

INTERFACING AN AGGREGATE WOOD SUPPLY MODEL  
WITH A GEOGRAPHIC INFORMATION SYSTEM

by

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for the Degree of Master of Science in Forestry

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## ABSTRACT

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By developing a general interface between forest planning models and geographic information systems, the forest planner is capable of spatially analyzing the results of wood supply analysis. The planner can change the results of the wood supply analysis by incorporating spatial constraints in the actual scheduling of stands for harvest. The effects of these changes can then be examined by inputting the changed data into the wood supply analysis.

This thesis reports on an interface developed as part of a forest management information system to spatially represent the results of a non-spatial wood supply model. The interface was developed to assist in the aggregation of the forest stands into forest units, and upon completion of running the wood supply model, enable the disaggregation of the forest units back into individual stands. It was also developed to assist in mapping of the stands to be treated and the scheduling of individual stands for treatment.

In this study, the FORMAN wood supply model and the ARC/INFO geographic information system were used. The interface was tested for: 1) the extent to which it assisted managers in the planning process; 2) whether it provided new information to the manager; 3) how well the results of the non-spatial wood supply analysis could be checked using the geographic information system; and 4) its ability to feed data back into the wood supply model.

**Key words:** ARC/INFO, forest management planning, forest planning models, FORMAN, geographic information system, spatial analysis, wood supply analysis.

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## 1.0 INTRODUCTION

To be effective, forest management requires continuous attention. With time, the forest changes both naturally and in response to management. The social demands on the forest change over time, and there is a changing understanding of all these interacting dynamics. Forest management must be continually tended in order to be continually consistent in this dynamic situation. It is therefore always possible to improve forest management. (Baskerville, 1986: 1).

### 1.1 FOREST MANAGEMENT PLANNING

A key objective of forest management is to attempt to ensure that the resource produces the goods that are required at the appropriate times they are needed. Timber management ensures a continuous supply of fibre at the levels and times required to maintain the timber-use activities taking place. Forest management controls the development of the forest in both time and space to ensure that the forest as a whole responds to the requirements for continuous fibre supply (Baskerville, 1986).

Baskerville (1986) defined several key decisions in regulating the development of a forest over time: how and when timber harvest will occur; whether to protect forest stands from natural disturbance; what the harvested products will be; and the silvicultural methods to be used.

Control of the forest takes place on individual stands which, when taken together, regulates the forest as a whole. For management to occur at this level, the spatial distribution of the harvest must be controlled as well as when and how the harvest will occur. Therefore, it is important for the planner to determine not only when and how the harvest will occur, but also where.

## 1.2 THE PROBLEM

Both forest planning models and geographic information systems (GISs) provide the forest planner with decision-support tools. However, most forest planning models do not provide spatial output (Lougheed, 1988). In fact, wood supply models lose any spatial analysis capabilities when stands are aggregated into classes based on similar characteristics. As a result, while forest planning models assist the planner in determining when and how the harvest will occur, they are limited in assisting the planner in determining where the harvest will occur.

Some spatial detail may be retained in analysis if location is used as a criterion for stand aggregation. However, this usually results in an increase in the problem size as the total number of forest classes will approximately double for each spatial class to be considered. Other possibilities may exist, depending on the wood supply model being used. Lougheed (1988) presented a

method for determining spatial attributes that can be incorporated into analysis using the Timber RAM (Navon, 1971) model. However, this still does not allow the results to be checked for spatial feasibility.

Geographic information systems can be used to indicate where management treatments are to occur. This makes GISs a powerful tool in forest management planning. After carrying out wood supply analysis, GISs can be used to map the results. The planner can then analyze the maps and make changes based upon spatial considerations. The problem of representing spatially the results from non-spatial wood supply analysis must be resolved if GISs are to play a major role in forest management planning.

Some progress has been made in addressing this problem using the ARC/INFO GIS (Kapron, 1985a, 1986). This involved programmes written to access data directly from ARC/INFO attribute files. Thus a spatial link to the data was maintained. Using a calculated allowable cut, defined accessibility zones and the rule of harvesting the oldest stands first, the programme used a stand-by-stand method to determine which stands were available for harvest.

Although integration makes the programmes easy to use with little user intervention, it also makes them quite specific in their function. As a result, they cannot be easily converted to use different wood supply models nor different GISs. In most cases, this precludes the

comparison of results using different models. Also, a forest manager may not have the choice of which wood supply model or GIS to be used (e.g. due to government regulations or standards).

### 1.3 A SOLUTION

An alternative to developing specific programmes for every GIS and wood supply model combination is to develop a general interface between the two technologies. Such an interface, if properly developed, will allow an easy conversion to different wood supply models and different GISs as well as providing a means to look at the spatial implications of the wood supply model results.

This thesis reports on the development of such a general interface, and the testing of the interface using the FORMAN (Wang et al., 1987) wood supply model and the ARC/INFO GIS (Aronson, 1985). The interface was tested to see if it could be used to check the spatial feasibility of the results output from a non-spatial wood supply model. The bases for testing the interface were: 1) the extent to which it assisted managers in the planning process; 2) whether it provided new information to the manager; and 3) how well the results of the non-spatial wood supply analysis could be checked using the GIS.

The interface was also tested for its ability to feed data back into the wood supply model. After the results of

a wood supply analysis have been mapped, changes in the harvest schedule may be needed based on operational constraints and the spatial layout of the stands to be harvested. These changes may invalidate the original simulation results, particularly if some of the stands that the model allocated for harvest are removed from the allocation by the forest planner. The planner can see what the available wood supply is without considering spatial constraints, but must also analyze effects on the wood supply when changes are made to the harvest schedule in making the schedule spatially feasible. Although these assessments are qualitative in nature, they are nonetheless meaningful because they are based upon the experience of actual forest planners.

Chapter 2 of the thesis presents a review of the development and use of aggregate forest planning models and GISs, and the limited developments made in interfacing the two. Chapter 3 provides a description of the methods used to develop the interface, the basics of the interface, the development of the forest planning system developed for this project, and the results of a case study using the interface. Chapter 4 discusses the results and the value of the linkage in forest management planning and chapter 5 presents the conclusions based on the linkage that was developed.



## 2.0 LITERATURE REVIEW

### 2.1 AGGREGATE FOREST PLANNING MODELS

One of the classes of tools used to assist with the decisions made in forest management is forest models. Alig et al. (1984) outlined some of the major planning models used for aggregate timber supply analysis in the United States and Canada. Iverson and Alston (1986) provided an historical review of planning models used by the United States Department of Agriculture (USDA) Forest Service.

Although the use of forest planning models is not new, there has been an increase in the development of models over the past 30 to 40 years. This increase in development is due largely to changes affecting planning which include a change in product demands, environmental concerns, more public input and criticism, and changing legislation (Iverson and Alston, 1986). However, while there has been an increase in development, the majority of the models lack any type of spatial capabilities. As a result, while the models produce tabular output, no locational data as to where operations should occur are produced.

Some of the major forest planning models developed over the past three decades include the Timber Assessment Market

Model (Adams and Haynes, 1980), the Timber Resources Economic Estimation System (Tedder et al., 1980), the Timber Resource Allocation Method (Navon, 1971), the Multiple Use-Sustained Yield Calculation Technique (Johnson and Jones, 1980) and the Forest Planning Model (Iverson and Alston, 1986).

In Canada, several provinces have incorporated wood supply modelling into their forest management process. Saskatchewan, Alberta and British Columbia have used the Timber Resource Allocation Method and the Multiple Use-Sustained Yield Calculation Techniques (Roberts, 1984). Other provinces have incorporated models developed within the province. The Ontario Wood Supply and Forest Productivity Model (Ontario Ministry of Natural Resources, 1982) is used in Ontario while the Forest Management model (Wang et al., 1987) is used in New Brunswick.

#### 2.1.1 The Timber Assessment Market Model

The Timber Assessment Market Model (TAMM) was used in the 1980 Resources Planning Act Assessment that was carried out in the United States (Alig et al., 1984). The model simulates lumber, plywood and stumpage markets through the use of a set of analytical processes. Equilibrium prices (the price at which the demand equals the supply) within these markets are determined by modelling supply and demand. The future prices, production and utilization of softwood

and hardwood lumber, softwood plywood, and softwood and hardwood stumpage are estimated by the procedures contained within TAMM (Alig et al., 1984). Short-term supply functions for which stumpage prices are independent variables are used to determine annual harvest flows. These harvest flow data are then incorporated into the Timber Resource Analysis System (TRAS; Alig et al., 1982) which is used as the inventory projection model for analysis using TAMM (Alig et al., 1984).

TRAS is a stand projection model developed by Larson and Goforth (1970). Since its development, it has been modified and changed and has resulted in the development of TRAS-1980 (Alig et al., 1982). TRAS-1980 was specifically designed to resolve differences in timber surveys, to update surveys that were carried out at different times to a common time base, and to project long-term timber supplies (Alig et al., 1982).

Within the analysis using TAMM, TRAS is used to calculate the timber inventory progression from one planning period into the next planning period. These data are then fed back into the short-term supply functions within TAMM as one factor in the calculation of the next periods harvest volume. This cycle of analysis repeats for the planning horizon (Alig et al., 1984).

### 2.1.2 The Timber Resources Economic Estimation System

The Timber Resources Economic Estimation System (TREES) was originally designed to assist with a comprehensive study of the future timber supply in the state of Oregon (Alig et al., 1984). The system was also used by the Pacific Northwest Regional Commission's Forest Policy Project that studied forest-related policies and alternatives for the states of Oregon, Washington and Idaho (Iverson and Alston, 1986).

TREES predicts different harvest levels based on assumptions defined for changes in land use, rates of growth, harvesting regulations, trends in silviculture and levels of utilization. Timber volumes for both naturally developing stands and treated stands can be projected along with timber inventories for both even-aged and uneven-aged forests. The model will also simulate harvesting at different levels of detail (e.g. regional and national) and will also consider multiple stocking levels within its inventory projection. However, to carry out these functions, yield table data must be input into the model (Alig et al., 1984).

One of the major strengths of TREES is its ability to track and keep separate a large number of forest units. Utilizing an elaborate control structure when it aggregates harvests, the model is able to track these areas separately. This control structure allow eight different levels of

resolution to be defined. However, the aggregate level of forest units is the lowest level for estimating harvests and inventory projections (Alig et al., 1984).

### 2.1.3 The Timber Resource Allocation Method

The Timber Resource Allocation Method (Timber RAM) was developed by Navon and others at the Pacific Southwest Forest and Range Experiment Station (Iverson and Alston, 1986). A major aim of the Multiple-Use Economics research unit of the station was the development of a Resources Allocation Method (RAM). Timber RAM is a subsystem of RAM which was developed to determine cutting and regeneration schedules for commercial forests that were being managed for multiple-use (Navon, 1971). These schedules are optimized in respect of harvest, costs and revenues and are also based on harvesting regulations and the available forest resource (Iverson and Alston, 1986).

The schedules determined by Timber RAM can extend into the future for a maximum of 350 years with output available for each decade. The schedules are determined through the use of linear programming; however, Timber RAM does not contain any linear programming capabilities. The model generates the matrix required for linear programming software and then generates reports based on the solution from the linear programming software. As a result, the model may require modifications depending on the linear

programming software being used (Navon, 1971). For a discussion of linear programming, see Dykstra (1984).

Timber RAM was widely used in the development of management plans for national parks in the western United States during the 1970's (Iverson and Alston, 1986). The model was also used in Alberta to look at timber supply at different cost levels (Beck, 1987). A modified version of Timber RAM was used to design strategies for the management of a forest for J.D. Irving Ltd. in New Brunswick (Walker and Loughheed, 1985).

#### 2.1.4 The Multiple Use-Sustained Yield Calculation

##### Technique

The Multiple Use-Sustained Yield Calculation Technique (MUSYC) evolved from an attempt to improve on the Timber RAM model (Iverson and Alston, 1986). The model incorporates many of the concepts developed in Timber RAM (Johnson and Jones, 1980) but the improvements made resulted in the projection of more realistic harvest schedules which helped the model gain acceptance with private forest companies (Iverson and Alston, 1986).

Initially, it appeared as though a complete overhaul of Timber RAM was necessary due to the desire to have constraints on timber harvest volume and silvicultural practices applied at or below the forest level. However, this complete overhaul did not occur. What did occur was

the development of two mathematical structures known as Model I and Model II (Iverson and Alston, 1986).

#### 2.1.4.1 Model I

With the Model I structure, a set of management treatments can occur on an area throughout the planning horizon. The area being treated maintains its identity throughout the analysis for the length of the planning horizon. As a result, it is possible to keep track of the location of these areas (Alig et al., 1984). The decision variables in Model I track treatments throughout the planning period and possibly through several harvests from future stands. The Timber RAM model follows the Model I structure (Iverson and Alston, 1986).

#### 2.1.4.2 Model II

With Model II, areas are redefined and aggregated based on the type of treatment. As a result, the problem size is kept to a minimum, but the ability to keep track of location is lost (Alig et al., 1984). In Model II, the decision variables are separate and while one set tracks the treatments on existing stands, a separate set tracks the treatments of regeneration and future harvest of treated stands. A stand or aggregate of stands is tracked with a separate set of decision variables each time it is reestablished (Iverson and Alston, 1986).

### 2.1.5 The Forest Planning Model

The Forest Planning Model (FORPLAN) was developed from the MUSYC model by K. Norman Johnson and others (Iverson and Alston, 1986). FORPLAN can accommodate the management of all lands and waters in the area of study instead of just the commercial forest as in MUSYC and Timber RAM (Iverson and Alston, 1986). The decision variables in FORPLAN track multiple-use activities throughout the planning horizon whereas the decision variables in previous models tracked treatments to produce timber. However, the model does retain emphasis on the capabilities of timber analysis (Alig et al., 1984).

The concept of aggregate emphasis as developed in the FORPLAN model allows the separation of decision variables for the allocation of land from the decision variables used for scheduling treatments. This ability allows the user to define a broader range of management treatments for a set of analysis areas (Iverson and Alston, 1986).

FORPLAN was applied to national forest planning in the United States under the National Planning Management Act of 1976 (Alig et al., 1984) and in 1979 it was designated as "the required analysis tool" for forest management planning by the USDA Forest Service (Iverson and Alston, 1986). However, there was a perceived bias in FORPLAN towards timber. This bias remained as a result of the existing bias towards timber in previous planning models. However, there



was also a large support base for the FORPLAN model. As a result, Norman Johnson developed FORPLAN Version 2 (Iverson and Alston, 1986).

#### 2.1.5.1 FORPLAN Version 2

Originally called Direct Entry FORPLAN (DE-FORPLAN), FORPLAN Version 2 was developed to allow the user to define treatments and products separately for the areas under study instead of applying yield table data for large and disperse aggregate areas. The model originally resembled ADVENT (Kirby et al., 1978) but the capabilities were soon expanded.

ADVENT was used for national forest planning in New Mexico and Arizona and was designed to evaluate competing projects. It was acceptable to planners as it was not linked to any one area and because it was primarily an accounting tool that looked at multi-year budgeting and program planning (Iverson and Alston, 1986).

FORPLAN Version 2 was intended to simplify data preparation but still maintain the capabilities of previous planning models and also provide for enhanced modelling and reporting capabilities. In addition, it also acted as an accounting system and allowed the inputs and outputs to be described in terms of the USDA Forest Service's management information system (Stuart, 1982).

### 2.1.6 The Ontario Wood Supply and Forest Productivity Model

The Ontario Wood Supply and Forest Productivity Model (OWOSFOP) simulates changes in the structure of the forest over time based on implementing a defined forest management strategy (Baskerville, 1986). Specifically designed for the forest management agreement (FMA) program in Ontario, OWOSFOP became the standard method of calculating the maximum allowable depletion (Kus, 1986). The model aggregates the forest stands into forest units (usually based on working group and site class) and updates the age-class structure in 5-year increments. The model accounts for the area to be depleted by removing it from the oldest age classes and then reassigning the area as cutover (Baskerville, 1986). The model also estimates the associated gross total volumes (all species) on the basis of the forest resource inventory (FRI) data entered at the beginning of the analysis (Kus, 1986).

OWOSFOP ignores geographic detail in that it aggregates stands with the same management characteristics. Thus, the model does not differentiate between two stands of the same age that are located at opposite ends of the management area. This lack of geographic detail is common to all aggregate timber supply models (Baskerville, 1986). Also, although the age-class structure used in OWOSFOP is 5-year age classes, the original data for the analysis is entered by 20-year age classes. As a result, the model does not

distinguish between stands that may be up to 20 years apart in age.

