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Even-aged Boreal Forest Management Planning Models: Applications

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EVEN-AGED BOREAL FOREST MANAGEMENT PLANNING MODELS:

APPLICATIONS

by

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ABSTRACT

A comparative analysis of current even-aged boreal forest planning models is made to assess the relative strengths and weaknesses of the models given a specified set of forest management planning objectives common to the boreal forest. The models tested included: FORMAN (version 2.3), GLFC-FORMAN, NORMAN, CROPLAN (FORMANCP), FORMAN + 1, HSG and SFMM (Strategic Forest Management Model). The evaluation also incorporates the use of ancillary data generators: PCNFCS and Forestry Canada's data generator for FORMAN + 1.

With practical demonstrations of capability and applicability, new users will find this study to be helpful in providing them with the information required to select the most appropriate model to simulate the task at hand.

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DISCLAIMER

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INTRODUCTION

TABLE 1 AN HISTORICAL OVERVIEW OF THE MODELS INCLUDED IN THIS STUDY

1987 FORMAN 2.1	Volume based simulation model with intensive and extensive silvicultural options.
1988 MADCALC	Area based simulation model, easier to use than predecessors - WOSFOP AND OWOSFOP.
1989 GLFC FORMAN	A user friendly FORMAN 2.1, for use on main frame computers.
1989 NORMAN	An improved FORMAN 2.3 - Allows for intensive, basic and extensive silvicultural options. Improved output reports.
1991 CROPLAN	Based on FORMAN 2.1 - Provides assistance in preparing input files and has some economic analysis capabilities.
1991 FORMAN+1	Additional flexibility with silvicultural treatment options, improved species reporting and allows for succession of older stands.
1994 HSG	Provides a stand level approach to modelling which allows results to be spatially displayed, improved options for succession of older stands and improved query and graphing capabilities.
1994 PCNFCS	Aggregates stand information and prepares input files for the FORMAN type models. Provides numerous helpful reports and can be used as a volume generator.
1995 SFMM	An optimization model that allows greater flexibility in defining and regulating forest management activities. Improved graphing and reporting options.
1994-95 GLFC-FRONT END LOADER FOR FORMAN+1	Aggregates stand information to ease the preparation of present yield curves for input into FORMAN+1.

1.3 SCENARIOS TO BE MODELLED

The design of the case studies took into account the results of the scoping exercise and the input received from the staff at Avenor. The following is an overview of the goals of each of the three case studies.

Case Study #1

Models are used to simulate a variety of management decisions. Results from these simulations are then used by the resource manager to select the most appropriate actions required to best meet the management objectives desired. A common decision required of the resource manager is the setting of the long term even-flow sustainable harvest level.

The goal in Case Study #1, is to compare the output from each of the six models, using the same inputs, to determine the long term even-flow sustainable harvest level. Runs were

1.0 INTRODUCTION

The objective of this study was to undertake a comparative analysis of current even-aged boreal forest planning models. The intent was to assess the relative strengths and weaknesses of the models given a specified set of forest management planning objectives common to the boreal forest.

Potential users of these products face a bewildering range of choices, i.e. what products will best serve a particular need or set of needs? To the uninitiated, each product holds great promise in terms of providing useful insights into difficult and sometimes vexing forest management problems and issues but, in terms of usability, these expectations are often diminished by a lack of data (to run the models), in applicability (to a specific problems or issues) and a lack of product documentation. With practical demonstrations of capability and applicability, new users will find this study to be helpful in providing them with the information required to select the most appropriate model to simulate the task at hand.

The models to be tested include: FORMAN (version 2.3), GLFC-FORMAN, NORMAN, CROPLAN (FORMANCP), FORMAN+1, HSG and SFMM (Strategic Forest Management Model). The evaluation also incorporates the use of ancillary data generators: PCNFCS and Forestry Canada's data generator for FORMAN+1.

1.1 BACKGROUND

To determine the current use of even-aged forestry planning models in Ontario, and to assist in the identification of the scenarios required to test the models, a questionnaire was distributed to resource managers working in a variety of positions with the Ontario Ministry of Natural Resources and the Forest Industry. The questionnaire was sent out in January of 1994 and responses were received from 14 of the 18 individuals. In addition to the questionnaire, interviews were held with 5 of the individuals, to gain further detail and insights. While the number of questionnaires distributed may seem low, only a few individuals use planning models on a regular basis in Ontario. A summation of the responses to the questions can be found in Appendix 1.

Also found in Appendix 1, for each of the models and data generators being tested is: a brief history of their development, a summary of their system application support/documentation available, and tables outlining their input requirements and the outputs generated.

1.2 CASE STUDY AREA

For this study, one of the forests being managed by Avenor Inc. (formerly Canadian Pacific Forest Products Ltd.) was used as the case study area. The case study area is located northwest of Thunder Bay, Ontario, and harvesting and silvicultural operations on it, date back to the early 1940's.

Due to its close proximity to the mill, Avenor wishes to maximize the sustainable harvest level from the forest, especially in spruce, which is a basic requirement for their newsprint mill. The area was selected because many of the situations common to the Boreal Forest occur on this forest. In-kind help from Avenor staff provided additional support to this project and offered practical and realistic planning scenarios.

4) To prepare the database for modelling several other steps were taken:

a) stands with less than 1 hectare in area were dropped from the inventory database,

b) modelling was not required for several working groups (i.e. red pine, white pine, cedar, other conifer, ash, and other hardwood). These stands were also removed from the inventory database, and

c) barren and scattered stands were changed to productive forest land, and assigned a stand description based on historical survey work for the 19 year old inventory. This step dramatically reduced the number of yield curves required by the models.

1.5 SET UP USING PCNFCS

PCNFCS was used to create the land base files and the volume and cost curves to be used by FORMAN 2.1, FORMAN CP, NORMAN and SFMM models. The conversion program in FORMAN+1 was used to convert the FORMAN 2.1 files for use with FORMAN+1. This conversion works well and because the basic, intensive and extensive curves are included by PCNFCS in the FORMAN 2.1 files, this information is also incorporated in the FORMAN+1 file conversion.

The edited land base was sorted using the FORMAN Management Unit (FMU[1]) option provided by PCNFCS. This option allowed for the separation of spruce upland and lowland stands, which requires a breakdown by species composition as well as by site class and working group. Also a conifer mixed wood FMU was developed so that a more intensive silvicultural strategy could be applied to these areas. Please refer to Table 2.

The primary species curve information used by AVENOR, was entered into PCNFCS. This yield information is primarily based on the Normal Yield Tables for Ontario (Plonski W.L. revised Jan. 1991) with minor adjustments made for local conditions. Due to the fact that the models require yield curve information up to 200 years of age, the curves were extended in a bell shape to 200 years. As some models do not allow for the conversion of older stands to different working groups no attempt was made to do so at this early stage of the comparisons. Site class cross reference information, and product percent information, provided by AVENOR was also entered into PCNFCS.

The stand information was then aggregated. The user should be aware that PCNFCS develops a curve for each age class specified in the aggregation. To reduce the number of curves developed, a 20 year age class aggregation was used for this scenario. For example, with ten FMU's, if a five year age class aggregation criteria was used, the program would develop 240 additional curves (24 additional age classes X 10 FMU's).

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[1]FMU is usually an abbreviation used in Ontario to denote "Forest Management Unit", because PCNFCS uses the abbreviation "FMU" in its output reports and to be consistent throughout this report, the reader should be aware that this abbreviation signifies Forman Management Units.

made to examine how each of the models perform using the different harvest rules. Addition runs were made to determine the effects of altering the curve Y factors for the FORMAN based models.

Case Study #2

Many resource managers rely on historical depletion data to determine what percentage of the land base is lost to: reserves, fires, insect and disease attack etc. This depletion information is then used in modelling, to project future losses.

The goal in Case Study#2, is to compare the assumptions commonly used in determining the area lost to riparian reserves versus actual loss and to determine the impacts of these assumptions on the long term sustainable conifer harvest level.

