/unit)		
Cable Yarding	5.75	2.00
Transportation/Haul Costs		
*($/unit*mile)*	0.20	0.10
Road Maintenance**		
*($/unit*mile)*	($1.25)	($0.50)
Seeding & Fertilization**		
($/unit)	($1.16)	($.65)

**activities performed by the Forest Service

Temporary Roads	
($/mile)	$1200.00

VITA

The author was born in Northampton, Massachusetts on November 12, 1965. After graduating from Portsmouth High School (1983) in Portsmouth, Rhode Island, he attended the University of Maine in Orono, Maine. As an undergraduate, he participated in a forest engineering internship program with Scott Paper Company - Northeast Timberlands in Greenville Junction, Maine and worked full and part-time for Diamond Occidental Forest Inc. in Old Town, Maine. Upon completion of a Bachelor of Science in Forest Engineering in May 1987, he continued to work for Diamond Occidental. He enrolled in the Industrial Forestry Operations program at Virginia Polytechnic Institute and State University in September 1988. After a short leave of absence to work for the Green Mountain Club and the State of Vermont during the summer of 1989, he received a Master of Science in Forestry in August 1990.

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