#### 2.1.7 The Forest Management Model

The Forest Management model (FORMAN) is a sequential inventory projection model originally developed by E.C. Wang at Fraser, Inc. in New Brunswick (Wang et al., 1987). Based on the WOSFOP model (Hall, 1977), FORMAN was developed to allow for greater flexibility in designing management scenarios and to better reflect the reality of these scenarios (Wang, 1982). WOSFOP was developed to allow planners to develop and assess alternative management strategies. In 1982, the determination of the annual harvest and silvicultural levels and the allocation of Crown land in the province of New Brunswick was carried out using WOSFOP (Wang et al., 1987).

The FORMAN model was originally applied to study the effect of different factors on the medium- and long-term supply of both spruce and fir on the timberlands of Fraser, Inc. This was carried out by determining the sustainable harvest level and by examining the changes in operable growing stock over time based on differing conditions (Wang, 1982).

The FORMAN model process is not complex; however, it reflects the manner in which the planned management options affect the growth of the forest. It does not optimize over

the planning horizon; it simulates the effects of the planned management scenarios. The basic FORMAN process is 1) input data on the initial state of the forest, the planned treatments, the cost of the treatments and the stand development patterns; 2) calculate the initial forest inventory; 3) determine the harvest queue and harvest stands starting at the top of the queue; 4) set up the planting queue and plant from the top of the queue; 5) assign the treated stands to growth curves; 6) space candidate stands; and 7) grow and report on the state of the forest. After the first period, the model cycles starting at (3) until the end of the planning horizon has been reached (Wang et al., 1987).

Although FORMAN aggregates stands into forest classes, it has several features that allow some geographic resolution to be incorporated into the supply analysis. In the classification of the forest stands into forest classes, the classes may be assigned to a management unit. Treatment levels may also be defined by management unit. As a result, the spatial distribution of the stands may be examined, at a coarse level, in the analysis. The model also allows the planner to define an optional curve that may affect the scheduling of forest classes for harvesting (Wang et al., 1987). This curve may also be used to examine the effects of spatial distribution in the FORMAN analysis.

The FORMAN model was used by the New Brunswick Department of Natural Resources and Energy and by several forest companies in New Brunswick to assist with analyses in support of their 1987 management plans. The model was also tested in assessing wood supplies for forests near Longlac, Ontario that were under the management of Kimberly-Clark of Canada Limited (Walker et al., 1986).

## 2.2 GEOGRAPHIC INFORMATION SYSTEMS

Another set of tools used to assist with forest management planning is geographic information systems (GISs). Although not as old as forest planning models; computer mapping systems and geographic information systems increased in popularity within the forest sector around the start of the 1980's. Many systems originated as computer mapping systems and later evolved into GISs. Other mapping systems remain as just that. Although not identical in function nor capabilities, there will be no attempt made here to distinguish between computer mapping systems and geographic information systems. Cooney (1986) argued that the primary difference between computer mapping systems and GISs is the inclusion of a database management system as well as modelling functionality for both spatial and non-spatial data within GISs. While there has been an increase in both development and use of GISs, the primary functionality is the analysis of spatial data. As a result,

the development of simulation capabilities, such as those provided for in wood supply models, has been lacking.

The first operational GIS was the Canada Land Data System (CLDS) which contains the Canada Geographic Information System (CGIS). Developed from 1968 to 1971, the system was still in operation during the 1980s (Crain and MacDonald, 1983). Through its ability to manipulate data and to produce land data in a variety of forms, CLDS could be used to assist with land-use planning and management. The model allowed this planning to be carried out at different scales, from municipal to national levels (Environment Canada Lands Directorate, n.d.).

In the United States, Amidon (1978) reported on the capabilities of computer mapping systems available for the natural resources. Two years later, Aalders (1980) outlined the elements and components found in GISs. That same year, a survey by Vaught and Miller (1980) indicated that of the forty states that replied to the survey, twenty-one indicated that they possessed a GIS and six reported that they were studying the acquisition of a GIS.

Around this same time, other agencies in Canada were also becoming interested in GISs. British Columbia became involved with GISs in 1978 and installed the Intergraph system (Hegyí, 1987). At the same time, the Ontario Ministry of Natural Resources was also considering GISs (Osborn, 1981). The province of Saskatchewan began

investigating GISs in 1979 (Benson, 1983), and in the fall of 1979 and spring of 1980, Tomlinson Associates carried out a study of several GISs for the Saskatchewan Department of Tourism and Natural Resources (Tomlinson and Boyle, 1981).

In 1981, Dendron Resource Surveys Ltd. carried out a study at the request of the Canadian Forest Inventory Committee (CFIC) to determine whether a unit should be established to 1) assist with the development of standards for computer mapping; 2) assist in the exchange of information; and 3) provide support to provincial agencies in respect of problems with computer mapping in forestry (Dendron Resource Surveys Ltd., 1981). Based on this study, a unit (FOREMOST) was established within the Canadian Forestry Service (CFS), Forestry Statistics and Systems Branch (FSSB) at the Petawawa National Forestry Institute (PNFI) in Chalk River.

FOREMOST was established in March 1982 and its staff spent most of the first year visiting GIS installations and vendors (Williams, 1983). At the CFIC meeting in 1983, FOREMOST reported on investigating eight GISs by visiting seven installations and five vendors. It also reported choosing Tomlinson Associates to recommend digitizing and editing software and hardware for the Forestry Statistics and Systems Branch (Williams, 1983).

At this same meeting, Osborn and Jenns (1983) reported on the status of the forest management agreement area

information system (FORMAGAIN). The FORMAGAIN software was produced under a contract with the University of Guelph to develop a GIS for the province of Ontario. Erdle (1983) also reported on the acquisition of the Environmental Systems Research Institute's (ESRI) ARC/INFO GIS by the New Brunswick Department of Natural Resources. By the summer of 1983, the Forestry Statistics and Systems Branch of the Canadian Forestry Service had acquired the ARC/INFO GIS and by the fall of 1983, Lakehead University had also acquired the ARC/INFO GIS (Westbroek, 1986).

Over the past decade, interest by the forest sector in GISs has increased. Tomlinson (1987: 204) states that "Every significant forest management agency in North America either has now installed a GIS, or is in some stage of acquiring one. No agency is known to have rejected GIS in the past 3 years." The reasons he states for this increased activity in GISs by the forest sector are: 1) practical forest management has become more of a social concern with a resulting increase in government funding; 2) GISs are effective for maintaining up-to-date inventories; 3) a GIS is an effective tool in assisting with planning forest management activities; and 4) it is now possible to consider additional themes of information in planning forest management activities. Another factor in this increased activity is the development of computer technology over the



past several years which has resulted in powerful systems becoming cost-effective.

Cooney (1986) listed 57 GISs available for mainframe computers, minicomputers and microcomputers. The 1990 GIS Sourcebook describes almost 100 systems (Parker, 1990). These systems can be described as raster and vector systems. In a raster or grid system, areas are represented by a grid or matrix comprised of cells. These cells usually contain coordinate data and attribute values. In a vector system, the map elements are defined by a set of vectors or line segments which describe lines, points and polygons. Attribute data are linked to corresponding map elements (Cooney, 1986).

Some of the more common systems in use by the forest sector in Canada are the Spatial Analysis System (Simmons, 1987), Intergraph systems (Rogal, 1987), TERRASOFT (Lemco, 1987), PAMAP (Sallaway, 1987) and ARC/INFO (Morehouse, 1985).

### 2.2.1 The Spatial Analysis System

The Spatial Analysis System (SPANS) was developed and is marketed by Tydac, an Ottawa based company. The micro-computer-based system was developed from experience with consulting in the management resource economics field. The system was designed to help the company solve problems arising from its consulting work with an emphasis on

analysis (Simmons, 1987). The system allows a number of maps to be overlaid at the same time. Analysis functions within the system include corridor definition, map transformations and edgematching adjacent map sheets. There are also interfaces with external statistical packages for further processing (Cooney, 1986).

SPANS is primarily raster-based although the input takes place in vector mode and the software utilizes a quad-tree structure to facilitate quick analysis. The system also has the functionality to accept input from other GISs and image analysis systems (Simmons, 1987).

In 1991, Tydac formed a business partnership with Intera Information Technologies Corporation and the IBM Corporation (Parker, 1992). As well, in addition to its SPANS GIS system, Tydac also offers SPANS MAP; a desktop mapping package (Parker, 1992).

### 2.2.2 Intergraph Systems

Intergraph has developed several vector-based utilities to assist with planning. These systems run on either Vax mini-computers or stand-alone workstations. The Polygon Processing Utilities package was developed to assist with planning and utilizes polygon processing utilities to deal with topological structures (Rogal, 1987).

Intergraph has also developed the Image Data Elements Analysis Library System (IDEALS) for image processing and

digital terrain modelling software. It has also released the Topologically Integrated Geographic Resource Information System (TIGRIS) family of products (Rogal, 1987).

Intergraph provides a unique solution to problems by providing both the hardware and the software. Its software solution is built around the Modular GIS Environment (MGE) line of products (Parker, 1992).

### 2.2.3 TERRASOFT

Known primarily by the forest community in British Columbia, was developed and is marketed by Digital Resource Systems Limited in Nanaimo, British Columbia. Developed by foresters with extensive field experience, there are over 400 installations of the software (Parker, 1992).

TERRASOFT is also a micro-computer, raster-based GIS with the cartographic features stored as vectors (Lemco, 1987). Terrasoft is also based upon a modular design with modules for mapping, analysis, coordinate geometry and digital terrain modelling (Parker, 1992).

### 2.2.4 PAMAP

Developed by PAMAP Graphics Ltd. in British Columbia, the PAMAP system was designed to solve analysis problems and to provide a cost-effective system to be installed in the field. Developed as a micro-computer, raster-based system, the software has now been developed for VAX mini-computers

and micro-VAX systems (Sallaway, 1987). The system contains interfaces to both the Intergraph and ARC/INFO systems and also contains modules for digital terrain modelling and image analysis (Cooney, 1986).

The development of PAMAP took place primarily with involvement from the Ministry of Forest's Inventory Section in British Columbia (Sallaway, 1987) and the system is installed in all regional forest offices (Cooney, 1986).

#### 2.2.5 ARC/INFO

The ARC/INFO GIS developed by the Environmental Systems Research Institute (ESRI) in Redlands, California is a vector-based system and is one of the fastest-growing GISs. In 1988, there were approximately 348 installations possessing ARC/INFO in twenty-nine countries with fifty-one of these installations related to forestry and/or natural resources. In North America, there were installations in forty-seven states and eight provinces. Of the twenty-eight systems installed in Canada, fifteen were associated with forestry and/or natural resources (Environmental Systems Research Institute, 1988). As of 1992, there were over 12,000 installations, and over 26,000 estimated users (Parker, 1992). As well, Parker (1992) also reports over 6,000 sales and 8,000 users of pcARC/INFO systems. Although it is marketed separately, the micro-computer based

pcARC/INFO retains the functionality of the mini-computer based software.

Developed by environmental consultants, ARC/INFO was designed to be as general yet as practical as possible (Morehouse, 1985). Following this general design, the software is commonly referred to as a toolbox of analytical functions for geographic data (Aronson, 1985).

The data model used for ARC/INFO is based on the idea of features that have both locational and descriptive attributes associated with them. The design is actually a hybrid model with locational data represented through the use of a topological data model which is similar to the USGS Digital Line Graph (DLG) model (United States Geological Survey, 1984) while the descriptive or attribute data are represented through the use of a tabular or relational model (Morehouse, 1985).

ESRI has also developed a raster-based GIS (GRID), map library software (LIBRARIAN), networking software (NETWORK), digital terrain modelling software (TIN), coordinate geometry software (COGO) and an interface with the ERDAS image analysis system (Sperry, 1988).

Continually evolving, revision 6 of ARC/INFO incorporates a fully integrated raster processing package. As well, ESRI is also marketing ArcView, it's desktop GIS package, and ArcCAD, its desktop CAD package (Parker, 1992).

### 2.3 INTERFACING GISs WITH FOREST MANAGEMENT MODELS

With more forestry organizations acquiring some type of GIS, there has been an associated increase in applying this technology to forest management problems. Many users of GISs are now past the data automation stage and into the development of applications that can assist with forest management planning. However, although some organizations started to develop applications immediately after acquiring a GIS, the development of applications in forest management seems slower than the acquisition of systems. There has also been a focus to build entirely new planning systems, totally within the GIS environment, rather than interfacing with other forest planning tools such as wood supply models. As described above, both wood supply models and GISs have strengths and weaknesses in regard to simulation and spatial analysis capabilities. By utilizing both technologies to assist with forest planning, the strengths of both tools are available to the planner.

Berry and Sailor (1981) discussed the use of a GIS to assist with timber supply analysis. Using the GIS, spatial units were defined by delineating areas having common accessibility. These areas were defined by: 1) determining the haul distance to reach the timber; 2) determining the accessibility of the timber; and 3) combining the results of (1) and (2) to produce spatially related timbersheds.

Tomlin and Tomlin (1982) also looked at the ability to utilize the spatial aspects of a GIS in the development of harvesting plans. In this study, the optimal harvesting schedule derived through timber supply modelling was analyzed for accessibility. Using a raster-based GIS, harvestable areas identified from the supply analysis were assigned an accessibility cost. These areas were then prioritized based on this cost and the harvest plan developed.

The province of New Brunswick has also carried out considerable work in applying GIS technology to forest management. Erdle et al. (1983) discussed the use of GISs to assist with the integration of rating areas for spruce budworm vulnerability, harvest scheduling and forest protection planning. In this study, the GIS was used to generate harvest schedule maps and budworm vulnerability maps. These sets of data were then used for forest protection planning.

Jordan and Vietinghoff (1987) also studied the ability of GISs to assist with forest protection planning against spruce budworm. They analyzed the capabilities of GISs in the planning process and also studied the ability of GISs to assist with the layout of spray blocks.

Erdle and Jordan (1984) looked at the development of harvest plans using a GIS. The primary use of the GIS was the production of maps identifying the location of stands to

be harvested based on the time of harvest. The time of harvest was determined through the use of wood supply modelling. The method presented by Erdle and Jordan (1984) has some similarities to the approach used in this thesis.

Since 1984, there has been an increase in the reported application of GIS technology which corresponds to the increase in the acquisition of GISs by the forest sector. The Lakehead University Centre for the Application of Resource Information Systems (LU-CARIS) has carried out considerable research into the development of applications. Wang (1984) discussed the requirements for developing a Forest Management Information System (FMIS) which is a combination of GISs and forest planning tools. Development of a FMIS was later carried out through projects with two forest companies in the Thunder Bay area (Kapron, 1985a).

Some of the work in developing a FMIS used the GIS to combine different themes of data. Soils data were combined with forest stand data to allow the use of soils information in the planning process (Kapron, 1986). This combination of data allowed planners to consider factors such as the time of year that stands could be harvested and areas possibly restrictive to mechanical harvesting machinery. Research into the use of soil and stand information was also carried out with the Northern Region of the Ontario Ministry of Natural Resources in the development of site-dependant



silvicultural data to assist with forest management planning (Kapron, 1985b).

Work was also carried out in the development of computer programmes to identify areas available for harvest based on allowable cut figures (Kapron, 1985a, 1986). These programmes would calculate an allowable cut based on either area or volume and then code stands available for harvest based on the rule of harvesting the oldest stands first. The programmes considered all working groups defined by the user and also considered accessibility zones if so desired. The procedures, working on a stand-by-stand basis, were effective but also time-consuming. Further studies (Kapron, 1987) were carried out to look at reducing the processing time and the storage requirements needed to carry out forest planning activities using GISs.

Young et al. (1988) have also carried out research in linking GISs to forest management decision support systems (DSS). Methods for using the GIS to graphically display output from a DSS are presented as well as procedures for using the GIS to create new data that can be used within the DSS. Using these processes, the effects of different harvesting scenarios on elk habitat were analyzed.

Richards and Eiber (1985) also discussed the use of GISs within forest planning processes. The ability to use GISs to assist with forest inventory modelling and multiple-use modelling for wildlife habitat, locating stands

requiring treatments and analyzing the effects of stand treatments on wildlife habitat were outlined.

Martin (1985) studied the ability of two databases to assist with timber management planning. Activities studied included updating the inventory, designing road and logging systems, and timber sale preparation. Hart et al. (1985) analyzed the capabilities of GISs for defining erosion hazard areas, analyzing road viewsheds and identifying areas critical for elk calving.