Case Study #3

Case Study #3 examines some of the options in evaluating timber supply and costs. This case study is broken down into several sections. The first section examines how the allowable harvest level for an individual species such as spruce can be determined, while maintaining the overall objective of maximizing the even flow sustainable conifer harvest level. Section two briefly examines one way of incorporating spatial considerations such as haul costs. Section three, examines the impacts of natural succession (as opposed to post renewal succession) on the allowable harvest level and the final section looks at the impacts of the different silvicultural investments on harvest levels.

1.4 LAND BASE INFORMATION PREPARATION

In preparation for modelling the following steps were taken to prepare the land base information:

1) Records for the areas that had been declared free to grow (FTG) were appended to the original FRI stand inventory file.

2) A Geographic Information System (GIS), was used to determine stand areas and to determine the area of cutover that had not been declared free to grow. It should be noted, that stand areas generated by the GIS, were generally slightly smaller in size than those initially estimated in the original FRI stand descriptions. It is not known if this reduction in area is typical of all FRI inventories or not, it depends on the method and accuracy used to determine original FRI areas.

   The stand description information, from the FRI database, was joined to the GIS area database, (using the map sheet and stand number to join the two tables). This database work was done using the software FOXPRO version 2.5.

3) The cutover area, that had not been declared free-to-grow (approximately 80,000 ha), was divided into four-five year age classes and given a species composition based historical silvicultural treatments. Historical free to grow and 5th year survey results, support this treatment of the cutover information as being valid.

The present volume, future volume and cost curves were then developed by PCNFCS based on the aggregated stand information and the silvicultural card information. PCNFCS allows for easy editing of all the parameters for the aggregated stands.

Sample PCNFCS input files, silvicultural cards and the resulting curve and stand aggregation information, can be found in Appendix 2.

1.6 Comments

Some resource managers may wish to edit the "stocking percent" developed in the aggregation stage of PCNFCS. Many of the younger age classes usually have very low stocking, if these are left unedited, then these stocking levels remain low as they are aged by the model (even though in reality, these younger stands will tend to fill in and their stocking levels will increase). It is probably not necessary in the older stands to reduce the aggregated stocking levels, as this is normally accounted for in the pure species yield curves.

In retrospect, some editing of the species composition, for the older jack pine stands should have been made. The sharp decline in volume for jack pine shown in the pure species curves was mitigated, due to the high jack pine species composition in the older inventory. This is one example of how older inventories projected into the future (20 years in this case) can be misleading.

Generally, it is advisable to have an up-to-date inventory before aggregating the stand information and modelling. Editing of the inventory at an early stage, while time consuming, provides more control to the user and can reduce the difficulties in trying to determine what the model(s) are doing. The old saying "garbage in, garbage out" holds true.

Operability limits are often confused with rotation ages. Operability limits are used by volume based models to assign the minimum volume required for the model to consider the area for harvest. It was felt by Avenor's field staff that the minimum conifer volume required before an area was considered operable was 30 m^3/ha. The ages used in FORMAN+1, HSG and SFMM, are not rotation ages, they are the age at which the minimum operable volumes are met. This was done to make a fair a comparison between the models. Please refer to Table 3 for a list of the operability levels and ages used by the various models.

TABLE 2 FORMAN MANAGEMENT UNIT (FMU) CRITERIA

FMU #1	BWALL	-working group white birch (all site classes)
FMU #2	POX1	-working groups poplar and balsam poplar (site class X or 1)
FMU #3	PO23	-working groups poplar and balsam poplar (site class 2 or 3)
FMU #4	PJX1	-working group jack pine (site class X and 1)
FMU #5	PJ23	-working group jack pine (site class 2 and 3)
FMU #6	BFX1	-working group balsam fir (site class X and 1)
FMU #7	BF23	-working group balsam fir (site class 2 and 3)
FMU #8	SPLOW	-lowland spruce -working groups black spruce or spruce -species composition for black spruce + cedar + larch = 100%
FMU #9	SPUP	-upland spruce (site class 1 or 2 or 3) -working groups black spruce, white spruce or spruce
FMU #10	MIXED	-conifer mixedwood stands (site class 1 or 2 or 3) -working groups black and white spruce,,balsam, and jack pine -species composition for poplar + balsam poplar + white birch + other hardwoods > =40%

Notes: -It was necessary to apply FMU #9 to the inventory before applying FMU #8. This allowed the selection of all lowland spruce from the upland spruce.
-FOXPRO was found to be useful in reviewing STANF files to check that the FMU's applied by PCNFCS were in fact, what was desired. *Caution-do not review the STANF file directly from FOXPRO because the index file required by PCNFCS will be altered by FOXPRO and lead to errors by PCNFCS when the criteria is aggregated.

The silvicultural card[2] information required for each FMU was then entered. It should be noted that the silvicultural cards requires the user to enter the PCNFCS working group naming convention when filling in future stand species compositions, i.e. the STANF file uses B and L for balsam fir and larch, the silvicultural cards require BF and OC (other conifer).

[2]Silvicultural Card -PCNFCS has an input form called a "silvicultural card". The card is used to enter specific information for each Forman Management Unit. For example, future species compositions by silvicultural intensity.

Comments on Table 3

PCNFCS generates a curve for each age class for each FMU. These curves are based on the average stocking and species composition of the stands. The operability limits generated by PCNFCS are the volumes/ha for the rotation ages specified in the silvicultural cards. For example, for the BIRCH_ALL FMU in the 1-20 age class the primary volume at age 65 (the first operable limit) is 1 m^3/ha, and the primary volume at age 101 (the second operable limit) is also 1 m^3/ha. If we look at the SP_LOW FMU for the 161-180 age class, the primary volume at age 100 is 68 m^3/ha and at age 140 the primary volume is 99 m^3/h.

By specifying a minimum of 30 m^3/ha for the minimum primary volume (shown in the PCNFCS EDITED OPERABILITY LIMITS column) it can be seen that for the BIRCH_ALL FMU, that the areas in age classes 1-40 and 121-160 never reach the minimum volume required. The areas associated with these age class will never be considered for harvest by the FORMAN based models. For the 41-60 age class, in the BIRCH_ALL FMU, the minimum volume of 30 m^3/ha is not reached until age 120 and falls below 30 m^3/ha at age 180. These ages were used in the FORMAN+1 modelling. MADCALC and SFMM models operate on the basis of the average volume per hectare in all age classes, and so the operable ages were set from 110 to 180 years. This gives the MADCALC and SFMM models a slight advantage over the FORMAN based models. While we are only dealing with differences in very low volumes per hectare for primary conifer volumes, the differences are more dramatic when we examined the secondary hardwood volumes harvested by SFMM and MADCALC.

Another important point to remember concerning operability limits, is the fact that with the FORMAN based models, the second operability level must be equal to or lower than the first operability limit, for the models to work correctly. For example if we look at SP_LOW in the 1-20 age class, PCNFCS generated the first operability level at 57 (the volume/ha at age 100) and the second operability limit at 83 (which is the volume/ha at age 140). As 83 is higher than the first operability level of 57, the second operability level was edited to 57 m3/ha. This raised the operable age from 140 to 200 years of age.

The cutover was also given one species composition to allow for the information to be shown spatially in the HSG results. A more appropriate way to handle the cutover would have been to separate the area into: 40% spruce, 30% poplar, 20% jack pine and 10% birch. To do this one would have to re-assign a species composition to all of the cutovers as HSG requires current spatial information in order to review the results of the modelling in map form. Unfortunately many resource managers do not usually have access to this information.