In recent years, the development of forest planning models integrating GISs has increased. Two such models are the HSG Wood Supply Model and GISFORMAN. Both models track individual stands rather than tracking aggregates of stands based upon common characteristics.

#### 2.3.1 The HSG Wood Supply Model

As a component of a co-operative project between Petawawa National Forestry Institute, Abitibi-Price Inc., (Iroquois Falls Division) and the former Northern Region (now the Northeast Region) of the Ontario Ministry of Natural Resources, a set of programmes was developed to assist with long-range timber harvest scheduling. These programmes were used to assist in the development of the 1991-1995 timber management plan for the Iroquois Falls Forest. The primary component of this system is the HSG wood supply model (Moore and Lockwood, 1990).

The HSG wood supply model functions by tracking the development of individual stands rather than by aggregating stands based upon similar characteristics. While the model utilizes a sequential forest inventory projection system similar to WOSFOP and FORMAN, it differs in its ability to use spatial data for analytical purposes (Moore and Lockwood, 1990).

Like other wood supply models, a forest inventory is used to describe the initial state of the forest. The model operates sequentially, forecasting changes to the forest over discrete time periods. These changes are based on yield look-up tables. However, in comparison to aggregate wood supply models, HSG tracks the development of individual stands rather than the aggregation of stands. In addition, HSG actually models the changes to the components that make up a stand to determine the change on the entire stand. These components are usually described in terms of the species, site-class and age-class that make up the stand (Moore and Lockwood, 1990).

As well, HSG differs from other wood supply models in that while the time scale is discrete, the increment for each step is defined at the start of each step. As a result, the planner can modify the time scale used during the simulation runs.

The output from the model is a listing of the stands to be treated, the year and type of treatment, and the state of

the stand at the time of treatment. This schedule can then be linked to spatial data using a GIS and maps produced displaying the results (Moore and Lockwood, 1990).

### 2.3.2 GISFORMAN

GISFORMAN is also a wood supply forecasting model that incorporates spatial data as well as tracking stands individually. It is based upon the concept and design of the original FORMAN model. However, GISFORMAN requires a GIS database to provide the spatial location of stands as well as the stand attributes. Like other wood supply models, GISFORMAN requires a starting inventory which describes the current state of the forest; however, it also requires this inventory to provide the spatial location of the stands. It is also similar to other wood supply models, in that it operates by determining the change to the forest over time and determining the time at which treatments should occur on the stands (Baskent and Jordan, 1991).

GISFORMAN differs from non-spatial wood supply models in that it also produces output on the spatial structure of the forest. While most wood supply models list individual stands, and the timing and type of treatment on these stands, GISFORMAN will create harvest blocks using the spatial distribution of the stands. A separate programme is used to determine the neighbouring stands for all of the

stands in a forest. GISFORMAN uses this information to assemble the harvest blocks (Jordan and Baskent, 1991).

The model was tested on an area comprised of 9,640 productive forest stands in the Canaan area of eastern New Brunswick covering some 111,296 hectares. Six spatial strategies were completed and compared to a non-spatial control strategy. While the results of these strategies showed that there was a decrease in the sustainable harvest level as a result of the blocking, the reduction was also dependant upon the harvest rules used (Jordan and Baskent, 1991).

### 3.0 METHODS

#### 3.1 PROJECT PROPOSAL

In September of 1986, NBIP Forest Products Inc., Dalhousie, N.B. requested LU-CARIS to enter into a co-operative project in the preparation of its 1987 management plan revision. The license was 382,736 hectares in size and was mapped on approximately 150 1:12,500 scale maps. The land base was comprised of: 330,515 hectares of forested land; 12,682 hectares of plantations; 22,597 hectares of recent cut-overs; 227 hectares of recent burns; and 16,715 hectares of non-productive and non-forested land.

After discussions with NBIP staff, it was agreed that a computerized Forest Planning System would be developed to assist in the analysis required for the plan revision. The system would perform at least the following tasks (NBIP Forest Products Inc., 1987a: 1):

1. Forecast the performance of the forest on crown land License #1, the Upsalquitch License, for a period of 80 years and determine the sustainable harvest level for the forest to compare two scenarios. First, the forest performance is evaluated with a minimum of operational constraints applied to the harvesting operations to

discover the maximum potential supply available from the forest, and second by applying realistic operational constraints, define the maximum potential supply from the forest.

2. Using the LU-CARIS facilities, develop and map a spatially feasible forty-year harvest schedule based on the wood supply results that meets the operational constraints of the company. With the constraints in place, a stand listing for the license identifying the stands that will be harvested in each 5-year period of the 40-year plan must also be produced. The development of the harvest schedule must be based on the wood supply analysis taking into account a number of variables relative to the species mix, block size, configuration and access, as well as incorporating the existing 5-year operating plan which covers the period from 1987 to 1991.

### 3.2 PROJECT REQUIREMENTS

After analyzing the requirements for the forest planning system, it was decided that the first task would be carried out using the FORMAN wood supply model and the second task using the ARC/INFO GIS. Based upon these requirements, a logical systems model was designed (Figure 1). However, to develop the physical system, an interface between FORMAN and ARC/INFO also had to be developed. The

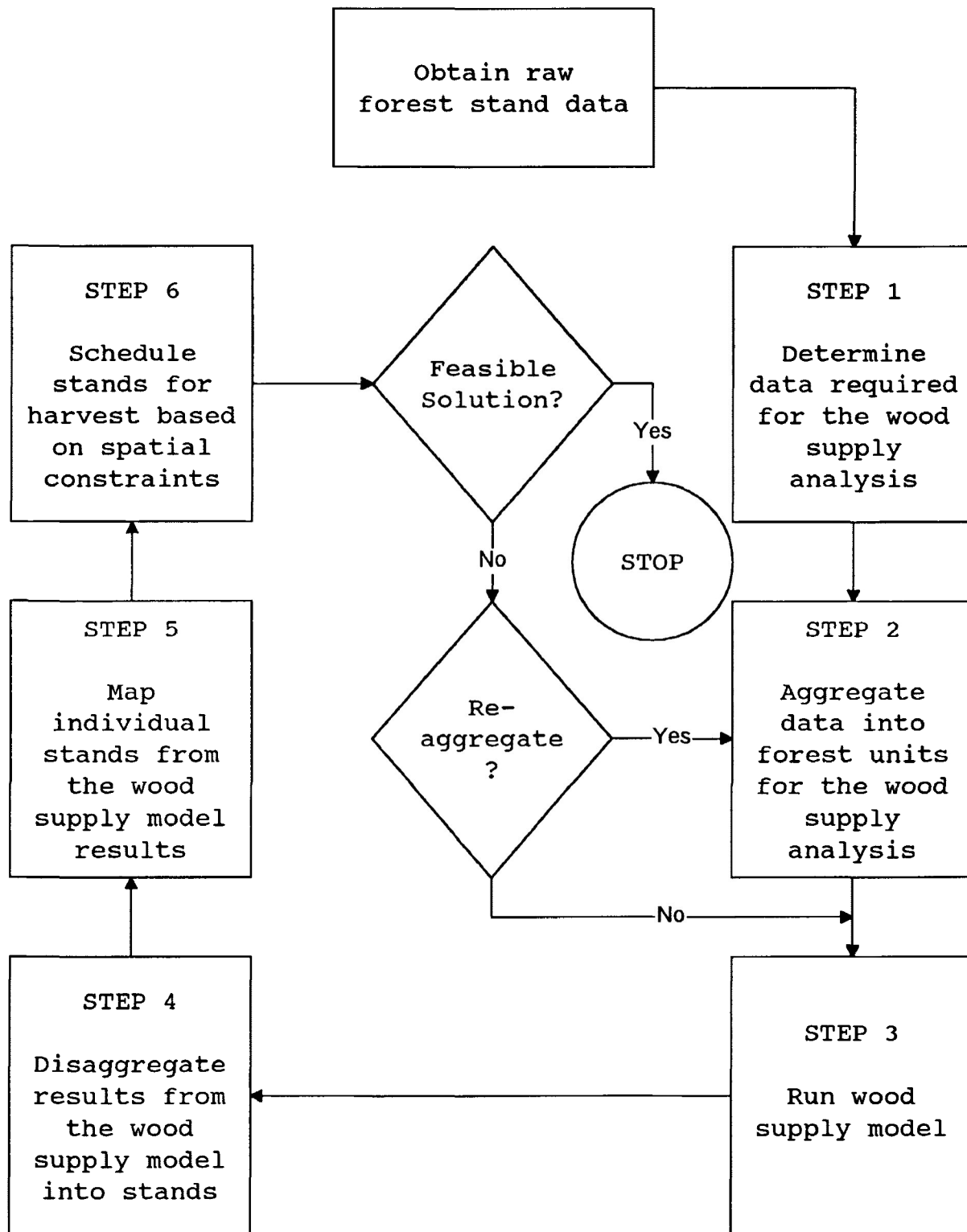


Figure 1. Forest planning system.



interface would be used primarily to carry out steps 2 and 4 in the system (Figure 1). While a large portion of the system requirements would be handled through the inherent capabilities of FORMAN and ARC/INFO, another component of the system would also have to be developed to carry out steps 5 and 6 (Figure 1): stand mapping, and harvest scheduling based on spatial constraints. As FORMAN allows the user to force a harvest sequence using a specified harvest sequence file, it was decided that the developed interface would also assist with the creation of this file. The harvest sequence file would be used if the forest planning process went from step 6 to step 3 in the system (Figure 1).

Through discussions with NBIP, it was determined that the interface was required to be flexible, easy to use and allow the planner to intervene into certain processes. To accomplish this, the routines would have to be kept to basic designs. When programmes were required to augment ARC/INFO commands, it was decided that they would be written either in INFO or FORTRAN 77, depending on their nature. Also, because of the different computer hardware platforms supporting ARC/INFO, and the different stages of software development on these platforms, programmes had to be as generic as possible. Therefore, stages of GIS software development would have to be considered in choosing commands to carry out certain functions. The interface would also

have to be designed to have several breakpoints and entrypoints so that different functions could be carried out separately and then merged back into the overall process. This would allow the required flexibility and the required intervention by the planners. By developing a basic structure, modifications could easily be made and the procedure streamlined for specific purposes.

Designing the interface to allow the planner to intervene was an important consideration. In changing the harvest schedule to make it spatially feasible, subjective trade-offs with the initial model-determined spatial allocation have to be made. By requiring the planner to make these changes and to analyze their effects on the wood supply, the planner can become aware of what the changes may cost.

The general outline of the overall process was: 1) carry out a first-approximation wood supply analysis using the FORMAN wood supply model; 2) check the spatial feasibility of the results using the ARC/INFO GIS; 3) schedule stands for harvesting based on spatial constraints; 4) re-aggregate and modify the input data for FORMAN; and 5) determine the effects of these changes by re-executing the wood supply model. This procedure would be repeated until a spatially feasible plan was developed that also met the wood supply requirements. Once the interface was developed, the forest planning system would be implemented and used to

assist in the preparation of the forty-year harvest plan for NBIP Forest Products Inc.

While not directly related to the interface, NBIP and LU-CARIS staff also agreed to take advantage of the strengths of both ARC/INFO and FORMAN in the development of the forest planning system. Therefore, if planning requirements were identified that could be handled effectively by either FORMAN or ARC/INFO, they would be incorporated into the overall system. If these additions were closely linked to the interface, they would be developed as part of the interface.

### 3.2.1 The Interface

Figure 2 outlines the basic structure of the planned interface. In preparation for running FORMAN, the stands must be aggregated into forest units, based on similar attributes, which form the input into the wood supply analysis. The results of the wood supply analysis are expressed in terms of silvicultural operations occurring on the forest units which are then disaggregated to identify individual stands.

The overall forest planning system also assists with the mapping of the wood supply analysis results and scheduling stands for harvest. Once the forest units have been disaggregated, the results of the analysis are mapped, identifying the individual stands and the year of the

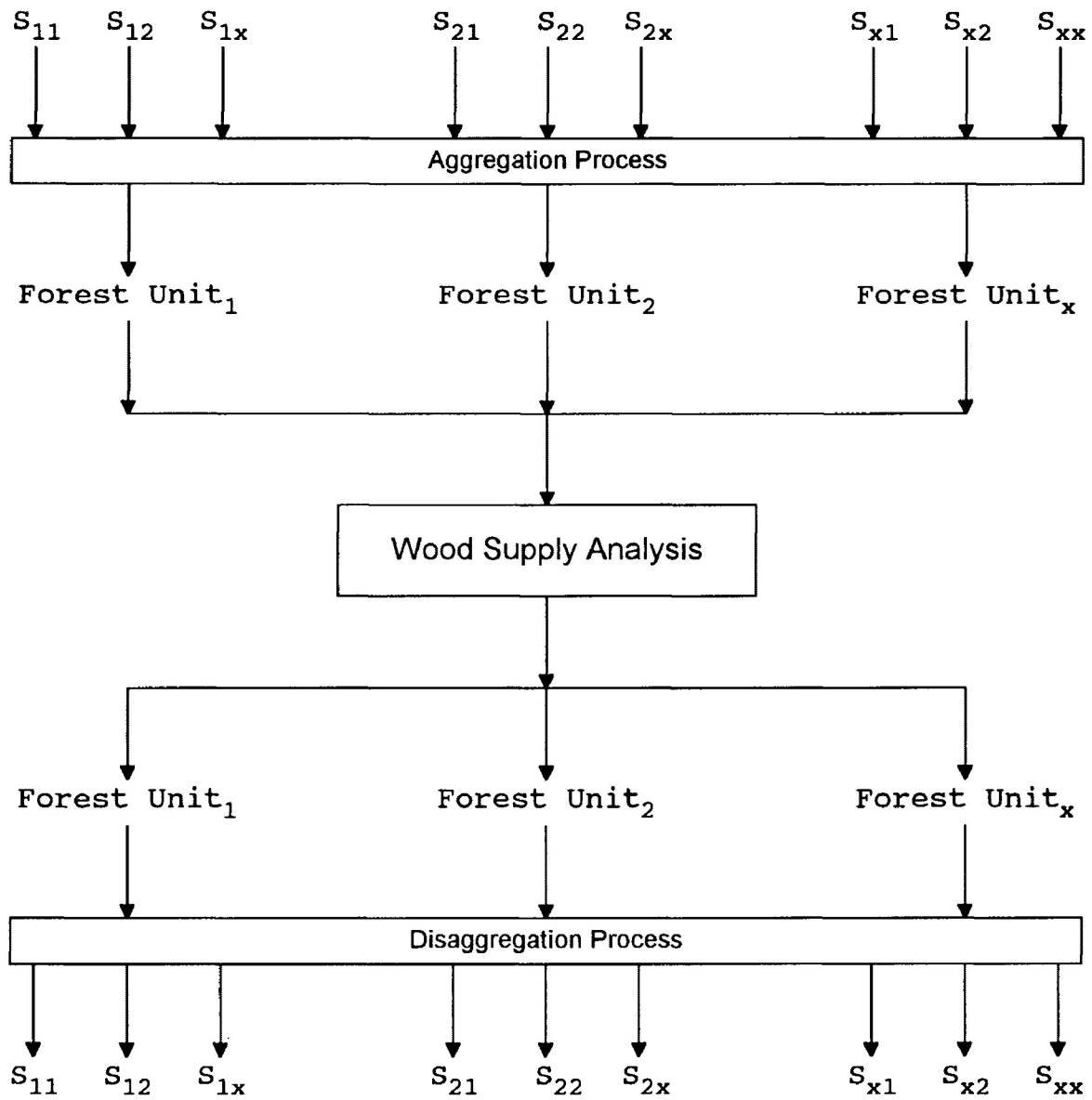


Figure 2. Basic structure of the process.

silvicultural treatment. The planner reviews this information and if necessary, makes modifications to the schedule to meet operational constraints. The silvicultural treatments and the year in which they occur are then re-scheduled. Once the changes have been made, the data are re-aggregated, based upon the changes, and input back into the wood supply analysis to determine and analyze the effects of the changes.

#### 3.2.1.1 Aggregation of the data

The first step in the interface is the aggregation of individual stand data into forest units or classes. Although this step is required by all aggregate wood supply models, GISs can assist with the process.

The first requirement in aggregating stands is determining a set of rules to define which stands will be managed using the same treatments. The rules are based upon stand characteristics that are important in determining silviculture methods. Stands managed using the same method are aggregated according to the defined rules. Examples of some of these characteristics are species composition, stand age, stocking, and site productivity.

Creating a forest unit through stand aggregation is carried out by summing together all of the individual stand areas that meet the criteria of a forest unit. The unit area is then used within the wood supply analysis, ignoring

the actual locations of the stands within the forest. By using a GIS, the aggregation process can take other types of information into consideration instead of just using stand characteristics. Soils information, if available, could be overlain with the stand information and then used subsequently in the determination of the forest units.

Distances from roads or mills can also be considered an important characteristic for the type of management to be carried out. Stands close to the mill might be treated more intensively than other stands due to the lower transportation costs for timber. Areas of concern for either wildlife or recreation can also be identified and incorporated into the aggregation process. The type of management in these areas can then be incorporated into the aggregation. In addition, areas that are to be excluded from analysis, such as deer wintering areas or ecological reserves, can be identified and removed before the analysis takes place.

#### 3.2.1.2 Disaggregation of the wood supply analysis results

To identify actual treatment locations, results from the wood supply analysis must be disaggregated into the actual stands treated in each future period. By doing this, the actual location of the stands to be treated can be mapped.

In some simulations, specific forest units might only be partially harvested, or harvested over several time periods. As a result, only some of the stands comprising the forest unit are denoted as requiring treatment at a specific time. In these cases, the planner can choose which stands to treat at which time.

The aggregation of forest stands into forest units and the disaggregation of the units back into the constituent stands are mirror-image processes. Just as the use of a GIS was important in the aggregation process, it also becomes important in the disaggregation of the data after the wood supply analysis has been carried out. In the aggregation process, stands are grouped into forest units based on rules around the stand characteristics. By employing the same classification scheme, the actual stands to be treated can be identified from the forest units that were treated.

### 3.2.2 Mapping the results

After the results of the wood supply analysis have been disaggregated, the stands treated can be identified as to the method of treatment, the location, and the future period in which the treatment will occur. By doing this, the forest planner can see the stand-by-stand operations proposed from the wood supply analysis, and also where there are choices open in planning the treatments.

### 3.2.3 Scheduling stands for harvest

Using the results of the wood supply analysis, the planner must define a harvest plan taking spatial factors into account. These factors consist of operational acceptability, the size of the cut blocks, the spatial arrangement of the blocks, the distance between blocks, the accessibility of the blocks, and the timing of the block harvest. In addition to these constraints, there may be additional changes to the data in order to define distinct operational harvesting blocks instead of harvesting small patches each period.

To enable comparison of the modified harvest plan with the plan arising from the wood supply analysis, individual stands are identified with their respective time period of harvest. These data are then aggregated and used as input back into another round of wood supply analysis. The planner can then determine the actual change in supply determined by the spatial constraints. This process would be carried out until an acceptable plan is determined.

### 3.3 THE PROJECT

Work began on the project at Lakehead University in the spring of 1987. While the development and application of the interface was an integral part of the work to be carried out, it was nonetheless a component of the overall project. Several procedures were developed to assist with the



preparation of data needed for the FORMAN analysis. These included analyzing the data for the development of yield curves, and the automation of area-constraint data for the FORMAN analysis.

At that time, the required information to be determined and provided to NBIP Forest Product Inc. as a result of the work were a license-wide listing of stands to be harvested in each five-year period for the 40-year plan and a set of associated maps (NBIP Forest Products Inc., 1987a). To test the interface and procedures, analysis was carried out on a subset of the data before using the entire database.

### 3.3.1 Yield curve construction

Early on, New Brunswick Forest Development Survey (FDS) sample plots were analyzed to assist with the development of yield curve data. Initially, the primary interest was to determine which forest classes had been surveyed. To do this, the FDS data were transferred from ASCII (American Standard Code for Information Interchange) files on computer diskettes into the INFO database management system. Once this was accomplished, an INFO programme was developed to classify the plots into forest classes. The output from the programme was a list of the frequency of each forest class.

The frequency list allowed NBIP staff to assess whether there were sufficient data for yield curve construction for each forest class. NBIP staff then analyzed which forest

classes needed to be combined to have enough data to develop yield curves.

Most of the subsequent development of yield curves was carried out by NBIP staff in consultation with LU-CARIS staff as questions arose. The development of the curves followed the guidelines from the New Brunswick Forest Research Advisory Committee (n.d.). Additional analysis was also carried out to assist in the definition of the operability limits for the yield curve data. To assist with this process, the 730 FDS sample plots were assigned to the company's final 46 yield curves for the existing forest and two reports were generated based on the data.

The first report to NBIP summarized 1) the average volume percentage, 2) the average diameter at breast height (DBH) and 3) the number of plots by forest unit by major species by diameter group. The second report was similar except that the average stem count was summarized instead of volume. To carry out this analysis, the data were transferred in the same manner as the original FDS plot sample data. The reports were then generated using a combination of INFO and FORTRAN programmes (Appendix III).

### 3.3.2 Area constraints

Concurrent with development of the yield curves, area constraint data were automated at LU-CARIS. The area constraints had been transferred onto mylar overlays from

1:50,000 scale National Topographic Series (NTS) map sheets by NBIP staff. These constraints consisted of deer wintering areas, ecological reserves, areas with a 35 to 50 percent slope, and areas with a slope greater than 50 percent. Also included were 100-metre reserves around lakes and 15-, 30- or 60-metre reserves around streams based upon riparian slopes. The reserves around the lakes and streams were generated using the GIS by buffering the features based upon a slope classification assigned by NBIP staff. These data were then combined using the GIS to create an area constraint coverage. This coverage was then overlaid with the digital forest stand maps that had been obtained from the New Brunswick Department of Natural Resources and Energy (NBDNR&E) using the GIS.

From the result of the overlay, each stand was characterized by an area constraint value where a zero indicated no constraints. In the overlay process, if a stand was divided by one or more constraint areas, new areas were created. Also, based on the identifier used for the constraint areas, it was possible to identify the type of area constraint assigned to the stands. Using these overlay data, areas were taken out of the database before the classification into forest classes took place based upon operational constraints. This resulted in only non-constrained areas being considered in the actual wood supply analysis.

Using only the non-constrained areas was an improvement over analyses that had been carried out for previous plans. Earlier, an area factor for the available land base was defined by the user and applied to all forest classes. This resulted in plantations being erroneously reduced by the factor. For the previous plan, a factor of 16% had been used. By utilizing the GIS, accurate constraint areas were determined. The data were then forwarded to NBDNR&E for classification into the forest classes. Also determined through this analysis was an overall area constraint percentage of 19.6% of the productive land base. This figure was used in the original wood supply analysis carried out by NBIP.

### 3.3.3 Determination and aggregation of the forest units

After the area constraints had been overlaid with the forest stands, the aggregation of the stands into the forest units could take place. For this project, 15 forest units were identified (based upon the initial analysis of the FDS data). The forest units were further defined by maturity classes resulting in 46 yield curves (Table 1; NBIP Forest Products Inc., 1987b). The actual procedure to do this was created by NBDNR&E and the company was required to use this procedure. Soils data also had to be incorporated into the procedure. For this project, three soil groupings were considered. The breakdown of forest units by soil groupings

Table 1. Growth curves.

CURVE #	FOREST UNIT	MATURITY CLASS <sup>1</sup>	SPECIES MIX DESCRIPTION <sup>2</sup>
1	BFSP L	Y	Balsam fir, Spruce,
2		I	Low Crown Closure
3		M	
4		O	
5	BFSP M	Y	Balsam fir, Spruce,
6		I	Medium Crown Closure
7		M	
8	BFSP H	Y	Balsam fir, Spruce,
9		I	High Crown Closure
10		M	
11	SFWP	M	Spruce-Fir, White pine
12	SFIH	Y	Spruce-Fir, Intol. Hardwood
13		I	
14		M	
15	SFTH	Y	Spruce-Fir, Tolerant Hardwood
16		I	
17		M	
18		O	
19	IHSF	Y	Intol. Hardwood, Spruce-Fir
20		I	
21		M	
22		O	
23	THSF	Y	Tolerant Hardwood, Spruce-Fir
24		I	
25		M	
26	TOHW L	Y	Tolerant Hardwood,
27		I	Low Crown Closure
28		M	
29	TOHW H	Y	Tolerant Hardwood,
30		I	High Crown Closure
31		M	
32	INHW	Y	Intolerant Hardwood
33		I	
34		M	
35	HWMX	Y	Hardwood Mix
36		I	
37		M	
38	OTSW	M	Cedar
39		O	
40	PINE	Y	Pine
41		I	
42		M	
43	SPBF	Y	Spruce-Fir
44		I	
45		M	
46		O	

<sup>1</sup>Y - Young, I - Immature, M - Mature, O - Overmature

<sup>2</sup>Balsam fir - *Abies balsamea*(L.)Mill., Spruce - *Picea A.Dietr*, White pine - *Pinus strobus* L., Cedar - *Thuja occidentalis* L., Pine - *Pinus* L.

was carried out by NBDNR&E staff and the data provided to LU-CARIS.

With the development of the yield curves completed, the area constraint data available, and the forest stands having been classified into forest units, the FORMAN analysis to determine the maximum available sustainable wood supply with a minimum of operational constraints was carried out. This analysis was completed in November, 1987.

#### 3.3.4 Disaggregation of the forest units

After the initial wood supply had been completed, work began on the interface to disaggregate the forest units into stands and the system to assist with mapping and making changes to the data. In January, 1988 NBDNR&E (1988a) added to the information requirements in the management plan a computerized listing of the stands to be harvested showing: 1) the stand number; 2) the map number; 3) the forest class; 4) the first harvest period for cutting; 5) the block number; 6) the percent area cut; and 7) the final harvesting period for the block.

A block listing was also required to be produced (both in hardcopy and computerized form) that included: 1) the time period in which the block was to be harvested; and 2) the map number on which most of the block was located.

The additional requirements defined by NBDNR&E did not affect the system to be developed, but rather provided the

format for the final results. Therefore, work on the system proceeded. The major steps involved were 1) modifying the FORMAN programme; 2) summarizing the data; 3) classifying the data; 4) producing output; 5) scheduling the stands for harvest; and 6) evaluating the results.

#### 3.3.4.1 Modifications to the FORMAN Programme

To allow the stand scheduling to take place, the FORMAN programme was modified to create an optional GIS file. The name for the GIS output file was requested immediately after the prompt for the **Long Report File Name** when running FORMAN.

The modifications consisted of changes to the main programme, changes to the menu subroutine, and the development of a new subroutine. The modifications also allowed the GIS file name to be changed during FORMAN runs to allow multiple runs to be carried out while maintaining the spatial results of each run. A copy of the FORMAN programme outlining the changes is included in Appendix I.

The GIS output file contained a listing of all forest classes treated during the time horizon of the FORMAN run. Two records were created depending on the type of treatment. If the forest class was harvested either entirely or

partially during the iteration, the output file contained the:

- 1) forest class [I4<sup>1</sup>];
- 2) age of the forest class [I4];
- 3) time of the treatment in years [I3];
- 4) area harvested [I7];
- 5) percent area of the forest class harvested [F3.0];
- 6) area planted [I7]; and
- 7) percent area of the forest class planted [F3.0].

If it was spaced, the output file contained:

- 1) forest class [I4];
- 2) age of the forest class [I4];
- 3) time of the treatment in years [I3];
- 4) blank fields [24X];
- 5) area spaced [I7]; and
- 6) percent area of the forest class spaced [F3.0].

If a forest class was treated in more than one period, the total area of the forest class was the area remaining in the class after the first treatment.

#### 3.3.4.2 Summarizing the Output Data

After the FORMAN analysis was carried out, the data in the GIS file had to be summarized before it could be used effectively. To summarize the data, the programmes HARVSUM, PLANTSUM and SPACESUM (Appendix II) were developed for the areas harvested, planted and spaced respectively. Throughout the rest of this chapter, reference will be made only to the summary of the area harvested; however, the same procedures would be used for both the planting and spacing summaries.

---

<sup>1</sup>The FORTRAN format specification for the record.



The new output file contained one record for each forest class harvested during the analysis. This record contained the:

- 1) forest class harvested [I3];
- 2) first period that harvesting occurred [I2];
- 3) percentage area harvested in the period [I3];
- 4) second period that harvesting occurred [I2];
- 5) percentage area harvested in the period [I3];
- 6) third period that harvesting occurred [I2];
- 7) percentage area harvested in the period [I3];
- 8) fourth period that harvesting occurred [I2];
- 9) percentage area harvested in the period [I3];
- 10) fifth period that harvesting occurred [I2]; and
- 11) percentage area harvested in the period [I3].

The programme was written to create data for a total of five periods (Table 2). The programme can easily be modified to generate data for fewer or additional periods.

#### 3.3.4.3 Classifying the Data

After the data were summarized, they were moved into the INFO database where the <cover>.PAT files for the map data were located. The INFO file was named HARVEST.DAT and had the item definition outlined in Table 3.

Table 2. Example of output records.

---

1.	20325100	0	0	0	0	0	0	0
2.	20435	8145100	0	0	0	0	0	0

where:

1. indicates that forest class 203 was harvested entirely in years 20-25.
2. indicates that 81% of forest class 204 was harvested in years 30-35 and 100% of the remaining area was harvested in years 40-45.

---

Table 3. Item definition for HARVEST.DAT file.

---

DATAFILE NAME: HARVEST.DAT					
11 ITEMS: STARTING IN POSITION					1
COL	ITEM NAME	WDTH	OPUT	TYP	N.DEC
1	FCLASS	3	4	I	-
4	HARV1	2	3	I	-
6	PCT1	3	4	I	-
9	HARV2	2	3	I	-
11	PCT2	3	4	I	-
14	HARV3	2	3	I	-
16	PCT3	3	4	I	-
19	HARV4	2	3	I	-
21	PCT4	3	4	I	-
24	HARV5	2	3	I	-
26	PCT5	3	4	I	-

---

To move the data into INFO, the INFO *GET* command was used with the *COPY* option specifying the full pathname of the file created from running HARVSUM (i.e. *ENTER COMMAND> GET <full pathname of file> COPY*).

To map the areas allocated for harvesting from the FORMAN output, four items had to be added to the end of the <cover>.PAT INFO files of the map data (Table 4).

Table 4. Item definition for <cover>.PAT INFO files.

---

ITEM NAME	WDTH	OPUT	TYP	N.DEC
FCLASS	3	4	I	-
YEAR	2	3	I	-
HPERIOD	2	3	I	-
BLOCK	4	5	I	-

---

To add these items, the ARC/INFO *ADDITEM* command was used with the <cover>.PAT file specified as both the input and output file. These items had to be added to all <cover>.PAT files for the map data. The item FCLASS contained the forest class that the stand was in, YEAR contained the period in years that the class was first harvested in, HPERIOD contained a value indicating the period of harvest, and BLOCK contained the final block identification number. The value assigned to the item FCLASS had to be the same value that was assigned by NBDNR&E to classify the stands into the forest classes for the FORMAN analysis. As a result, the <cover>.PAT file contained the items found in Table 5.

The following items also had to be kept in the <cover>.PAT file: 1) AREA; 2) PERIMETER; 3) <cover>#; 4) <cover>-ID; 5) FOREST-ID; and 6) MAPNO. The other items contained in the <cover>.PAT file could have been moved into lookup files and dropped from the <cover>.PAT file.

The items FCLASS, YEAR, HPERIOD and BLOCK could also have been put into lookup files instead of the <cover>.PAT file along with the item <cover># and relate files used while carrying out the analysis. This method was not used in this system as at the time that this work was carried

Table 5. Item definition of INFO file <cover>.PAT.

---

DATAFILE NAME: <cover>.PAT

45 ITEMS: STARTING IN POSITION 1

COL	ITEM NAME	WDTH	OPUT	TYP	N.DEC
1	AREA	4	12	F	3
5	PERIMETER	4	12	F	3
9	<cover>#	4	5	B	-
13	<cover>-ID	4	5	B	-
17	FOREST#	4	5	B	-
21	FOREST-ID	4	5	B	-
25	FCOV-ID	4	5	B	-
29	MAPNO	4	4	I	-
33	P1S1	2	2	C	-
35	P1S1%	2	2	I	-
37	P1S2	2	2	C	-
39	P1S2%	1	1	I	-
40	P1S3	2	2	C	-
42	P1S3%	1	1	I	-
43	P1DS	1	1	C	-
44	P1CC	2	2	I	-
46	P1S	1	1	C	-
47	P1H	1	1	C	-
48	P1V	1	1	C	-
49	SILV1	2	2	C	-
51	SILV2	2	2	C	-
53	FUNA	4	4	C	-
57	P2S1	2	2	C	-
59	P2S1%	2	2	I	-
61	P2S2	2	2	C	-
63	P2S2%	1	1	I	-
64	P2S3	2	2	C	-
66	P2S3%	1	1	I	-
67	P2DS	1	1	C	-
68	P2CC	2	2	I	-
70	SILV-ID	4	4	I	-
74	NULL	4	4	I	-
78	OCOV-ID	4	5	B	-
82	HOLDER	2	2	I	-
84	WTHDRL#	4	5	B	-
88	WTHDRL-ID	4	5	B	-
92	DEER	1	1	I	-
93	ECOL	1	1	I	-
94	SLOPE	1	1	I	-
95	STRBUF	1	1	I	-
96	LAKBUF	1	1	I	-
97	FLG	2	2	I	-
99	FCLASS	3	4	I	-
102	YEAR	2	3	I	-
104	HPERIOD	2	3	I	-
106	BLOCK	4	5	I	-
	** REDEFINED ITEMS **				
92	RESERVE	5	5	I	-

---

out, ARC/INFO did not possess the ability to use relate files for this type of analysis.