TABLE 3 OPERABILITY LEVELS AND AGES USED IN CASE STUDIES 1 AND 2 (selected examples)

CURVE NO.	FMU Age class	Desired Rotation Ages	PCNFCS Generated Operability Limits (M^3/HA)	PCNFCS Edited Operability Limits (M^3/HA)	Resulting Operable Ages (Years)	Ages used in MADCALC & SFMM (Years)
	MU #1 BIRCH_ALL					
1	1-20	66-101	1-1	30-30	NA	110-180
2	21-40		0-14	30-30	NA	110-180
3	41-60		3-23	30-30	120-180	110-180
4	61-80		7-27	30-30	110-180	110-180
5	81-100		2-19	30-30	150-160	110-180
6	101-120		1-18	30-30	140-160	110-180
7	121-140		0-14	30-30	NA	110-180
8	141-160		4-16	30-30	NA	110-180
	MU #4 PJ_X1					
27	1-20	70-120	117-109	117-109	70-140	70-150
28	21-40		127-126	127-126	70-120	70-150
29	41-60		125-139	125-125	70-120	70-150
30	61-80		180-181	180-180	70-140	70-150
31	81-100		183-176	183-176	70-130	70-150
32	101-120		154-152	154-152	70-120	70-150
33	121-140		128-127	128-128	70-120	70-150
34	141-160		92-105	92-92	70-150	70-150
	MU #8 SP_LOW					
59	1-20	100-140	57-83	57-57	100-200	100-200
60	21-40		67-97	67-67	100-200	100-200
61	41-60		80-116	80-80	100-200	100-200
62	61-80		114-165	114-114	100-200	100-200
63	81-100		99-143	99-99	100-200	100-200
64	101-120		99-144	99-99	100-200	100-200
65	121-140		98-143	98-98	100-200	100-200
66	141-160		40-75	43-43	100-200	100-200
67	161-180		68-99	68-68	100-200	100-200

CASE STUDY #1

TABLE 4 CASE STUDY #1 COMPARISON OF HARVEST RULES BETWEEN THE MODELS

Annual harvest volumes in NM³/YR, Unlimited Silvicultural funding in the form of planting or seeding

Model	Oldest First	Minimize Primary Volume Loss*	Maximize Primary Volume Harvested*	Minimize Secondary Volume Harvested*	Maximize Secondary Volume Harvested*	Maximize Sawlog Volume Harvested**	Minimize Silvicultural Costs***
FORMAN 2.3		610,000 (160,800)	555,000	490,000 (148,000)	535,000 (151,000)	515,000 (68,000)	585,000 ($3.8)
GLFC-FORMAN		610,000 (159,600)	555,000	490,000 (148,000)	535,000 (151,000)	510,000 (68,000)	585,000 ($3.8)
NORMAN		610,000 (160,700)	555,000	490,000 (148,000)	535,000 (151,000)	515,000 (68,000)	585,000 ($3.8)
CROPLAN		625,000 (167,000)	580,000	465,000 (130,000)	590,000 (206,000)	570,000 (74,000)	595,000 ($3.9)
FORMAN + 1		640,000 (181,800)	585,000	515,000 (168,000)	600,000 (172,000)	560,000 (69,000)	595,000 ($4.2)
HSG	635,000	660,000	620,000				
SFMM -20 yr. age classes			586,000 (237,000)		577,000 (257,000)	582,000 (77,000)	573,000 ($0.0)
SFMM -10 yr. age classes			665,000 (275,000)		614,000 (329,000)	650,000 (95,000)	620,000 ($0.005)
MADCALC	629,000****						

* Average secondary volumes harvested over the 100 year planning horizon, shown in brackets.
** Average total product (sawlogs) volumes harvested over the 100 year planning horizon, shown in brackets.
*** Average annual silvicultural cost in millions of dollars.
**** Average harvest level over the 140 year planning horizon.

2.0 CASE STUDY #1

As mentioned previously, the goal in Case Study #1, is to compare the output from each of the seven models, using the same inputs, to determine the long term even-flow sustainable harvest level. Although MADCALC was not officially part of this investigation, the model was run and results were compared to the volume based models.

The input files generated by PCNFCS were then entered into the FORMAN based models. For MADCALC and SFMM, the average yield curve and area information from PCNFCS was used. The edited inventory file was used as the basis for the HSG model runs.

The harvest rules for each model were then tested. The results can be found in Table 4. Graphs were prepared to examine how the various models grew, harvested and regenerated the forests. Where required, additional runs were done to further investigate how the models operated.

2.1.0 OBSERVATIONS ON THE HARVEST RULE- MINIMIZE PRIMARY VOLUME LOSS

The harvest rule "minimize primary volume loss", provided the highest sustainable harvest level for all the models except SFMM. SFMM does not incorporate this rule, so it could not be tested. Using this rule, the models direct the harvest by using the steepest negative slope on the curves.

Originally it was expected that when using the same landbase and curve information, the results from each of the models would be identical or very close. This however was not the case. While the results between the original FORMAN model and it's derivatives NORMAN/GLFC-FORMAN were identical, there were substantial differences with CROPLAN, FORMAN+1 and HSG.

To isolate and determine the cause for these differences, additional runs were conducted and analysed . NORMAN was used in the comparisons because of its better "short reports" . FORMAN 2.1 and GLFC FORMAN were assumed to be identical to NORMAN because each of the three models gave identical results[3].

2.1.1 NORMAN vs CROPLAN

The additional volume available from CROPLAN when compared to NORMAN using the minimize primary volume loss, was suspected to be the result of CROPLAN only using 10 age classes for its curves. The other FORMAN based models, use 20 age classes in their future and present curves. With fewer age classes, the thought was that CROPLAN might be calculating slope differently particularly, when the peak of the curve is at one of the age classes not on the CROPLAN curves. To verify this, a number or runs were conducted and graphs were prepared as a visual aid.

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[3]GLFC- FORMAN was not updated when a programming change for harvest Rule 5 was made to FORMAN 2.1

2.1.2 NORMAN vs FORMAN+1

It was suspected that the additional harvest available from FORMAN+1 over NORMAN was due to the fact that FORMAN+1 has a set of "silvicultural rules", which must be used in order for the model to work. For the FORMAN+1 runs, Silvicultural Rule 1, (which minimizes the return to operability) was used. Similar to the investigation made into the differences between CROPLAN and NORMAN, graphs were prepared to compare NORMAN and FORMAN+1.

While not provided, graphs showed that at a sustainable harvest of 510,000 m3/ year with no silviculture, NORMAN and FORMAN+1 are almost identical in terms of available growing stock and in the species the models harvested. When unlimited silvicultural funding is applied, and the sustainable harvest level is increased to NORMAN's maximum, of 610,000 m^3/ yr, the growing stock available for harvest in FORMAN+1 increases over the amount of growing stock available for NORMAN. Please refer to Figure 3L in Appendix 3.

Figure 3M in Appendix 3, shows where and when the two models are harvesting. At the 610,000 nm^3 harvest level with unlimited silvicultural funding, the major difference in the species harvested between the two models was that FORMAN+1 cut over two million more cubic metres of jack pine, where NORMAN cut more upland spruce and mixedwood. Thus the increase in the long term sustainable wood supply from FORMAN+1, results from the differences in how each model applied silvicultural Rule 1 (which favours harvesting and regenerating areas that quickly return to an operable age i.e. jack pine).

2.1.3 HSG

The volume harvested by HSG is directly related to the volumes in the individual stands selected by the model. It was found that the outputs from HSG do not allow for a comparison based on the FMU's used for the other models, so a comparison to harvests by the other models is limited.

As the model can select any stand from the entire forest, it is not surprising that the results from HSG were higher than the FORMAN based models. However, the sustainable harvest level of 660,000 nm3/yr is only 3% higher than FORMAN+1, so the results were taken at face value. Users should realize that only stands they wish to consider for harvest should be loaded into the inventory file (i.e. parks, patent lands, protection forest etc. should first be removed from the inventory).

Difficulties encountered using ARC/INFO to rasterise the test forest, also meant that the results from HSG could not be mapped. However, looking at the treatment schedule file revealed that the HSG selected stands to harvest, throughout the forest. While spatially related, HSG cannot be directed spatially to where it harvests.

At the suggestion of the author, Dr. J. Williams, an attempt was made to run the same curves and landbase with 20 age classes on the FORMAN-CP part of CROPLAN. However, the program would not accept 20 age classes. Also an attempt was made to run NORMAN with only ten age classes. The program ran, but the highest sustainable conifer harvest that could be achieved with unlimited silviculture was 470,000 m3/yr, not even close to the 625,000 m3/yr determined by CROPLAN.