The value of HPERIOD, ranging from one to eight, designated the period of harvest. Ten was added to the value if harvesting in the stand occurred in more than oneperiod. Therefore, five indicated that the stand was cut entirely in period five (years 20-25) while sixteen indicated that the stand was harvested in more that one period with the first harvest taking place in period six (years 25-30). The value for HPERIOD was also used as a look-up to a shade table for plotting (Table 6) where the shade table file was named HPERIOD.SHD and had the item definitions found in Table 7.

Table 6. Initial shade table values.

---

\$RECNO	HPERIOD	SYMBOL	\$RECNO	HPERIOD	SYMBOL
1	0	0	14	14	36
2	1	9	15	15	45
3	2	10	16	16	46
4	3	11	17	17	47
5	4	12	18	18	48
6	5	21	19	20	0
7	6	22	20	21	69
8	7	23	21	22	71
9	8	24	22	23	72
10	10	0	23	24	74
11	11	33	24	25	70
12	12	34	25	99	0
13	13	35			

---

Table 7. Item definitions for shade table file.

---

DATAFILE NAME: HPERIOD.SHD					
2 ITEMS: STARTING IN POSITION 1					
COL	ITEM NAME	WDTH	OPUT	TYP	N.DEC
1	HPERIOD	2	3	I	-
3	SYMBOL	4	5	B	-

---

The following values were assigned to the item HPERIOD in <cover>.PAT for "non-harvestable" areas so that these areas could be identified on the output maps: 1) 21 if FCLASS = 0; 2) 22 if DEER or ECOL = 1; 3) 23 if STRBUF or LAKBUF = 1; 4) 24 if SLOPE = 1; and 5) 25 if SLOPE = 3.

INFO programmes (Figures 3 and 4) were then used to assign the appropriate symbol values. The programme NONHARV assigned values for the "non-harvestable" areas. The programme HPERIOD assigned values to YEAR and HPERIOD. Both of these programmes were located in the INFO database containing the digital coverage files and would be executed once for each <cover>.PAT file by *SELECTING* the <cover>.PAT file and then running the programme.

### 3.3.5 Producing the output

Maps shaded according to the period of harvest were then produced. This was carried out by using the ARCPLOT *POLYGONSHADES* command specifying HPERIOD as the item and

---

```

PROGRAM NAME: NONHARV
10000 PROGRAM SECTION ONE
10001 CALC HPERIOD = 0
10002 RESELECT P1DS EQ ' '
10003 CALC HPERIOD = 21
10004 ASELECT
10005 RESELECT RESERVE GT 0
20000 PROGRAMME SECTION TWO
20001 IF ( STRBUF = 1 OR LAKBUF = 1 )
20002     CALC HPERIOD = 23
20003     ELSE
20004         IF SLOPE = 1
20005             CALC HPERIOD = 24
20006             ELSE
20007                 IF SLOPE = 3
20008                     CALC HPERIOD = 25
20009                     ELSE
20010                         IF ( DEER = 1 OR ECOL = 1 )
20011                             CALC HPERIOD = 22
20012                             ENDIF
20013                         ENDIF
20014                     ENDIF
20015                 ENDIF
30000 PROGRAMME SECTION THREE
30001 ASELECT
40000 PROGRAMME END
99999 PROGRAM END

```

---

Figure 3. Assignment of values to "non-harvestable" areas.

---

```

PROGRAM NAME: HPERIOD
10000 PROGRAM SECTION ONE
10001 RESELECT FCLASS GT 0
10002 RESELECT HPERIOD LT 20
10003 CALC HPERIOD = 0
10004 RELATE HARVEST.DAT 1 BY FCLASS ORDE RO
10005 RESELECT $1HARV1 LE 40
10006 RESELECT $1PCT1 GT 0
10007 CALC YEAR = $1HARV1
10008 CALC HPERIOD = YEAR / 5
10009 RESELECT $1PCT1 LT 100
10010 CALC HPERIOD = HPERIOD + 10
10011 RELATE
10012 ASELECT
20000 PROGRAMME END
30000 PROGRAM END

```

---

Figure 4. Programme to assign values to YEAR and HPERIOD.

HPERIOD.SHD as the lookup table (i.e. *POLYGONSHADES* <cover>.PAT HPERIOD HPERIOD.SHD).

As an alternative to full shading, point symbology drawn at the polygon label positions could have been used for "harvestable" stands with "non-harvestable" stands shaded. In this case, the ARCPLOT LABELMARKERS command would be used (i.e. LABELMARKERS <cover>.PAT HPERIOD HPERIOD.SHD).

Using a lookup table could increase the execution time required to create the plot files; however, changes could be made to the plotting shades much easier as only the values in the lookup table needed to be changed. The shading patterns could have been assigned to the item HPERIOD; however, this would have resulted in changes having to be made to the programmes NONHARV and HPERIOD, plus the programmes would have had to be rerun if any changes were made to the plotting symbols used.

### 3.3.6 Scheduling the stands for harvest

Before the actual scheduling took place, reference maps and reports were generated. The maps indicated the internal record number of harvestable stands and also identified "non-harvestable" areas. The reports listed as a minimum:

- 1) the internal record number (<cover>#);
- 2) the stand number (FOREST-ID);
- 3) the map number (MAPNO);
- 4) the forest



class (FCLASS); and 5) the age (development stage) of the stand (P1DS).

The maps from 3.3.5 were then used together with these plots and reports. Using these data, changes were made to the period of harvest based on block layout constraints. In this project, the spatial constraints to be used in allocating the stands for harvest were (NBIP Forest Products Inc., 1987a):

1. A workable mix of operation in softwood and mixed stands which has to be acceptable to both the operating department and the forestry department.
2. Minimum block size as a function of condition of wood, block size not exceeding 125 hectares, and the adjacent blocks not to be harvested for a period of approximately 10 years; and
3. Adjacent blocks must be separated by at least 500 metres.

In conjunction with hardcopy maps, graphic plots could also be used. The user had the option of using ARCPLOT, ARCEDIT or the DRAW command to draw the information on a graphic terminal and then zoom in on certain areas. The use of the graphics terminal had some advantages over just using the hardcopy maps in being able to zoom in on areas containing a large number of small polygons. If ARCEDIT was used, care was required to ensure that no changes were made

to the digital data; otherwise, the data could have been altered and the process would have had to be repeated.

At the time the system was developed, the preferred procedure for making changes to the item HPERIOD was to record the changes and then make them using the INFO UPDATE command (i.e. *ENTER COMMAND> SELECT <cover>.PAT* followed by *ENTER COMMAND> UPDATE HPERIOD PROMPT*). Changes were then made by specifying the internal record number (obtained from existing plots) and the new value for HPERIOD at the prompts. Other methods that could have been used for making these changes were:

1. Using ARCEDIT to *RESELECT* stands and *CALCULATE* new values for HPERIOD; however, this would have resulted in the coverage having to be *BUILT* which is both time consuming plus it would have destroyed the link to the existing maps and reports.
2. using ARCPLLOT to *RESELECT* stands and then using the *INFOFILE* command.

The latter method may have had some potential use. The user would have to make sure that all stands that were harvested in more than one period had a value between one and eight assigned to HPERIOD.

As the overall system was designed to be flexible, a single method was used to do the blocking and make the changes to harvest period. However, the different options were also developed.

### 3.3.7 Evaluating the results

#### 3.3.7.1 Creating a Harvest Sequence File

After all changes to the harvest periods were made, the data were summarized to create a Harvest Sequence File for input back into FORMAN. This was carried out using the ARC *FREQUENCY* command (i.e. *ARC: FREQUENCY <cover>.PAT <cover>.FREQ*) where the frequency items specified were FCLASS and HPERIOD and the summary item was AREA. The data were then summarized using the INFO procedure in Figure 5 where HSEQ.FILE had the item definition defined in Table 8.

---

```
1.  ENTER COMMAND> SELECT HSEQ.FILE
2.  ENTER COMMAND> PURGE
3.  ENTER COMMAND> SELECT <cover>.FREQ
4.  ENTER COMMAND> RESELECT HPERIOD LT 21
5.  ENTER COMMAND> RELATE HSEQ.FILE 1 BY FCLASS APPEND
6.  ENTER COMMAND> CALC $1FCLASS = FCLASS
7.  ENTER COMMAND> CALC $1AREA = AREA / 10000
8.  ENTER COMMAND> CALC $1HPERIOD = HPERIOD
    {REPEAT STEPS 3-8 FOR ALL <cover>.FREQ FILES}
9.  ENTER COMMAND> SELECT HSEQ.FILE
10. ENTER COMMAND> SORT HPERIOD, FCLASS
11. ENTER COMMAND> SAVE <full pathname> COMPRESS INIT
```

---

Figure 5. INFO procedure to summarize data.

Table 8. Item definitions for INFO file HSEQ.FILE.

---

```
DATAFILE NAME: HSEQ.FILE
  3 ITEMS: STARTING IN POSITION      1
COL  ITEM NAME      WIDTH OPUT TYP N.DEC
  1  FCLASS         3      4  I    -
  4  AREA           10     10  I    -
 14  HPERIOD        2      3  I    -
```

---

### 3.3.7.2 Testing the Results Using FORMAN

The FORMAN analysis was executed a second time; however, this time the file created in 3.3.7.1 was input as the harvest sequence file. Based upon the changes in the wood supply results, the planner could analyze whether the proposed harvest schedule was acceptable. If the proposed schedule was not acceptable, the procedure would be run again; however, depending on the changes to be made, the entire procedure might not have to be run. For example, if changes were only going to be made to the harvest periods defined, just the wood supply analysis would be run again.

### 3.3.7.3 Block Numbering

After an acceptable schedule was determined, the numbering of the harvest blocks was carried out. This was done by reviewing the harvest schedule and updating the item BLOCK in the <cover>.PAT files using the INFO UPDATE command (i.e. ENTER COMMAND> SELECT <cover>.PAT followed by ENTER COMMAND> UPDATE BLOCK PROMPT).

An alternative to this would have been to assign the block number to the stands when determining the period of harvest. In doing this, the user could have assigned a block number made up of the period of harvest multiplied by 1000 plus a sequential number. From this, the period of harvest and the block number could be derived. This procedure would result in more work when carrying out the

scheduling, as the value of HPERIOD would have had to be changed, but it would have greatly reduced the time in assigning the block numbers to the stands later on. If this procedure was followed, the command to calculate HPERIOD would have been `CALC $1HPERIOD = HPERIOD / 1000`. To assign the values to BLOCK, the procedure in Figure 6 would have been used.

---

```
ENTER COMMAND> SELECT <cover>.PAT
ENTER COMMAND> CALC BLOCK = HPERIOD / 1000
ENTER COMMAND> CALC BLOCK = HPERIOD - ( BLOCK * 1000 )
```

---

Figure 6. Procedure to assign values to the item BLOCK.

### 3.3.8 Completing the project

By the end of February, 1988, both the interface and the system to assist with mapping the stands and the stand scheduling were completed and tested. All that remained was carrying out the analysis with NBIP Forest Products Inc. This analysis could not take place until the original wood supply analysis had been approved by NBDNR&E.

Before the analysis could take place, the final output requirements were changed by NBDNR&E effective April, 1988. At this time it was decided that as the harvest scheduling after blocking could differ from the original wood supply analysis, the impact of this change was to be considered. This was to be done by creating a Harvest Sequence File to

be input into FORMAN (New Brunswick Department of Natural Resources and Energy, 1988b). The use of a Harvest Sequence File and the comparison of results was included in the original proposal to NBIP Forest Products Inc (NBIP Forest Products Inc., 1987a). As a result, the interface that had been developed could be used to generate the data required by NBDNR&E.

#### 4.0 DISCUSSIONS

The wood supply for NBIP Forest Products Inc.

Upsalquitch License was finally approved in the fall of 1988, with the final mapping being carried out at LU-CARIS in the Spring of 1989. This was more than two years from when the project was originally proposed in September of 1986. At the time of the original proposal, the actual requirements except for the wood supply analysis and the stand scheduling were left open. It was from these requirements that the proposal to develop an interface between FORMAN and ARC/INFO was created. It was also originally proposed to determine the effects of the spatial constraints on the wood supply by feeding the changed stand schedule back into FORMAN. This is the value that the developed interface provided. It allowed for the comparison of different harvesting scenarios, based upon the introduction of spatial constraints, using a non-spatial wood supply model.

The bases defined for testing and evaluating the interface were: 1) the extent to which it assisted managers in the planning process; 2) whether it provided new information to the manager; 3) how well the results of the

non-spatial wood supply analysis could be checked using the GIS; and 4) the ability to feed data back into the wood supply model.

In its final form, the interface assisted the manager in several areas of the planning process. It assisted in:

1. The development of the forest classes and yield curves to be used in the analysis by allowing the manager to analyze the data from the survey plots and compare this information to the proposed forest classes. This enabled the manager to identify which classes did not contain sufficient data and therefore needed to be combined with other forest classes. It also enabled the manager to check that all forest stands within the license would be aggregated into forest classes that could be derived from the plot data. As well, the process allowed the manager to stratify the forest units by soil type and to use soil attributes in aggregating the stands into forest units.
2. The determination of the actual land base to be used in the wood supply analysis by allowing the manager to remove withdrawal areas accurately. This process reduced the individual stand areas by the portion of the stand located within a withdrawal. As a result, when the stands were aggregated into forest units, only the areas outside of withdrawals were summed. In



previous plans, an overall area reduction factor was applied to the entire land base.

3. The aggregation of the data into forest units based upon the characteristics of the forest unit including the incorporation of soils information. As the interface facilitated the use of spatial information, the stand data could be overlaid with the soils data to derive which soil unit the stand was located in. For this project, each stand was assigned to one soil unit; stands were not subdivided by soil units.
4. The disaggregation of the forest units into individual stands. This was possible as the process maintained a link between the individual stands and the forest units. Therefore, based upon the additional output from the wood supply analysis, it was possible for the manager to identify the actual stands treated within any given period.
5. The mapping of the stands to be treated. This was achieved from the additional output generated from the modifications made to FORMAN. This output provided a record of the time period in which forest units were treated. This information, together with the process to disaggregate the forest units into individual stands enabled the manager to output the individual stands to be treated.

6. The scheduling of stands for treatment. Once output, the manager could make changes to the actual stands to be treated during a specific time period, or change the time period during which a stand would be treated. The manager could do this as the interface allowed him to modify certain attributes within the data which recorded this information. The interface also kept track of the changes made to the treatment schedule.
7. Analyzing the effects of changes to the treatment schedule. Once changes were made to the stand schedule, the information was used to generate a harvest sequence file. This file forces the wood supply model to harvest stands in a particular order and in a specific time period. As a result, the manager could compare the results of the different wood supply scenarios with the results from the original run.

New information was provided to the planner in terms

of:

1. The actual derivation of area withdrawals rather than applying a percentage reduction to the entire land base as was done with previous plans. In the previous plan, a reduction factor of 16% was used. Based upon the spatial information used for this plan an overall reduction value of 19.6% was calculated.