Further runs were attempted to isolate the reason(s) for the difference. Figure 3A in Appendix 3, shows how both NORMAN and CROPLAN, grow the forest with **no harvesting**. While both models start and end at the same point, there are slight differences between the models for primary volumes during the 35 to 60 year period. Figure 3B in Appendix 3, shows the level of mortality that occurs in the forest with **no harvesting**. The results are similar to Figure 3A, in that both the NORMAN and CROPLAN models start and end at the same points, but during years 20 to 30 and again at years 65 to 85, slight differences occur.

Initially it was considered unlikely that small differences in how the forest is grown by the two models could account for such a large difference in the long term sustainable harvest level. Further runs were undertaken to see how the models would behave with no silviculture funding. This was necessary to eliminate factors associated with how the two models handle silvicultural options and associated future curves.

With **no silviculture**, the maximum sustainable harvest level using NORMAN (minimize primary volume loss) was 510,000 m3/yr. For an even comparison CROPLAN was also run at the same harvest level. Figure 3C in Appendix 3, shows where each of the two models are harvesting with no silviculture (natural regeneration only). From this, it is suggested that major differences occur **when** the models are cutting the different FMU's, rather than how much the models are cutting from each of the different FMU's. These differences are more noticeable in Figures 3D through to 3F, in Appendix 3. Figure 3G in Appendix 3, also compares the growing stock available for the two models. The higher growing stock available in NORMAN, during the majority of the 100 year period was confusing. With more growing stock available for harvest, one would think that NORMAN would have a higher sustainable harvest level.

Further runs were tried, using **unlimited silvicultural** funding at NORMAN's maximum harvest level of 610,000 m3/yr. Figure 3F in Appendix 3, shows that the situation that resulted in Figure 3G, has reversed. Now CROPLAN has a higher level of available growing stock than NORMAN. Graphs of when and where each of the models were harvesting are shown in Figures 3H though 3K in Appendix 3. The primary differences between where the models were cutting, occurred in the final 25 years of the run. CROPLAN choose to cut more in the PJX1 FMU, whereas NORMAN concentrated on cutting in the SPUP FMU. Overall, CROPLAN harvested more jack pine than NORMAN and since jack pine grows faster and returns to operability sooner, there was more growing stock available to harvest by CROPLAN.

For the previously mentioned graphs, it has been shown that small differences in the yield curves, (which were the result from differences in the number of age classes in the curve) can cause small changes in the way the forest is grown by the models. These differences resulted in the models cutting in different FMU's at different times. Later in this report, when silvicultural costs are examined, the magnitude of these differences will be more apparent. **(This exercise also pointed out that not only are the shape and size of a given curve important, but how that curve relates to other curves from different forest units is also very important.)**

Figure 3O, compares the growing stock available with no harvest, for NORMAN, CROPLAN and SFMM. While each model starts at the same point, differences quickly appear. A dip in the curves for NORMAN and CROPLAN, is due to mortality and area growing past the 200 year limit. SFMM retains area and volume in the oldest age class and does not report mortality. With no succession, the growing stock reported by SFMM can be misleading.

Figure 3P, shows where the model SFMM is harvesting when using ten and twenty year age classes. Given differences in growing stock available, the model selected different FMU's to harvest. For the run with ten year age classes, the model harvested more in the PJ_23 FMU and at much higher levels in the BF_X1 FMU. For the run with 20 year age classes, the model cut more in the SP_LOW FMU. Similar to the experience with FORMAN+1, as jack pine and balsam return to operability sooner, the model also has more available volume to harvest from these two FMU's during the 80-100 time period. In fact, the run with the ten year age classes, harvested 81,000 nm3 more PJ_23 and 72,000 nm3 more BF_X1 annually, during the final 20 years of the run.

As expected from an optimization model, SFMM calculated the highest overall annual harvest level of all the models at 665,000 m^3/yr, when using ten year age classes. This calculated volume, is very similar to HSG and FORMAN+1. The larger differences between SFMM and NORMAN, is in part due to the conifer volume in some of the hardwood stands that NORMAN does not consider because these stands never reach the minimum operability volume required.

2.3 OBSERVATIONS ON THE HARVEST RULE- MINIMIZE SECONDARY VOLUME HARVESTED

This harvest rule produced the greatest reduction in the primary volume harvest level when compared to results from the "minimize primary volume lost", run. A significant volume of conifer is found in the CON_MIXED FMU, and when the amount of poplar is minimized, the models try and avoid this FMU. FORMAN 2.3, GLFC-FORMAN, NORMAN, and FORMAN+1 showed a 20% reduction in the conifer harvest level and reduced the secondary volume (poplar in this case) by 10%. CROPLAN showed a 25% reduction in the conifer harvest level but managed to reduce the volume of harvested poplar by 23%. The difference between CROPLAN and the other FORMAN models stems from the difference in the number of age classes for the input curves. HSG and SFMM do not have this harvest rule, so a comparison could not be made.

2.4 OBSERVATIONS ON THE HARVEST RULE- MAXIMIZE SECONDARY VOLUME HARVESTED

The results from using this rule were unexpected. FORMAN 2.3, GLFC-FORMAN, NORMAN and FORMAN+1 all showed not only a reduction in the confer harvest level, but also a reduction in the secondary volume harvested. All of these models actually cut more poplar when trying to minimize primary volume lost. CROPLAN showed a 6% drop in the primary harvest level and a 23% increase in the harvest level for poplar (which is more or less the expected results). HSG does no have this harvest rule and could not be tested.

2.2.0 OBSERVATIONS ON THE HARVEST RULE- MAXIMIZE PRIMARY VOLUME HARVESTED

The harvest rule "maximize primary volume harvested", is different from the rule minimize primary volume lost, in that it directs the models to harvest at the peak of the curves when the maximum conifer volume is available.

The FORMAN based models all showed a similar response, in that the sustainable harvest level dropped an average of 10% from the volume calculated using the minimize primary volume lost rule. HSG showed a drop of 15%, which is the same ballpark but because the model is selecting unique stands, it can not be said that this would be a typical response of the model when using this rule.

2.2.1 SFMM

For SFMM, two sets of runs were made for each of the harvest rules. The first set of runs were made using, twenty year age classes and ten time periods. The second set of runs used ten year age classes and twenty time periods. This was done based on the difficulties encountered previously with the use of the CROPLAN model, which also uses twenty year age classes and was later confirmed by others using SFMM, as giving more accurate results. Although SFMM is usually run over a 160 year planning horizon at this stage of the comparison, only a 100 year planning horizon was used so an even comparison to FORMAN+1 could be made.

The results from SFMM shown in Table 3, are in fact the average volumes harvested over the 100 year period. A difference of ten percent was allowed in the harvest level between planning horizons. With this optimization model, if you try and find the exact "even flow sustainable harvest level", the model is constrained too much and gives you a very low answer or an infeasible solution message. While some may think that this 10% allowance may provide SFMM with an unfair advantage over the other models, others may find this ten percent leeway too constraining for the model. **Every effort was made to try and find the most even flow sustainable harvest level. While the results presented here are not the "highest" average sustainable harvest level they are considered by the authors to be the fairest for this comparison.**

For the harvest rule, maximize primary volumes harvested, there was a 13% increase in the sustainable harvest level when using curves with 10 year age classes. While it was expected that there would be an increase in the harvest level, it was not expected that it would be this large. Other users of the model concurred, reporting gains in the range of 5 to 10 percent. To analyse the differences graphs were prepared to how the model was growing and harvesting the forest. These graphs can be found in Appendix 3.

Figure 3N compares the differences in growing stock available with no harvest. When shown at this scale there appears to be little difference between how the forest is grown when using ten and twenty age classes. However, the difference is quite significant. At twenty years, the conifer growing stock available with the twenty age classes is actually 493,000 nm3 higher than the growing stock available with ten age classes. With harvesting, differences in growing stock become increasingly apparent with time.