2. The area reductions were applied to the actual stands and forest units rather than being averaged over the entire land base. If the area reduction factor had been applied to the entire land base, the area of plantations and recent cut-overs would have been reduced by 6915 hectares. This would have also resulted in the area of the productive land base used in the analysis being inflated by the same amount. As a result, the analysis would have predicted a higher sustainable harvest in the early time periods. The effect in later time periods is not known due to the cumulative affect of the early increased harvest values together with a reduction in the volume coming on stream from plantations.
3. The spatial distribution of the stands to be treated. As a result of the ability to disaggregate the forest units into individual stands, the manager could produce output indicating the actual stands to be treated. Using this new information, the manager could assess the output against the spatial constraints that had to be met and make changes to the treatment schedule as required.
4. The costs of adding spatial constraints to the actual treatment schedule in comparison to the initial model-driven schedule. If the manager made changes to the treatment schedule, these changes were captured through

the interface. Once the changes were completed, a harvest sequence file could be generated to be input back into the model. This would force the model to treat stands in a particular order. The manager could then review the result of the new analysis against previous analyses and assess the impact of the changes. The results of the wood supply model could easily be checked and analyzed using the GIS through:

1. The production of maps on either graphic display terminals or hardcopy. As a result of the linkages that were maintained through the interface, the actual stands to be treated could be identified and output.
2. Once the output maps were created, the manager could review the stands to be treated against the spatial constraints that were to be met. If changes to the schedule were required to meet the spatial constraints, the interface allowed the manager to make these changes and then generate a harvest sequence file to be input into the wood supply model.
3. Once changes were made to the treatment schedule, and the changes input into the wood supply model using the harvest sequence file, the manager could compare the results of the new analysis against previous analyses. This also allowed the manager to analyze the results of the new analysis to ensure that the output from the model is what they expected in terms of the timing of

treatments and the adherence to the required spatial constraints.

The interface also allowed the modified treatment schedule to be aggregated and input back into the wood supply model. This component was crucial to allow the planner to analyze the costs associated with different scenarios. This was achieved by:

1. Enabling the manager to output the results of the wood supply analysis; allowing the manager to make changes to the treatment schedule; and capturing the changes made by the manager.
2. Generating a harvest sequence file based upon the changes that the manager made to meet the required spatial constraints. This harvest sequence file was then input into the wood supply model to force stands to be treated in a particular sequence.

From the results of using the interface, it was clear that it met the bases that were identified to test it. As well there were certain tasks and conditions that were defined for the process and interface. NBIP Forest Products Inc., (1987a: 1) defined two broad tasks that had to be met:

1. Forecast the performance of the forest on crown land License #1, the Upsalquitch License, for a period of 80 years and determine the sustainable harvest level for the forest to compare two scenarios. First, the forest performance is evaluated with a minimum of operational

constraints applied to the harvesting operations to discover the maximum potential supply available from the forest, and second by applying realistic operational constraints, define the maximum potential supply from the forest.

2. Using the LU-CARIS facilities, develop and map a spatially feasible forty-year harvest schedule based on the wood supply results that meets the operational constraints of the company. With the constraints in place, a stand listing for the license identifying the stands that will be harvested in each 5-year period of the 40-year plan must also be produced. The development of the harvest schedule must be based on the wood supply analysis taking into account a number of variables relative to the species mix, block size, configuration and access, as well as incorporating the existing 5-year operating plan which covers the period from 1987 to 1991.

Both of these requirements, plus the additional requirements identified during the life of the project, were met.

It was also required that the interface be flexible, easy to use and allow the planner to intervene into certain processes. The resultant process was flexible in that it was developed in modules that could be modified as required; for many of the steps, options were identified, and one

chosen based on how well it met the current need; and it was developed as a stand-alone process. The flexibility of the interface became more important through the life of the project as the requirements for the final plan were changed substantially by NBDNR&E.

When NBDNR&E changed the criteria for assessing different wood supply scenarios in April, 1988 (New Brunswick Department of Natural Resources and Energy, 1988b), they also changed the requirements for the procedures and file structures to be used. In order to determine the final stand schedule, the timing of the harvest had to be considered on the basis of: 1) the relative softwood volume over periods 1 through 5; 2) block layout due to spatial constraints; and 3) other factors such as hardwood fallout. As the interface and overall system had been developed to be flexible, these requirements could be easily addressed. The data to be used in scheduling based on volume were calculated at LU-CARIS, the blocking was undertaken by NBIP Forest Products Inc., and these data were then incorporated into the final reports.

While implemented using a specific GIS and Wood Supply Model, the required functions were identified first, and then carried out using the specific software. As a result, the same methodology could be used to develop specific interfaces between any of the wood supply models and GISs described in chapter 2.

The one specific change made in the development of the interface was the modification made to FORMAN to facilitate identifying the actual time period in which forest units were treated. While this modification to FORMAN was not absolutely required, it was decided that it would be more efficient than developing a programme to extract the required information from the output files created by the FORMAN model. A similar modification could be made to other wood supply models or programmes could be developed to determine the same information from the output files from the wood supply models.

The interface was easy to use in that it was built totally within the framework of the GIS and wood supply model. Thus anyone working with these systems would be comfortable with the environment for the interface. The majority of the processing was carried out at LU-CARIS as LU-CARIS was under contract to carry out the analysis and the work.

However, as per the third requirement, the interface was developed to allow the planner to intervene at certain points in the analysis. In fact, the process was developed so that the planner was required to review the spatial distribution of stands and to make changes to the treatment schedule to meet spatial constraints. These reviews and changes were made by NBIP Forest Products Inc. staff. As a result, the planner was aware of the changes made; the



changes being forced upon the wood supply model; and the impact of making these changes. The interface also provided different options to the planner for actually making these changes.

While the interface was successfully implemented, the project was not without issues. Over the two years that the project was carried out, the requirements by NBDNR&E for the final plan changed substantially. In the end, the company was required to carry out the analysis that was originally proposed. In addition, the actual file structures and procedures to be used for this analysis were defined. This did not detract from the project as it reinforced the original assessment of what was required to develop the plan according to the original requirements. Although not identical, the procedures that later became a requirement by NBDNR&E were similar to those initially proposed and then developed to create the forest planning system for this project. The flexible nature of the interface and overall system were also proven by the ability to provide the required information resulting from these changes.

The timing of the data acquisition also presented problems. As the Province of New Brunswick was in the process of automating its forest data when this project started, many of the data were received later than originally anticipated. When they were received, immediate processing was required and the results returned as quickly

as possible. In some cases this resulted in rushing the data through instead of trying to develop the most efficient methods of analysis.

## 5.0 CONCLUSIONS

The interfacing system reported here is operational and can easily be modified to work with other GISs or wood supply models. It could easily be modified to work with the database format for Forest Resource Inventory data in Ontario with either the FORMAN or OWOSFOP wood supply models. The design of the system also allows it to be easily converted to other operating systems and computers.

The interface allows the user to 1) move data from the existing database into the wood supply model for analysis; 2) view the spatial distribution of the stands selected in the wood supply analysis by mapping the stands to be treated on either a graphics terminal or by plotting the maps; 3) change the treatment schedule based on the spatial distribution and spatial constraints; and 4) monitor the results of these changes by feeding the data back into the wood supply analysis.

The project demonstrated the value in utilizing GISs in wood supply analysis and from the changes that took place over the two years it was quite visible that the parties were learning as the work was carried out. Due to the power

and flexibility of the system developed, it is possible to start looking at the next planning cycle so that additional scenarios and impacts can be studied. It would also allow the planners to implement changes easily instead of rushing and not fully analyzing the potential impact of the changes, or not implementing a change because the time frame does not allow it.

This system could also be modified to assist with the actual annual planning for the harvest. As the original wood supply analysis was for five-year time horizons, the data set could be limited to the stands scheduled in the period and the system used to assist with the annual stand allocation. The system can also be easily expanded to assist with scheduling the planting and spacing treatments as the base data are available in the GIS output file.

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## APPENDICES

APPENDIX I

MODIFICATIONS TO FORMAN

CHANGES TO THE FORMAN PROGRAMME

```
C
C *****
C * THIS FOREST DEVELOPMENT SIMULATION MODEL WAS DESIGNED AND *
C * WRITTEN IN 1981 BY ERIK C. WANG. IT WAS MODIFIED AND *
C * UPDATED IN 1982/83 BY THOM ERDLE. *
C * CONVERTED TO F77 IN JUNE 1985 BY T.G ROUSSELL, D.F.M.E., N.B. *
C * REVISED IN MARCH/86 BY T.G. ROUSSELL, D.F.M.E., N.B. *
C * REVISED IN APRIL/87 BY T.G. ROUSSELL, D.F.M.E., N.B. *
C * VERSION: 2.1 *
C *****
C
```

```
LOGICAL OP
CHARACTER*32 FCNAME, YCNAME, ONAME1, ONAME2, IRES*1, CNAME, HSNAME
CHARACTER*32 XNAME, HSNAME, MANF*1, ONAME3
COMMON /YC/YCURVS /CM/CMATRIX /AC/ACS /CO/HCOST, PCOST, MCOST, TCOST
COMMON /OR/NP10, IYCPLO, IYCFUO, IYCPRO, MANAGO, AGESO, AREASO, HSARO,
&OPVPO, OPVSO, PRVOLO
COMMON /SI/PLPR, IYCPL, SPACF, THCURV, ARTH, ARPL, ARNAT, HPRVOL, FLAG
COMMON /RE/IYCPR, IYCFU, ID /XA/X
WRITE(*, 8100)
ONAME1 = ' '
ONAME3 = ' '
MANF = ' '
YPI = 5
NSPAC = 0
```

```
C
C *****
C * READ OWNERSHIP *
C *****
C
```

```
C
C *****
C * HAVE USER SET UP HARVEST AND SILVICULTURE RULES *
C *****
C
```

```

C
      IF (NRUN.EQ.1) THEN
      CALL ENTLNG(ONAME1)
      CALL ENTGIS(ONAME3)
      CALL ENTRUL(YPI,NIT,PCCUT,RULE)
      CALL ENTHRV(YPI,NIT,NMAN,MHARV)
      CALL ENTMH(YPI,NIT,NMAN,NRUN,MHARV)
      CALL ENTPL(YPI,NIT,PLANTO)
      CALL ENTSP(YPI,NIT,SPACO,LTA,UTA)
    ELSE
      CALL MENU(YPI,NIT,NMAN,ONAME1,MHARV,NRUN,PLANTO,SPACO,LTA,
&      UTA,PCCUT,RULE,ONAME3)
    END IF

C
C
C
C
C
*****
* WRITE OUT THE MANAGEMENT PLAN *
*****

610      CONTINUE
      WRITE(6,4200) TAREA,TOVOLP,TOVOLS,TPRVOL,TVOCP,TVOCS,
&      THPRV,TARC,TARPL,TARTH,THCOST,TPCOST,TCOST,TTTCOST
      WRITE(6,4300) XMOR1,XMOR2
    END IF

C
C
C
WRITE TO GIS FILE

      IF (ONAME3.NE.' ') THEN
      DO 2002 I=1,NCLAS
      PCTCUT=0.0
      PCTPL=0.0
      PCTSPC=0.0
      IF (CUTF(I).GT.0)THEN
&      PCTCUT=(FLOAT(ARCUT(CUTF(I)))/(FLOAT(ARCUT(CUTF(I))
&      +FLOAT(AREAS(I)))))*100.0
&      PCTPL=(FLOAT(ARPL(CUTF(I)))/FLOAT(ARCUT(CUTF(I))))
&      *100.0
      AGE=AGES(I)*YPI
&      WRITE(8,2003)ID(I),AGE,ITIME,ARCUT(CUTF(I)),PCTCUT
&      ,ARPL(CUTF(I)),PCTPL
2003      FORMAT(2I4,I3,2(I7,F5.0))
      ELSE IF (SPACF(I).GT.0) THEN
      AGE=AGES(I)*YPI
&      PCTSPC=(FLOAT(ARTH(SPACF(I)))/(FLOAT(ARTH(SPACF(I))
&      +FLOAT(AREAS(I)))))*100.0
&      WRITE(8,2004)ID(I),AGE,ITIME,ARTH(SPACF(I)),PCTSPC
2004      FORMAT(2I4,I3,24X,I7,F5.0)
      ENDIF
2002      CONTINUE
      ENDIF

C
C
C
END OF WRITING GIS REPORT

      IF (ONAME2.NE.' ') THEN
      ITIME = IIT * YPI
      WRITE(7,4250) ITIME,TOVOLP,TOVOLS,TPRVOL,TVOCP,TVOCS,
&      THPRV,TARC,TARPL,TARTH,THCOST,TPCOST,TCOST,TTTCOST,
&      XMOR1,XMOR2
    END IF

```

620           CONTINUE

```

      CLOSE(6)
      CLOSE(7)
      !   CLOSE(8)
      C
1000  FORMAT(1X, '   ENTER THE NAME OF THE CURVE SET FILE')
```



ADDITIONAL SUBROUTINE

```
C
C
C           SUBROUTINE ENTGIS
C
C *****
C * SET UP OUTPUT FILE FOR GIS REPORT (OPTIONAL) *
C *****
C
SUBROUTINE ENTGIS(ONAME3)
  INTEGER*4 IERR
  LOGICAL OP
  CHARACTER*32 ONAME3,XNAME
C
  XNAME = ONAME3
10  WRITE(*,1000)
  READ(*,2000) ONAME3
  IF (ONAME3.NE.' ') THEN
    INQUIRE(8,OPENED=OP)
    IF (OP) THEN
      IF (ONAME3.EQ.XNAME) THEN
        CLOSE(8,STATUS='DELETE',IOSTAT=IERR)
      ELSE
        CLOSE(8,IOSTAT=IERR)
      END IF
    END IF
    OPEN(8,FILE=ONAME3,STATUS='NEW',IOSTAT=IERR)
    IF (IERR.NE.0) THEN
      WRITE(*,3000)
      GOTO 10
    END IF
  END IF
  IF (ONAME3.EQ.' ') ONAME3 = XNAME
1000 FORMAT(4X,'ENTER NAME OF THE OUTPUT FILE FOR THE GIS REPORT')
2000 FORMAT(A32)
3000 FORMAT('*** COULD NOT OPEN FILE. TRY AGAIN. ***')
RETURN
END
```

MODIFIED MENU SUBROUTINE

```

C          SUBROUTINE MENU
C
C          *****
C          * DISPLAY MENU FOR CHANGING HARVEST AND TREATMENT ON SUCCESSIVE *
C          * ITERATIONS *
C          *****
C
SUBROUTINE MENU(YPI,NIT,NMAN,ONAME1,MHARV,NRUN,PLANTO,SPACO,LTA,
&UTA,PCCUT,RULE,ONAME3)
    INTEGER*2 YPI,NIT,NMAN,NRUN,LTA,UTA,DUMMY,RULE(6,40)
    INTEGER*4 MHARV(13,40),PLANTO(40),SPACO(40)
    REAL PCCUT(2,40)
    CHARACTER*32 ONAME1,ONAME3
    WRITE(*,1000)
    READ(*,*,ERR=10) DUMMY
    IF ((DUMMY.LT.1).OR.(DUMMY.GT.9)) GOTO 10
    GOTO (20,25,30,40,50,60,70,80,90) DUMMY
20    CALL ENTLNG(ONAME1)
    GOTO 10
|25    CALL ENTGIS(ONAME3)
|    GOTO 10
30    CALL ENTRUL(YPI,NIT,PCCUT,RULE)
    GOTO 10
40    CALL ENTHRV(YPI,NIT,NMAN,MHARV)
    GOTO 10
50    CALL ENTMH(YPI,NIT,NMAN,NRUN,MHARV)
    GOTO 10
60    CALL ENTPL(YPI,NIT,PLANTO)
    GOTO 10
70    CALL ENTSP(YPI,NIT,SPACO,LTA,UTA)
    GOTO 10
80    CALL ENTLNG(ONAME1)
|    CALL ENTGIS(ONAME3)
    CALL ENTRUL(YPI,NIT,PCCUT,RULE)
    CALL ENTHRV(YPI,NIT,NMAN,MHARV)
    CALL ENTMH(YPI,NIT,NMAN,NRUN,MHARV)
    CALL ENTPL(YPI,NIT,PLANTO)
    CALL ENTSP(YPI,NIT,SPACO,LTA,UTA)
    GOTO 10
1000   FORMAT(20X,'1. ENTER LONG REPORT NAME'/20X,
&      '2. ENTER GIS REPORT NAME'/20X,
&      '3. ENTER HARVEST RULE'/20X,'4. ENTER HARVEST'/20X,
&      '5. ENTER HARVEST BY MANAGEMENT UNIT'/20X,
&      '6. ENTER PLANTING'/20X,'7. ENTER SPACING'/20X,
&      '8. CHANGE ALL PARAMETERS'/20X,
&      '9. START RUN'/25X,'OPTION:')
90    RETURN
    END

```

EXAMPLE OF OUTPUT IN THE GIS FILE

21	65	5	541	100.	0	0.	
22	65	5	359	100.	359	100.	
23	95	5	112	100.	0	0.	
24	95	5	75	100.	75	100.	
61	115	5	36	100.	0	0.	
62	115	5	25	100.	25	100.	
65	55	5	162	100.	0	0.	
66	55	5	106	100.	106	100.	
71	55	5	27	100.	0	0.	
72	55	5	19	100.	19	100.	
114	95	5	34	100.	0	0.	
115	95	5	22	100.	22	100.	
116	110	5	63	100.	63	100.	
117	130	5	94	100.	0	0.	
118	130	5	63	100.	63	100.	
146	125	5	152	100.	152	100.	
172	20	5					359 85.
176	20	5					140 100.
177	20	5					92 100.
186	65	5	154	100.	0	0.	
187	65	5	102	100.	102	100.	
188	85	5	154	100.	0	0.	
243	55	5	123	100.	0	0.	
244	60	5	44	27.	0	0.	
245	65	5	238	100.	0	0.	
565	100	5	210	100.	0	0.	
566	100	5	279	100.	162	58.	
567	125	5	194	100.	0	0.	
726	85	10	19	100.	19	100.	
5	45	10	349	100.	0	0.	
6	45	10	231	100.	231	100.	
19	60	10	279	100.	0	0.	
230	45	10	324	100.	0	0.	
244	60	10	119	100.	0	0.	
257	115	10	143	100.	0	0.	

APPENDIX II  
SUMMARY PROGRAMMES

PROGRAMME HARVSUM.F77

```
C
C   PROGRAMME TO SUMMARIZE GIS FILE FOR HARVESTING
C
C   WRITTEN BY: JOSEPH KAPRON
C               CENTRE FOR THE APPLICATION OF RESOURCES
C               INFORMATION SYSTEMS
C               LAKEHEAD UNIVERSITY, SCHOOL OF FORESTRY
C               SEPT. 1987
C
C   INTEGER NHARV(1000),THARV(1000,5),PHARV(1000,5)
C   INTEGER FCLASS,ITIME,PCT
C   CHARACTER*32 IFILE,OFILE
C   DATA NHARV/1000*0/,THARV/5000*0/,PHARV/5000*0/
C
C   ENTER THE INPUT AND OUTPUT FILE NAMES
C
C   WRITE(1,'(A)')'ENTER THE NAME OF THE GIS INPUT FILE'
C   READ(1,'(A)')IFILE
C   WRITE(1,'(A)')'ENTER THE NAME OF THE OUTPUT FILE'
C   READ(1,'(A)')OFILE
C
C   OPEN THE FILES AND READ IN THE DATA
C
C   OPEN(5,FILE=IFILE,STATUS='OLD',ACTION='READ')
C   OPEN(6,FILE=OFILE,STATUS='NEW',ACTION='WRITE')
10  CONTINUE
C   READ(5,900,END=999)FCLASS,ITIME,PCT
C   IF (PCT.LE.0) GOTO 10
C
C   SUMMARIZE AND OUTPUT THE DATA
C
C   NHARV(FCLASS)=NHARV(FCLASS)+1
C   THARV(FCLASS,NHARV(FCLASS))=ITIME
```

```
    PHARV(FCLASS,NHARV(FCLASS))=PCT
    GOTO 10
999  CONTINUE
    DO 11 I=1,1000
    IF (NHARV(I).GT.0) THEN
        WRITE(6,901) I, (THARV(I,J),PHARV(I,J),J=1,5)
    ENDIF
11   CONTINUE
900  FORMAT(I4,4X,I3,7X,I4)
901  FORMAT(I3,5(I2,I3))
    CLOSE(5)
    CLOSE(6)
    STOP
    END
```

PROGRAMME PLANTSUM.F77

```
C
C   PROGRAMME TO SUMMARIZE GIS FILE FOR PLANTING
C
C   WRITTEN BY: JOSEPH KAPRON
C               CENTRE FOR THE APPLICATION OF RESOURCES
C               INFORMATION SYSTEMS
C               LAKEHEAD UNIVERSITY, SCHOOL OF FORESTRY
C               SEPT. 1987
C
C   INTEGER NPLANT(1000), TPLANT(1000,5), PPLANT(1000,5)
C   INTEGER FCLASS, ITIME, PCT
C   CHARACTER*32 IFILE, OFILE
C   DATA NPLANT/1000*0/, TPLANT/5000*0/, PPLANT/5000*0/
C
C   ENTER THE INPUT AND OUTPUT FILE NAMES
C
C   WRITE(1, '(A)') 'ENTER THE NAME OF THE GIS INPUT FILE'
C   READ(1, '(A)') IFILE
C   WRITE(1, '(A)') 'ENTER THE NAME OF THE OUTPUT FILE'
C   READ(1, '(A)') OFILE
C
C   OPEN THE FILES AND READ IN THE DATA
C
C   OPEN(5, FILE=IFILE, STATUS='OLD', ACTION='READ')
C   OPEN(6, FILE=OFILE, STATUS='NEW', ACTION='WRITE')
10  CONTINUE
C   READ(5, 900, END=999) FCLASS, ITIME, PCT
C   IF (PCT.LE.0) GOTO 10
C
C   SUMMARIZE AND OUTPUT THE DATA
C
C   NPLANT(FCLASS)=NPLANT(FCLASS)+1
C   TPLANT(FCLASS, NPLANT(FCLASS))=ITIME
C   PPLANT(FCLASS, NPLANT(FCLASS))=PCT
C   GOTO 10
999 CONTINUE
C   DO 11 I=1, 1000
C   IF (NPLANT(I).GT.0) THEN
C       WRITE(6, 901) I, (TPLANT(I, J), PPLANT(I, J), J=1, 5)
C   ENDIF
11  CONTINUE
900 FORMAT(I4, 4X, I3, 19X, I4)
901 FORMAT(I3, 5(I2, I3))
C   CLOSE(5)
C   CLOSE(6)
C   STOP
C   END
```

PROGRAMME SPACESUM.F77

```
C
C   PROGRAMME TO SUMMARIZE GIS FILE FOR SPACING
C
C   WRITTEN BY: JOSEPH KAPRON
C               CENTRE FOR THE APPLICATION OF RESOURCES
C               INFORMATION SYSTEMS
C               LAKEHEAD UNIVERSITY, SCHOOL OF FORESTRY
C               SEPT. 1987
C
C   INTEGER NSPACE(1000),TSPACE(1000,5),PSPACE(1000,5)
C   INTEGER FCLASS,ITIME,PCT
C   CHARACTER*32 IFILE,OFILE
C   DATA NSPACE/1000*0/,TSPACE/5000*0/,PSPACE/5000*0/
C
C   ENTER THE INPUT AND OUTPUT FILE NAMES
C
C   WRITE(1,'(A)')'ENTER THE NAME OF THE GIS INPUT FILE'
C   READ(1,'(A)')IFILE
C   WRITE(1,'(A)')'ENTER THE NAME OF THE OUTPUT FILE'
C   READ(1,'(A)')OFILE
C
C   OPEN THE FILES AND READ IN THE DATA
C
C   OPEN(5,FILE=IFILE,STATUS='OLD',ACTION='READ')
C   OPEN(6,FILE=OFILE,STATUS='NEW',ACTION='WRITE')
10  CONTINUE
C   READ(5,900,END=999)FCLASS,ITIME,PCT
C   IF (PCT.LE.0) GOTO 10
C
C   SUMMARIZE AND OUTPUT THE DATA
C
C   NSPACE(FCLASS)=NSPACE(FCLASS)+1
C   TSPACE(FCLASS,NSPACE(FCLASS))=ITIME
C   PSPACE(FCLASS,NSPACE(FCLASS))=PCT
C   GOTO 10
999  CONTINUE
C   DO 11 I=1,1000
C   IF (NSPACE(I).GT.0) THEN
C       WRITE(6,901)I,(TSPACE(I,J),PSPACE(I,J),J=1,5)
C   ENDIF
11  CONTINUE
900  FORMAT(I4,4X,I3,31X,I4)
901  FORMAT(I3,5(I2,I3))
C   CLOSE(5)
C   CLOSE(6)
C   STOP
C   END
```

EXAMPLE OF THE SUMMARIZED DATA FROM HARVSUM.F77

130100	0	0	0	0	0	0
230100	0	0	0	0	0	0
330100	0	0	0	0	0	0
430100	0	0	0	0	0	0
510100	0	0	0	0	0	0
610100	0	0	0	0	0	0
720100	0	0	0	0	0	0
820100	0	0	0	0	0	0
920100	0	0	0	0	0	0
1020100	0	0	0	0	0	0
1315100	0	0	0	0	0	0
1415100	0	0	0	0	0	0
1525100	0	0	0	0	0	0
1625100	0	0	0	0	0	0
1715100	0	0	0	0	0	0
1815100	0	0	0	0	0	0
1910100	0	0	0	0	0	0
2010100	0	0	0	0	0	0
21 5100	0	0	0	0	0	0
22 5100	0	0	0	0	0	0
23 5100	0	0	0	0	0	0
24 5100	0	0	0	0	0	0
2525 230100	0	0	0	0	0	0
2630100	0	0	0	0	0	0
2725100	0	0	0	0	0	0
24025100	0	0	0	0	0	0
24115100	0	0	0	0	0	0
24215100	0	0	0	0	0	0
243 5100	0	0	0	0	0	0
244 5 2710100	0	0	0	0	0	0
245 5100	0	0	0	0	0	0
246 5100	0	0	0	0	0	0
247 5100	0	0	0	0	0	0



APPENDIX III  
OPERABILITY LIMITS

PROGRAMME TO CALCULATE VOLUME SUMMARY

```
C
C   PROGRAMME VOL.F77
C
C   WRITTEN BY: JOSEPH KAPRON
C               CENTRE FOR THE APPLICATION OF RESOURCES
C               INFORMATION SYSTEMS
C               LAKEHEAD UNIVERSITY, SCHOOL OF FORESTRY
C               SEPT. 1987
C
C   INTEGER CURVE(730),VOL(46),TMERCH
C   INTEGER PLOT(46,9),OLDID
C   REAL*8 DBH(46,9),CELL(46,9,6),OUT(46,9,5),FREQ(46,9)
C   REAL*8 VMERCH(730),SPECV(46)
C   CHARACTER*8 STRATA(46)
C   CHARACTER*3 SPECIES(9),SPEC
C
C   INITIALIZE VARIABLES
C
C   DATA CURVE/730*0/,CELL/2484*0./,OUT/2070*0./
C   DATA PLOT/414*0/,FREQ/414*0./
C   DATA DBH/414*0.0/
C   DATA VMERCH/730*0./
C
C   ASSIGN FOREST UNITS FOR OUTPUT
C
C   STRATA(1)='BFSP L Y'
C   STRATA(2)='BFSP L I'
C   STRATA(3)='BFSP L M'
C   STRATA(4)='BFSP L O'
C   STRATA(5)='BFSP M Y'
C   STRATA(6)='BFSP M I'
C   STRATA(7)='BFSP M M'
C   STRATA(8)='BFSP H Y'
```

STRATA(9)='BFSP H Y'  
STRATA(10)='BFSP H M'  
STRATA(11)='SFWP A M'  
STRATA(12)='SFIH A Y'  
STRATA(13)='SFIH A I'  
STRATA(14)='SFIH A M'  
STRATA(15)='SFTH A Y'  
STRATA(16)='SFTH A I'  
STRATA(17)='SFTH A M'  
STRATA(18)='SFTH A O'  
STRATA(19)='IHSF A Y'  
STRATA(20)='IHSF A I'  
STRATA(21)='IHSF A M'  
STRATA(22)='IHSF A O'  
STRATA(23)='THSF A Y'  
STRATA(24)='THSF A I'  
STRATA(25)='THSF A M'  
STRATA(26)='TOHW L Y'  
STRATA(27)='TOHW L I'  
STRATA(28)='TOHW L O'  
STRATA(29)='TOHW H Y'  
STRATA(30)='TOHW H I'  
STRATA(31)='TOHW H M'  
STRATA(32)='INHW A Y'  
STRATA(33)='INHW A I'  
STRATA(34)='INHW A M'  
STRATA(35)='HWMX A Y'  
STRATA(36)='HWMX A I'  
STRATA(37)='HWMX A M'  
STRATA(38)='OTSW A M'  
STRATA(39)='OTSW A O'  
STRATA(40)='PINE A Y'  
STRATA(41)='PINE A I'  
STRATA(42)='PINE A M'  
STRATA(43)='SPBF A Y'  
STRATA(44)='SPBF A I'  
STRATA(45)='SPBF A M'  
STRATA(46)='SPBF A O'

C  
C  
C

ASSIGN SPECIES FOR OUTPUT

SPECIES(1)='BF'  
SPECIES(2)='SP'  
SPECIES(3)='SF'  
SPECIES(4)='IHW'  
SPECIES(5)='THW'  
SPECIES(6)='HWD'  
SPECIES(7)='OSW'  
SPECIES(8)='PI'  
SPECIES(9)='ALL'

C  
C

INITIALIZE VARIABLE

```

C
    OLDID=0
C
C    READ IN FOREST CLASSES FOR FDS PLOTS
C
    OPEN(5,FILE='CURVE.LIST',STATUS='OLD',ACTION='READ')
    DO 10 I=1,730
        READ(5,900) CURVE(I)
10    CONTINUE
        CLOSE(5)
C
C    READ IN TOTAL STAND MERCHANTABLE VOLUME FROM VOL1 FILE
C
    OPEN(5,FILE='VOL1.DAT',STATUS='OLD',ACTION='READ')
    DO 26 I=1,730
        READ(5,904) TMERCH
        VMERCH(I)=DBLE(TMERCH)
26    CONTINUE
        CLOSE(5)
C
C    OPEN FILES FOR READING AND WRITING
C
    OPEN(5,FILE='DBH.DAT',STATUS='OLD',ACTION='READ')
    OPEN(6,FILE='DBH.REP',STATUS='NEW',ACTION='WRITE')
C
C    READ IN PERCENT OF TOTAL STAND MERCHANTABLE VOLUME BY
C    2 cm. DIAMETER AND GRADE CLASS FOR CORRECT FDS PLOTS
C
11    CONTINUE
        READ(5,901,END=1000) SPEC, (VOL(I),I=1,46), LOCID
        IF(LOCID.GT.730)GOTO 1000
        IF(CURVE(LOCID).EQ.0)GOTO 11
        ICURVE=CURVE(LOCID)
        DO 12 I=1,9
            IF(SPEC.EQ.SPECIES(I))GOTO 13
12    CONTINUE
13    CONTINUE
        IROW=I
C
C    CALCULATE MERCHANTABLE VOLUME BY 2 cm. DIAMETER CLASS
C
    DO 27 I=1,46
        SPECV(I)=(DBLE(VOL(I))/100.)*VMERCH(LOCID)
27    CONTINUE
C
C    ACCUMULATE THE NUMBER OF PLOTS
C
    IF(LOCID.EQ.OLDID)GOTO 100
    PLOT(ICURVE,9)=PLOT(ICURVE,9)+1
    OLDID=LOCID
100    CONTINUE
        PLOT(ICURVE,IROW)=PLOT(ICURVE,IROW)+1

```

```

C
C   ACCUMULATE VOLUME BY DIAMETER GROUPINGS AND
C   ACCUMULATE DIAMETER BY VOLUME
C
DO 14 I=1,8
  K=((I+1)/2)*2
  CELL(ICURVE,IROW,1)=CELL(ICURVE,IROW,1)+SPECV(I)
  CELL(ICURVE,IROW,6)=CELL(ICURVE,IROW,6)+SPECV(I)
  FREQ(ICURVE,IROW)=FREQ(ICURVE,IROW)+(SPECV(I)*K)
14 CONTINUE
DO 15 I=9,14
  K=((I+1)/2)*2
  CELL(ICURVE,IROW,2)=CELL(ICURVE,IROW,2)+SPECV(I)
  CELL(ICURVE,IROW,6)=CELL(ICURVE,IROW,6)+SPECV(I)
  FREQ(ICURVE,IROW)=FREQ(ICURVE,IROW)+(SPECV(I)*K)
15 CONTINUE
DO 16 I=15,18
  K=((I+1)/2)*2
  CELL(ICURVE,IROW,3)=CELL(ICURVE,IROW,3)+SPECV(I)
  CELL(ICURVE,IROW,6)=CELL(ICURVE,IROW,6)+SPECV(I)
  FREQ(ICURVE,IROW)=FREQ(ICURVE,IROW)+(SPECV(I)*K)
16 CONTINUE
DO 17 I=19,24
  K=((I+1)/2)*2
  CELL(ICURVE,IROW,4)=CELL(ICURVE,IROW,4)+SPECV(I)
  CELL(ICURVE,IROW,6)=CELL(ICURVE,IROW,6)+SPECV(I)
  FREQ(ICURVE,IROW)=FREQ(ICURVE,IROW)+(SPECV(I)*K)
17 CONTINUE
DO 18 I=25,46
  K=((I+1)/2)*2
  CELL(ICURVE,IROW,5)=CELL(ICURVE,IROW,5)+SPECV(I)
  CELL(ICURVE,IROW,6)=CELL(ICURVE,IROW,6)+SPECV(I)
  FREQ(ICURVE,IROW)=FREQ(ICURVE,IROW)+(SPECV(I)*K)
18 CONTINUE
GOTO 11
C
C   CALCULATE VALUES FOR COMBINATIONS SF, HWD, ALL
C
1000 CONTINUE
DO 19 I=1,46
  DO 20 J=1,6
    CELL(I,3,J)=CELL(I,1,J)+CELL(I,2,J)
    CELL(I,6,J)=CELL(I,4,J)+CELL(I,5,J)
    CELL(I,9,J)=CELL(I,3,J)+CELL(I,6,J)+CELL(I,7,J)
    &   +CELL(I,8,J)
20 CONTINUE
    FREQ(I,3)=FREQ(I,1)+FREQ(I,2)
    FREQ(I,6)=FREQ(I,4)+FREQ(I,5)
    FREQ(I,9)=FREQ(I,3)+FREQ(I,6)+FREQ(I,7)+FREQ(I,8)
19 CONTINUE
C
C   CALCULATE AVERAGE VOLUMES AND