TABLE 5 SILVICULTURAL COST AND ASSOCIATED TREATMENTS FOR THE FORMAN BASED MODELS

Model	Minimize Primary Volume Loss M3/YR	Minimum Intensive Treatment (Planting) Area in HA*	Minimum Intensive Treatment (Planting) at 610,000 M3/YR Area in HA*
FORMAN 2.3	610,000	3,000 ($245.9)**	
GLFC-FORMAN	610,000	3,000 ($245.0)**	
NORMAN	610,000	3,000 ($250.0)**	
CROPLAN	625,000	3,800	2,200 ($168.7)
FORMAN+1	640,000	5,000 ($343.0)	1,600 ($136.3)

Amounts shown in brackets are in millions of dollars, and represent the total cost for the 100 year planning horizon.

* Minimum annual target area.
** Slight differences are due to rounding errors in the short reports.

Observations from Table 5

In Table 4, models were asked to minimize silvicultural costs and in doing so, the sustainable harvest level dropped by 4%. **In Table 5, by re-running the models iteratively to find the minimum target area required for intensive treatment, it was shown that the maximum harvest level can be maintained and the average annual silvicultural costs even further than calculated in Table 4.** CROPLAN and FORMAN+1 show lower silvicultural costs because they are harvesting and regenerating more of the PJX1 FMU, than the other models. The intensive silvicultural treatment for PJX1 is aerial seeding and is much cheaper than planting.

Though not shown in Table 5, SFMM, with 20 age classes and when using the harvest rule "maximize primary volume", calculated the average annual cost at $ 3.9 million dollars per year at the average harvest level of 665,000 m^3/yr ($5.86 /$nm^3$). FORMAN+1 calculated an average annual cost of $ 3.43 million dollars per year at an average harvest level of 640,000 m3/yr ($5.36 /$nm^3$).

When SFMM was asked to maximize the secondary volume harvested, at ten year age classes, the model increased the poplar harvest by 20%, with a 9% drop in the primary volume harvest level. With twenty year age classes, the model was not as successful, as the poplar volume harvested only increasing by 8% and the primary volume decreasing by 2%.

It should be noted that by placing a minimum operable conifer volume restriction (i.e. 30 m^3/ha) the result was that some hardwood areas never became eligible for harvest, thus the results do not adequately show the complete picture of what poplar is actually available.

2.5 OBSERVATIONS ON THE HARVEST RULE- MAXIMIZE PRODUCT VOLUME HARVESTED

FORMAN 2.3, GLFC-FORMAN, NORMAN and FORMAN+1 showed similar results in that the primary volume harvest level dropped by 15% and the average annual production of products (or sawlogs) was 68,000 m^3/yr. CROPLAN results were higher in that the primary volume harvest level only dropped by 9%, and the average annual product harvest was 74,000 nm^3.

For SFMM, the harvest rule had only a slight effect on the sustainable conifer harvest level. The model, with both 10 and 20 age classes calculated a small decrease of 1 or 2%. The average volume of sawlogs for the 20 age classes showed an 9% increase over the sawlog volume calculated using the maximize primary volume harvested rule.

This set of runs also showed that GLFC-FORMAN was not updated when the correction was made in the FORMAN 2.1 program for this harvest rule.

HSG does not have this harvest rule and could not be tested.

2.6 OBSERVATIONS ON THE HARVEST RULE- MINIMIZE SILVICULTURAL COSTS

Results for the FORMAN based models showed, on average a 4% reduction in sustainable primary volume harvested. The **"average annual"** silvicultural costs are shown in brackets in millions of dollars (i.e. total dollars for the 100 year planning horizon/100 years). CROPLAN reports silvicultural cost in discounted dollars and produced an average cost of $0.7 million. To determine the actual cost for the areas treated by CROPLAN, in current dollars, the area treated in each FMU was multiplied by the cost for that FMU and added together to obtain the figure of $3.9 million. **It was interesting to note, that while the models were given unlimited basic and intensive funding, none of the FORMAN based models used any basic treatments to regenerate the areas being harvested.** Therefore the job of comparing the output from the models was simplified, as FORMAN 2.3 and GLFC-FORMAN, do not have provisions for "basic silvicultural treatments" (just extensive and intensive).

When SFMM was run for the 100 year planning horizon the model did not need to do any intensive silviculture. While this is efficient from a mathematical perspective, it is not very practical.

To further explore how the FORMAN based models handled silvicultural costs some additional runs were made. These runs are shown in Table 5.

TABLE 6 ADDITIONAL SFMM RUNS (USING 10 YEAR AGE CLASSES)

	Maximize Primary Volume *	Maximize Both Primary & Secondary Volume**	Minimize Area Harvested*
Ave. Sustainable Conifer Harvest NM3/Year	665,000	664,000	640,000
Ave. Sustainable Poplar Harvest NM3/Year	275,000	270,000	230,800
Ave. Annual Silvicultural Cost in $000	$3,927.6	$4,213.4	$3,976.2
Ave. Area Harvested in HA	7,300	7,314	6,660

* Conifer Target of 640,000 M3/Year, +- 10% Between periods

** Conifer Target of 610,000 M3/Year and Secondary Target of 200,000 M3/Year , +- 10% Between periods

Observations on Table 6

The ability to maximize both primary and secondary volumes (as well as products) is an asset to resource managers. When the FORMAN based models are asked to maximize conifer, the results are extreme fluctuations in the poplar harvest. If you asked the model to maximize poplar you would end up with extreme fluctuations in the conifer volumes. Surprising in this case is that the overall annual harvest of conifer and poplar did not drop that much. However the costs of maintaining an even flow harvest do increase, as seen in the silvicultural costs.

Minimizing the area harvested directed the model to cut in the FMU's with the highest yields, but in doing so, the sustainable harvest level dropped 5%. When we look at where the model was cutting under this target, it is evident that the model cut less in the hardwood stands and relied on intensive silviculture in the initial periods to obtain higher yields in the last 40 years of the run.

2.7 OBSERVATIONS ON THE HARVEST RULE-OLDEST FIRST

Using the "oldest first rule" HSG showed that the long term sustainable harvest level drops by approximately 4%, when compared to harvest levels calculated using the harvest rule "minimize primary volume loss". This lower harvest level was expected. On an oldest first basis, the stands being selected for harvest have less volume. The drop in harvest level in this case is understandably small because of higher volumes in the pure species curves at the higher ages and given that only a small percentage of the forest was originally in the upper age classes.

Although not officially part of this investigation, it was decided that due to the high reliance on MADCALC shown in the scoping exercise, at least one comparison should be tried. The MADCALC volume shown in Table 4 was determined by adding the results together from ten separate runs for each of the FU's. The average yield curve information and area by age class calculated by PCNFCS was used. **Acceleration factors were manually adjusted so that the model did not harvest below the operable ages used by the other the models.** It should be noted that MADCALC does not use future curves, the model assumes the area will be regenerated back to the same FMU, and with the same yields. For this run, it was assumed that all the areas would be successfully regenerated.

The harvest level of 629,000 nm3/yr, shown in Table 4, is the average harvest over the 140 year simulation period. Typical of MADCALC, the initial harvest for the first twenty year period is very high. At the end of the simulation the harvest level starts to level off at 550,000 m3/yr. **The 140 year average was considered to be the best time horizon to make the comparison.** Though not shown, it is possible to reduce the initial harvest level and raise the harvest level for the remainder of the simulation. This can be done by limiting the acceleration factor(s) for the first twenty year period, thus leaving more area to harvest from latter.

Although not documented in any of the manuals, it is possible to run the FORMAN based models using the principal of "oldest first" by typing in "0,0,0", instead of the harvest rule. This is really a "default" for these models and not a harvest rule. This option was discovered by accident late in this study and there was insufficient time to verify that these models work correctly with this option.

2.7.1 SFMM -OTHER

SFMM also provides the resource manager with additional harvest rules, which are referred to as targets and policies. While the policies and targets associated with costs were not investigated at this early stage of the project, two additional runs were made to investigate the options of minimizing the area harvested and maximizing both primary and secondary volumes. The results of these runs are shown in Table 6.