```

```

C     AVERAGE DIAMETER BY VOLUME
C
DO 21 I=1,46
  DO 22 J=1,9
    IF(CELL(I,J,6).EQ.0.0)GOTO 22
    DO 23 K=1,5
      OUT(I,J,K)=(CELL(I,J,K)*100)/CELL(I,J,6)
23    CONTINUE
      DBH(I,J)=FREQ(I,J)/CELL(I,J,6)
22    CONTINUE
21  CONTINUE
C
C     OUTPUT DATA
C
L=0
DO 24 I=1,46
  IF(L.EQ.0)WRITE(6,903)
  L=L+1
  DO 25 J=1,9
    WRITE(6,902)STRATA(I),SPECIES(J),(OUT(I,J,K),K=1,5)
&    ,DBH(I,J),PLOT(I,J)
25  CONTINUE
    IF(L.GT.6)L=0
    WRITE(6,'(A)')' '
24  CONTINUE
C
C     CLOSE FILES
C
CLOSE(5)
CLOSE(6)
C
C     FORMAT STATEMENTS
C
900  FORMAT(10X,I2)
901  FORMAT(A3,46I3,I5)
902  FORMAT(' ',2X,A8,4X,A3,5(2X,F5.0),2X,F5.1,2X,I3)
903  FORMAT('1',/,',',3X,'FOREST',19X,'DIAMETER GROUP'
& ,13X,'AVE',3X,'NO.',/,',',3X,'STRATA',5X,'SPE'
& ,3X,'2-8',3X,'10-14',2X,'16-18',2X,'20-24',3X
& ,',26-+',3X,'DBH',3X,'PLT',/,',',2X,'-----'
& ,4X,'---',6(2X,'-----'),2X,'----')
904  FORMAT(61X,I3)
C
C     END OF PROGRAMME
C
CALL EXIT
END

```

PROGRAMME TO CALCULATE STEM COUNT SUMMARY

```
C
C   PROGRAMME STEM.F77
C
C   WRITTEN BY: JOSEPH KAPRON
C               CENTRE FOR THE APPLICATION OF RESOURCES
C               INFORMATION SYSTEMS
C               LAKEHEAD UNIVERSITY, SCHOOL OF FORESTRY
C               SEPT. 1987
C
C   INTEGER CURVE(730),STEM(23)
C   INTEGER PLOT(46,9),OLDID
C   REAL*8 DBH(46,9),CELL(46,9,6),OUT(46,9,5),FREQ(46,9)
C   CHARACTER*8 STRATA(46)
C   CHARACTER*3 SPECIES(9),SPEC
C
C   INITIALIZE VARIABLES
C
C   DATA CURVE/730*0/,CELL/2484*0./,OUT/2070*0./
C   DATA PLOT/414*0/,FREQ/414*0./
C   DATA DBH/414*0.0/
C
C   ASSIGN FOREST UNITS FOR OUTPUT
C
C   STRATA(1)='BFSP L Y'
C   STRATA(2)='BFSP L I'
C   STRATA(3)='BFSP L M'
C   STRATA(4)='BFSP L O'
C   STRATA(5)='BFSP M Y'
C   STRATA(6)='BFSP M I'
C   STRATA(7)='BFSP M M'
C   STRATA(8)='BFSP H Y'
C   STRATA(9)='BFSP H Y'
C   STRATA(10)='BFSP H M'
C   STRATA(11)='SFWP A M'
C   STRATA(12)='SFIH A Y'
C   STRATA(13)='SFIH A I'
C   STRATA(14)='SFIH A M'
C   STRATA(15)='SFTH A Y'
C   STRATA(16)='SFTH A I'
C   STRATA(17)='SFTH A M'
C   STRATA(18)='SFTH A O'
C   STRATA(19)='IHSF A Y'
C   STRATA(20)='IHSF A I'
C   STRATA(21)='IHSF A M'
C   STRATA(22)='IHSF A O'
C   STRATA(23)='THSF A Y'
C   STRATA(24)='THSF A I'
C   STRATA(25)='THSF A M'
```

```

STRATA(26)='TOHW L Y'
STRATA(27)='TOHW L I'
STRATA(28)='TOHW L O'
STRATA(29)='TOHW H Y'
STRATA(30)='TOHW H I'
STRATA(31)='TOHW H M'
STRATA(32)='INHW A Y'
STRATA(33)='INHW A I'
STRATA(34)='INHW A M'
STRATA(35)='HWMX A Y'
STRATA(36)='HWMX A I'
STRATA(37)='HWMX A M'
STRATA(38)='OTSW A M'
STRATA(39)='OTSW A O'
STRATA(40)='PINE A Y'
STRATA(41)='PINE A I'
STRATA(42)='PINE A M'
STRATA(43)='SPBF A Y'
STRATA(44)='SPBF A I'
STRATA(45)='SPBF A M'
STRATA(46)='SPBF A O'

C
C   ASSIGN SPECIES FOR OUTPUT
C

SPECIES(1)='BF'
SPECIES(2)='SP'
SPECIES(3)='SF'
SPECIES(4)='IHW'
SPECIES(5)='THW'
SPECIES(6)='HWD'
SPECIES(7)='OSW'
SPECIES(8)='PI'
SPECIES(9)='ALL'

C
C   INITIALIZE VARIABLE
C

OLDID=0

C
C   READ IN FOREST CLASSES FOR FDS PLOTS
C

OPEN(5,FILE='CURVE.LIST',STATUS='OLD',ACTION='READ')
DO 10 I=1,730
  READ(5,900) CURVE(I)
10 CONTINUE
CLOSE(5)

C
C   OPEN FILES FOR READING AND WRITING
C

OPEN(5,FILE='STEM.DAT',STATUS='OLD',ACTION='READ')
OPEN(6,FILE='STEM.REP',STATUS='NEW',ACTION='WRITE')

C
C   READ IN NUMBER OF STEMS BY 2cm. DIAMETER CLASS FOR

```

```

C      CORRECT FDS PLOTS
C
11     CONTINUE
      READ(5,901,END=1000)SPEC,(STEM(I),I=1,23),LOCID
      IF(LOCID.GT.730)GOTO 1000
      IF(CURVE(LOCID).EQ.0)GOTO 11
      ICURVE=CURVE(LOCID)
      DO 12 I=1,9
        IF(SPEC.EQ.SPECIES(I))GOTO 13
12     CONTINUE
13     CONTINUE
      IROW=I
C
C      ACCUMULATE THE NUMBER OF PLOTS
C
      IF(LOCID.EQ.OLDID)GOTO 100
      PLOT(ICURVE,9)=PLOT(ICURVE,9)+1
      OLDID=LOCID
100    CONTINUE
      PLOT(ICURVE,IROW)=PLOT(ICURVE,IROW)+1
C
C      ACCUMULATE STEM COUNT BY DIAMETER GROUPINGS AND
C      ACCUMULATE DIAMETER BY STEM COUNT
C
      DO 14 I=1,8
        CELL(ICURVE,IROW,1)=CELL(ICURVE,IROW,1)+DBLE(STEM(I))
        CELL(ICURVE,IROW,6)=CELL(ICURVE,IROW,6)+DBLE(STEM(I))
        FREQ(ICURVE,IROW)=FREQ(ICURVE,IROW)+DBLE(STEM(I)*I*2)
14     CONTINUE
      DO 15 I=9,14
        CELL(ICURVE,IROW,2)=CELL(ICURVE,IROW,2)+DBLE(STEM(I))
        CELL(ICURVE,IROW,6)=CELL(ICURVE,IROW,6)+DBLE(STEM(I))
        FREQ(ICURVE,IROW)=FREQ(ICURVE,IROW)+DBLE(STEM(I)*I*2)
15     CONTINUE
      DO 16 I=15,18
        CELL(ICURVE,IROW,3)=CELL(ICURVE,IROW,3)+DBLE(STEM(I))
        CELL(ICURVE,IROW,6)=CELL(ICURVE,IROW,6)+DBLE(STEM(I))
        FREQ(ICURVE,IROW)=FREQ(ICURVE,IROW)+DBLE(STEM(I)*I*2)
16     CONTINUE
      DO 17 I=19,24
        CELL(ICURVE,IROW,4)=CELL(ICURVE,IROW,4)+DBLE(STEM(I))
        CELL(ICURVE,IROW,6)=CELL(ICURVE,IROW,6)+DBLE(STEM(I))
        FREQ(ICURVE,IROW)=FREQ(ICURVE,IROW)+DBLE(STEM(I)*I*2)
17     CONTINUE
      DO 18 I=25,46
        CELL(ICURVE,IROW,5)=CELL(ICURVE,IROW,5)+DBLE(STEM(I))
        CELL(ICURVE,IROW,6)=CELL(ICURVE,IROW,6)+DBLE(STEM(I))
        FREQ(ICURVE,IROW)=FREQ(ICURVE,IROW)+DBLE(STEM(I)*I*2)
18     CONTINUE
      GOTO 11
C
C      CALCULATE VALUES FOR COMBINATIONS SF, HWD, ALL

```



```

C
1000 CONTINUE
    DO 19 I=1,46
        DO 20 J=1,6
            CELL(I,3,J)=CELL(I,1,J)+CELL(I,2,J)
            CELL(I,6,J)=CELL(I,4,J)+CELL(I,5,J)
            CELL(I,9,J)=CELL(I,3,J)+CELL(I,6,J)+CELL(I,7,J)
            &      +CELL(I,8,J)
        20 CONTINUE
            FREQ(I,3)=FREQ(I,1)+FREQ(I,2)
            FREQ(I,6)=FREQ(I,4)+FREQ(I,5)
            FREQ(I,9)=FREQ(I,3)+FREQ(I,6)+FREQ(I,7)+FREQ(I,8)
    19 CONTINUE
C
C   CALCULATE AVERAGE STEM COUNTS AND
C   AVERAGE DIAMETER BY STEM COUNT
C
    DO 21 I=1,46
        DO 22 J=1,9
            IF(CELL(I,J,6).EQ.0.0)GOTO 22
            DO 23 K=1,5
                OUT(I,J,K)=(CELL(I,J,K)*100)/CELL(I,J,6)
            23 CONTINUE
                DBH(I,J)=FREQ(I,J)/CELL(I,J,6)
        22 CONTINUE
    21 CONTINUE
C
C   OUTPUT DATA
C
    L=0
    DO 24 I=1,46
        IF(L.EQ.0)WRITE(6,903)
        L=L+1
        DO 25 J=1,9
            WRITE(6,902)STRATA(I),SPECIES(J),(OUT(I,J,K),K=1,5)
            &      ,DBH(I,J),PLOT(I,J)
        25 CONTINUE
            IF(L.GT.6)L=0
            WRITE(6,'(A)')' '
    24 CONTINUE
C
C   CLOSE FILES
C
    CLOSE(5)
    CLOSE(6)
C
C   FORMAT STATEMENTS
C
900 FORMAT(10X,I2)
901 FORMAT(A3,24I5)
902 FORMAT(' ',2X,A8,4X,A3,5(2X,F5.0),2X,F5.1,2X,I3)
903 FORMAT('1',/,',',',',3X,'FOREST',19X,'DIAMETER GROUP'

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```
&,13X,'AVE',3X,'NO.',/,/,',3X,'STRATA',5X,'SPE'  
&,3X,'2-8',3X,'10-14',2X,'16-18',2X,'20-24',3X  
&,'26-+',3X,'DBH',3X,'PLT',/,/,',2X,'-----'  
&,4X,'----',6(2X,'-----'),2X,'----')
```

C  
C  
C

END OF PROGRAMME

CALL EXIT  
END

EXAMPLE OF OUTPUT FROM VOL.F77

FOREST			DIAMETER GROUP					AVE	NO.
<u>STRATA</u>	<u>SPE</u>	<u>2-8</u>	<u>10-14</u>	<u>16-18</u>	<u>20-24</u>	<u>26-+</u>	<u>DBH</u>	<u>PLT</u>	
BFSP	L Y	BF	0.	34.	31.	29.	6.	17.2	6
BFSP	L Y	SP	0.	26.	18.	38.	17.	21.2	6
BFSP	L Y	SF	0.	32.	28.	31.	8.	18.0	0
BFSP	L Y	IHW	0.	48.	24.	5.	23.	16.5	6
BFSP	L Y	THW	0.	0.	0.	20.	80.	30.5	2
BFSP	L Y	HWD	0.	38.	19.	8.	34.	19.4	0
BFSP	L Y	OSW	0.	0.	0.	13.	87.	36.8	3
BFSP	L Y	PI	0.	0.	0.	0.	100.	46.0	1
BFSP	L Y	ALL	0.	27.	23.	26.	23.	21.4	6
BFSP	L I	BF	0.	37.	29.	25.	9.	17.4	16
BFSP	L I	SP	0.	20.	16.	37.	27.	21.8	1
BFSP	L I	SF	0.	32.	25.	29.	14.	18.8	0
BFSP	L I	IHW	0.	36.	13.	19.	32.	22.7	15
BFSP	L I	THW	0.	20.	15.	26.	39.	23.8	11
BFSP	L I	HWD	0.	29.	14.	22.	35.	23.2	0
BFSP	L I	OSW	0.	0.	6.	23.	72.	30.5	6
BFSP	L I	PI	0.	0.	0.	1.	99.	43.7	6
BFSP	L I	ALL	0.	27.	20.	24.	29.	22.7	16

EXAMPLE OF OUTPUT FROM STEM.F77

FOREST			DIAMETER GROUP					AVE	NO.
<u>STRATA</u>	<u>SPE</u>	<u>2-8</u>	<u>10-14</u>	<u>16-18</u>	<u>20-24</u>	<u>26-+</u>	<u>DBH</u>	<u>PLT</u>	
BFSP	L Y	BF	57.	28.	10.	5.	0.	9.4	6
BFSP	L Y	SP	68.	23.	4.	4.	0.	8.5	6
BFSP	L Y	SF	60.	27.	8.	5.	0.	9.2	0
BFSP	L Y	IHW	88.	9.	2.	0.	0.	4.5	6
BFSP	L Y	THW	0.	0.	0.	44.	56.	27.9	2
BFSP	L Y	HWD	88.	9.	2.	0.	1.	4.6	0
BFSP	L Y	OSW	0.	0.	0.	33.	67.	31.2	3
BFSP	L Y	PI	0.	0.	0.	0.	100.	46.0	1
BFSP	L Y	ALL	67.	22.	6.	4.	1.	8.1	6
BFSP	L I	BF	71.	20.	5.	3.	0.	7.1	16
BFSP	L I	SP	56.	26.	7.	8.	3.	9.8	1
BFSP	L I	SF	69.	21.	6.	3.	1.	7.5	0
BFSP	L I	IHW	79.	16.	3.	1.	1.	5.9	15
BFSP	L I	THW	71.	18.	4.	4.	2.	8.1	11
BFSP	L I	HWD	77.	17.	3.	2.	1.	6.5	0
BFSP	L I	OSW	0.	0.	13.	30.	57.	27.4	6
BFSP	L I	PI	0.	0.	0.	5.	95.	41.6	6
BFSP	L I	ALL	70.	20.	5.	3.	1.	7.4	16