FORMAN 2.3, GLFC-FORMAN and NORMAN, do not automatically adjust the operability limits because they are related to volume, and the volume has been modified. The 16% drop in primary sustainable volume is a result of changes to the curves and is compounded by the effects of the operability limits. This effect is only applicable when the "Y" factor is lowered. When the "Y" factor is raised the operability limits still have their constraining effect, and do not need adjusting. It is unknown why GLFC FORMAN determined a different sustainable harvest level than FORMAN 2.3 and NORMAN. Perhaps this is another example where the model has not been updated to the same specifications .

In general using the "Y" factor to test the sensitivity of the models to the curves is not very effective. It is helpful though in further understanding the effects of the operability limits and how the model works. The option of changing the "Y" factor by FMU would have been more applicable and useful in testing the sensitivity of the model to changes in the curves.

2.9.0 CONCLUSIONS - CASE STUDY #1

a) By setting up each species (or group of species) as a separate FORMAN Management Unit, the user can easily determine from the reports generated, when and where the models are actually cutting.

b) All of the models were useful in providing insights into how the forest would behave based on the assumptions used in the inputs. By testing these assumptions with a variety of models, the extent to which each of the assumptions contributed to the results was more apparent than if just one model was used. For example, the differences identified through CROPLAN, as to when the models were cutting in the various FMU's, showed that it is not only important to consider the shape and size of a curve for a specific FMU, but to also examine the curves attributes with respect to the other curves being used. Slight changes in the negative slope of a curve can cause the model to harvest from a different FMU, which in turn can affect the available volumes and dramatically alter silvicultural funding requirements.

c) Operability limits based on minimum primary volumes have a significant impact on desired rotation ages and can significantly impact on the availability of secondary volumes. By setting the minimum operability level to 30 m3/ha for conifer, conifer and poplar volumes in some of the age classes for hardwood working groups were never considered available for harvest. Users must be fully aware of the implications of these assumptions before using models that rely on operability limits. Certainly the trend away from operability limits, towards operable ages is an improvement in the more recent models.

d) As seen with the use of "Y" factor options in the FORMAN based models, the relationships between operable ages and/or operable volumes with respect to the shape of the yield curve being used, needs to be correlated. While changes in operable ages and volumes can be analysed in isolation, changes in yield curves should also be accompanied with a change in operable levels to fully understand the possible impact. Another example of this occurred when using the silvicultural cards of PCNFCS. It was originally thought that the spruce planted on SP_UP sites would reach a harvestable volume by age 50. Actually, with the setting of the minimum volume at 30 m3/ha, these plantations did not reach the minimum volume until age 70.

2.8 "Y" FACTORS - THEIR EFFECT(S) ON HARVEST LEVELS

The FORMAN models offer the user the opportunity to examine the sensitivity of the models to the curves through the use of a "Y Factor". This factor scales the present and future curves, on the "Y" axis. Two runs were made to determine the impacts on the long term sustainable conifer harvest level, with the five FORMAN based models. The first run was made with the factor set at 90% and the second run was made with the factor set at 110%. The other models, HSG and SFMM, were not tested because they do have this feature. To test the impacts of raising or lowering the curves by ten percent using HSG, would require re-entering the primary curve information. For SFMM, testing of the curves can easily be done. The "easy to use" Window's interface allows the user to "pick up" the curve and drag it to the desired position.

TABLE 7 OBSERVATIONS FROM FACTORING THE "Y" CURVES

Volumes in NM^3/Year

Model	Min. Prim. Volume Loss	"Y" Factor at 90%*	% Change	"Y" Factor at 110%	% Change
FORMAN 2.3	610,000	510,000	-16%	670,000	+10%
GLFC-FORMAN	610,000	530,000	-13%	670,000	+10%
NORMAN	610,000	510,000	-16%	670,000	+10%
CROPLAN	625,000	570,000	-9%	680,000	+9%
FORMAN+1	640,000	575,000	-11%	710,000	+11%

* No attempt was made to edit the operability levels.

Comments on Table 7

In general, for each model, a 10% increase in the "Y" factor resulted in a direct volume increase of 10 % to the sustainable conifer harvest level . This was expected. What was not expected was that the range in sustainable harvest volumes between the models when the yield curves were reduced by 10%. By changing the "Y" factor for the curves, two things happen, not only do the curves change in height but the operability limits are also effected.

Both CROPLAN and FORMAN+1 automatically change the operability limits when the "Y" factor is changed because operability is related to age for these models. Thus the 10% change in the "Y" factor, results in a 10% drop in the sustainable harvest level.

In one way, the strong reliance on MADCALC identified in the scoping exercise, is a symptom of how difficult it actually is to apply the results from the models. Its also a symptom of how much more effort is required to come up with a similar answer.

More effort is needed in defining the forest units we are trying to manage. These forest units should be based on species and product requirements, realistic silvicultural treatment options, and in older forests, possibly on successional pathways.

e) It was difficult to make a fair comparison between HSG and the other models. HSG is fundamentally different in that it operates at a stand level, whereas the other models operate on an aggregate basis. Also the comparison between HSG and the other models was limited because the model cannot be directed to harvest areas by anything other than a primary volume target. As a result, HSG does not have many of the harvest rules the other models have.

f) The testing done on the SFMM and CROPLAN models, showed that the use of only twenty year age classes and ten time periods for the curves, may provide the user with less accurate results. While not an option for CROPLAN, it is strongly recommended that when using SFMM, 10 year age classes with twenty time periods be used.

g) While having a variety of harvest rules allows the user to further investigate the forest, the results from the different harvest rules should be carefully examined. In this case study, for the FORMAN based models, harvest rules such as "minimize silvicultural costs" and "maximize secondary volume harvested" did not work as well as anticipated. Lower silvicultural costs could be achieved by manually lowering planting targets and higher secondary volumes were harvested with the "minimize primary volume" loss rule.

h) All of the models tested can be used to calculate the long term sustainable harvest level for a forest. The question now becomes which result is correct, or the best for timber management planning purposes ? In essence, they all are correct. The job of the resource manager is to select the model, or the result from the model, that is most applicable to the forest that is being managed.

2.9.1 COMMENTS

In many instances the results of forest modelling are taken out of context and misused. People tend to look at the final number and disregard the assumptions that went into the model. While SFMM, offered the highest harvest level given the same assumptions it does not mean its the best model. In fact all the models were within 5% of the average harvest level, which is well within the accuracy range of the inventory and the curve assumptions used. Users often find that SFMM gives lower estimates of wood supply when the model is used to consider a broader array of management objectives than only wood supply.

Another problem in the use of these models, (other than SFMM) is how to apply the results. When examining the graphs showing were each of the models had to cut to give us the highest sustainable harvest level, how applicable are they? No mill can operate on a harvest, that spends ten years cutting nothing but jack pine and the next ten years cutting nothing but balsam. But this is what the models are telling us is required, if we want to maximize the harvest. How many Timber Management Plans actually follow the results of the modelling that was done? SFMM is different from in other models in this regard in that it is equipped with not only volume control, but also area control. This allows the user to control the fluctuations in the harvest areas within a particular forest unit (or in this case FMU).

CASE STUDY #2

b) GIS was very helpful in providing the adjusted landbase. To fully understand and investigate the impacts of land alienation on wood supply, accurate information is required. Estimates based on a "broad brush" approach, are not sensitive to changes within the age class structure of the forest and can be misleading. It is not known if the reduction in the land base and the resulting age class distribution is typical of all forests.

c) The FORMAN based models all have "area factors" which are easily applied and helpful in estimating land withdrawals for reserves. SFMM also has additional capabilities in identifying the type of reserve involved and the model can vary the percentage of land in reserves over time. HSG has no "area factor" capability and requires an adjusted landbase to calculate the impacts of land withdrawals.

d) The economic impacts of land withdrawals are significant. In this particular case a 10% loss in area, due to shoreline reserves, resulted in a 5 to 10% loss in the long term sustainable conifer harvest. Different models showed different sensitivities to the changes in the actual forest types affected.

3.3.1 Comments

The age class structure of the forest is the greatest factor influencing the long term sustainable harvest level. For the Case Study Forest, the sustainable harvest is limited by the shortage of area in the 21-40 and the 41-60 year age classes. The differences in the harvest level would have been much more dramatic if these two age classes had been affected to a greater extent.

Rather than continue with an unequal comparison, the testing of HSG was stopped at this point in the study. Further runs with the FORMAN 2.3 and GLFC-FORMAN models were also terminated. FORMAN 2.3 was eliminated due to the poor short reporting abilities and it produced the same results as NORMAN. The decision to stop testing GLFC-FORMAN at this point is based upon the fact that the model, as a variant of FORMAN Version 2.1, does not contain the revisions and updates introduced with the development of Forman Version 2.3 (for example, the correction to the harvest rule to maximize product volumes). An overall evaluation of FORMAN 2.3, GLFC-FORMAN and HSG can be found at the end of this report in the summation.

3.2 OBSERVATIONS

Table 8 shows the results of adjustments to the landbase for shoreline reserves. The ten percent estimate for shoreline reserves proved to be quite accurate. Originally it was suspected that more spruce and older stands associated with the waters edge, would be removed from the landbase. It was surprising that the landbase was generally reduced by 10%, in all forest units. As shown in Table 9, there are greater variances in the age class structure of the forest, especially in poplar, jack pine, mixed and balsam fir forest units.

Table 10 shows the impacts of the change in landbase on the sustainable conifer harvest level versus the area reduced by buffering. When the 90% area factor was applied to the original land base, all the models showed a 10% direct loss in the sustainable harvest level. HSG does not have this factor so it could not be tested.

For the adjusted land base, FORMAN 2.3, GLFC-FORMAN and NORMAN showed only a 4.9% decrease in the sustainable conifer harvest level whereas CROPLAN and FORMAN+1 showed a 9% decrease in the harvest level. The harvest target of 570,000 m^3/yr is used for comparison as that was CROPLAN's maximum sustainable harvest level. Although not as pronounced as in Case Study #1, the graphs showed that each of the models chose to harvest from different FMU's, at different time periods.

SFMM showed a 9% drop in the average sustainable harvest level. Graphs showed that SFMM basically harvested from the same FMU's during the same time period. The only difference was in the volume harvested.

Differences between the sustainable conifer harvest levels calculated by the models is due to the fact that NORMAN, CROPLAN and GLFC-FORMAN all cut more heavily to the FMU's that were least affected by shoreline reserves. FORMAN+1, CROPLAN and SFMM on the other hand, all cut more heavily in FMU's affected the most. While the differences in the harvest level between the models is only in the magnitude of 4%, they relate directly to the differences in the losses between FMU's which also ranged by 4%.

For HSG, the drop in the sustainable harvest level was only 2.3%. Apparently not many of the stands chosen by this model to harvest from, were effected by shoreline reserves.
Originally it was hoped that the spatial aspect of HSG, could be used to place its own buffers on all the lakes and streams. This however, proved to be beyond the capabilities of IDRISI. To go to a fifty metre buffer, a fifty metre pixel size would have to be used and the size of the file required would be too large.

3.3 CONCLUSIONS - CASE STUDY #2

a) The 10% estimate based on historical depletions was a reasonable estimate of the overall loss of area to shoreline reserves. However this "broad brush" application failed to consider variances within the age class structure of the forest.

CASE STUDY #3

4.0.2 OBSERVATIONS

Three runs were made. The first run used the harvest rule "minimize primary volume loss" to determine the maximum spruce harvest level. The second run was made with the harvest rule "minimize silvicultural costs" to determine if changes to the allocation could result in lower costs. The third run was based on the minimum planting target level required to maintain the harvest level in the second run. The results of these runs are shown in Table 12.

TABLE 12 SPRUCE HARVEST COMPARISON

Model	Min. Primary Volume Loss* NM3/Year	Min. Cost (silviculture & haul) NM/YR	Min. Annual Planting Target (HA)**
NORMAN	260,000 ($590.3) ($22.70/NM3)	265,000 ($435.1) ($16.73/NM3)	1,300
CROPLAN	260,000	265,000	1,900
FORMAN+1	260,000 ($642.4) ($24.71/NM3)	250,000 ($307.1) ($12.28/NM3)	0

Amounts shown in brackets are in millions of dollars, and represent the total haul and silvicultural costs for the 100 year planning horizon.

* Unlimited silvicultural funding.

** No amount of basic treatment could maintain the harvest level using the harvest rule "minimize costs"

All three models calculated the spruce sustainable harvest level at 260,000 nm^3/yr, using the harvest rule minimize primary volume loss, with unlimited silvicultural funding. When the models were asked to minimize silvicultural cost (which in this instance, includes haul costs), NORMAN and CROPLAN calculated a slightly higher sustainable conifer harvest level of 265,000 nm^3/yr. The sustainable conifer harvest for FORMAN+1, dropped to 250,000 nm^3/yr.

While the sustainable harvest levels between the models and runs are quite close, there is a considerable difference between when and what they harvest. This becomes apparent when we look at the costs between the runs for NORMAN and FORMAN+1. CROPLAN reports costs in discounted dollars, so those costs have not been used in this comparison. Figures 4A and 4B, in Appendix 4, provide an example of where and when the NORMAN model is harvesting. Table 13 summarizes the differences in where the models were harvesting.

CASE STUDY #3

4.0 DETERMINATION OF THE HARVEST LEVEL FOR SPRUCE

Spruce is used by Avenor's mill in Thunder Bay to produce good quality newsprint. The demand for spruce is high and a great deal of resources are used to ensure an even flow of this species to the mill. To a great extent, the supply of spruce to the mill directs the overall allocation planned on the Case Study Forest. To identify the available supply of spruce to the mill several modelling approaches were taken.

4.0.1 SPRUCE WORKING GROUP COMPARISON

The first approach was to model the forest with only the spruce working groups. Using PCNFCS to prepare the required input files, the spruce working group (from the updated inventory) was broken down into two forest units, upland and lowland spruce. In addition to this, the forest was further broken down into five areas to determine approximately where the spruce was located. The breakdown was done on a "per basemap" basis, and the area was identified by using the working circle field. For example, for haul area #4, "WC" was replaced by the area number 4 and used as a key in the sort by PCNFCS . Haul costs were added to the silvicultural costs to query the model on the most economical harvest pattern. Not all of the models have the ability to track harvesting costs separately, so for the purpose of this comparison haul costs were added to the silvicultural costs. This also allowed for the models to consider the total costs being examined. Please refer to Table 11. Runs were made with NORMAN, CROPLAN and FORMAN+1.

TABLE 11 HAUL COSTS BY AREA

Area	Ave. Haul Distance KM	Ave. Haul Cost/HA
Area 1	85	$ 736
Area 2	110	$ 949
Area 3	150	$1,303
Area 4	140	$1,204
Area 5	170	$1,472

Costs are based on an average volume of 140 NM3/HA and a historic average haul cost $0.0618 NM3/KM

b) The results from the harvest rule "minimize silvicultural costs" should be examined closely to determine if the model handled the situation as you would expect. While this rule works well, in many instances the results are not what you really were looking for.

c) A long term sustainable harvest level for spruce from the spruce working group was determined. Although this harvest volume does not include spruce volumes available from the other working groups, it can serve as a bench mark to the resource manager. A further investigation into the actual spruce volume available is investigated further in the next section of this report.

4.1 SPRUCE AS A PRODUCT COMPARISON

As identified in the scoping exercise, many resource managers do not rely on the models to identify product volumes available. They are however, concerned with the lack of ability in the models to determine the volumes of individual species being harvested. As a result, the second approach taken in determining the allowable harvest level for spruce, was to substitute 100% of the spruce volume, as the sawlog or product volume. Using the updated land base, PCNFCS was used to prepare the input files for modelling. This was a simple job, requiring the construction of a product percent table where all black and white spruce volumes on all site classes, go to sawlogs.

4.1.1 OBSERVATIONS

Table 14 and Figure 4C in Appendix 4, show the results for NORMAN, FORMAN+1 and SFMM when using this method of substituting a species such as spruce in the product curve.

TABLE 14 SPRUCE AS A "PRODUCT"

Model	Minimize Primary Volume	Maximize Primary Volume	Maximize Sawlog Volume	Spruce Volume (Average)
NORMAN	580,000			323,950
FORMAN+1	580,000			323,138
SFMM		606,000		326,000
SFMM			582,000	366,000*

Volumes shown are in NM^3/Year

* Spruce harvest volume were very high for the 80-100 year period, which increases the overall average volume.

TABLE 13 DIFFERENCES BETWEEN WHERE THE MODELS HARVESTED

Model	Minimize Primary Volume Loss			Minimize Costs		
	Upland	Lowland	Total	Upland	Lowland	Total
NORMAN	19,112	6,883	25,995	19,193	7,304	26,497
CROPLAN	18,606	7,337	25,943	19,231	7,225	26,456
FORMAN+1	18,458	7,536	25,994	17,868	7,132	25,000

100 Year volumes in thousands of NM^3

For the harvest rule "minimize primary volume loss", NORMAN cut more in the upland spruce areas and FORMAN+1 the least. The reverse is true for the lowland sites, where FORMAN+1 cut more and NORMAN cut the least.

For the minimize cost scenario, the increase in the harvest level for NORMAN and CROPLAN was found to be the result of these two models generally cutting earlier in the upland spruce (when compared to the first scenario) and because this forest unit returns to operability more quickly than lowland spruce (70 years versus 100 years) there was slightly more growing stock to support the higher harvest level. For NORMAN, the overall costs dropped by $5.07 /$nm^3$. FORMAN+1, was more aggressive and let all the existing spruce upland regenerate naturally. While sacrificing a small drop in the allowable harvest level (4%), it was able to reduce the costs dramatically from $24.71 to $12.28 /$nm^3$. **This is a little misleading and would not be possible if the modelling was done over a longer period where the results of the regeneration become more critical. This also points out again, that with the harvest rule "minimize silvicultural costs", the results of the modelling do not always produce the expected results.**

The breakdown in the output reports from all three models identified the areas where the harvest was taking place. While this information is not truly spatial, it gives the resource manager an idea as to where the harvest allocation should be located.

4.0.3 CONCLUSIONS

a) Some spatial considerations can be incorporated into non-spatial models with a little bit of set-up work and use of tools like PCNFCS. While only modelling in this case, with two treatment units (upland and lowland spruce) and five haul areas, it is possible with SFMM to set up a more complex "spatial" modelling scenario with more areas and treatment units. It should be noted that this only works up to a certain point. Manipulation of input files to achieve a special purpose beyond the standard capabilities of a model result in complex output files which are difficult to interpret. The complexity of the graphs showing where and when the models were harvesting (Figures 4A and 4B) is an illustration of this point.

Initial investigations into the impacts of natural succession on this land base did not show any significant results. The main reason for this was the operability ages and volumes being used. In most instances, due to the minimum volume requirements, the operable ages and volumes allowed the stands to be harvested up to 200 years of age. Having them succeed to new stands did not have much of an effect, because they had usually been harvested first.

To show how important natural succession can be to a forest, two changes were made. The first change was that the original "operable" ages desired by the area forester were used. The second change made, was that the age of natural succession was set to ten years after the rotation period, and **all the areas past this age (in the original land base), were transferred manually into the appropriate FMU and age class. This step is necessary to avoid area being lost in FORMAN+1. Unlike SFMM, FORMAN+1 will not accept any area past the break-up age.** Ten years after rotation may seem early to send the areas onto a new curve, but waiting 50 years and then sending the area into an older age class did not make much sense either. Table 15, shows the assumptions used to model natural succession. While these assumptions may not be considered valid by everyone, they can be used to verify the ability of the models to handle natural succession.

TABLE 15 NATURAL SUCCESSIONAL PATHS USED

FMU	Break-up Age	New FMU	ENTRY AGE
BW_ALL	110	MIXED	40
PO_X1	130	PO_X1	40
PO_23	130	PO_23	40
PJ_X1	130	MIXED	50
PJ_23	130	MIXED	50
BF_X1	110	MIXED	50
BF_23	110	MIXED	40
SP_LOW	160	SP_LOW	50
SP_UP	160	SP_UP	60
MIXED	160	MIXED	40

FORMAN+1 and SFMM were then run with no harvest to see what the impacts of natural succession were on the growing stock available. Please refer to Figure 4D in Appendix 4. Also additional runs were made to see what effect natural succession had on the sustainable harvest level. The results of these runs are shown in Table 16.

The spruce harvest level shown in Table 14 and Figure 4C, are ten year averages for NORMAN and FORMAN+1. This was done to enable the reader to make the comparison to the outputs from SFMM. The actual five year fluctuations in the spruce harvest calculated by NORMAN and FORMAN+1 are much greater.

NORMAN and FORMAN+1 showed a high initial spruce harvest and a low harvest at the end of the 100 year planning horizon. SFMM was the reverse, with a low spruce harvest at first and a high harvest level at the end, although we could have limited these effects through greater volume and/or area control of the harvest. All three models were similar at the critical middle period when the shortages in the 21-40 and 41-60 age classes come into play.

When using SFMM and "maximizing the spruce harvest", the model stayed with the 280,000 m^3/yr target for the first 70 years (the volume calculated in earlier as the sustainable harvest level for the spruce working groups), and increased rapidly for the last 30 years.

4.1.2 CONCLUSIONS

a) While this method does not result in an even flow sustainable harvest level, it does enable the resource manager to determine how much spruce will be harvested while still "managing" the overall conifer volume available from the forest.

b) In this investigation only one species was examined in relationship to the sustainable conifer harvest available from the forest. SFMM has greater flexibility than the other models, and in fact, can be set up to target harvest on the whole forest and report on an individual species basis.

c) SFMM lets the user set targets on individual species and groups of species (such as conifer or hardwoods). Even when the model is not "bound" to these targets, the fact that they have been set, affects the outcome of the scenario being modelled. High initial targets produced a shortfall at the end of the modelling period. Low initial targets resulted in the reverse situation, where the last two periods had exceptionally high harvest volumes. It was difficult finding middle ground, without dramatically effecting the overall conifer harvest. These outcomes are a direct result of the shortfall in the initial 20-40 and 41-60 age classes.

4.2.0 NATURAL SUCCESSION

In certain situations the resource manager may wish to consider the impacts of natural succession on the forest. Many of Northern Ontario's forests have an uneven age class distribution and as a result, some stands grow old and are never harvested. Both FORMAN+1 and SFMM allow the modeller to consider the impacts of natural succession for these stands. While HSG also allows for natural succession, as discussed earlier, it will not be included in this evaluation.

Natural succession in modelling does two things. First, it eliminates the need to depend upon the "pure species curves" past the rotation age of the species. (For example, many resource managers had trouble predicting what a 160 year old jack pine stand would look like when in reality everyone knew they do not exist.) Secondly, natural succession allows the resource manager to consider changes in species composition within a stand as the older trees die off and the younger understorey gradually takes its place.

4.2.3 COMMENTS

a) The ability to model natural succession is a powerful tool. The knowledge required to use this tool however, for many forest ecosystems has not been scientifically validated. Similar to the situation with predicting future curves for various silvicultural treatments most resource managers will probably be conservative in their assumptions.

b) Reports showing morality are useful in determining how the forest is growing and dying. SFMM does not report on mortality and FORMAN+1 does not report on volume when stands are succeeding.

4.3 SILVICULTURAL INTENSITIES

Up to this point in the case studies, the results shown have been with only two silvicultural intensities, extensive and intensive. With the exception of SFMM all of the models with the capability of using basic silvicultural treatments have chosen not to do so. To keep the comparisons even, this ability in SFMM was disabled.

The reasons behind the models (NORMAN, CROPLAN, FORMAN+1) not conducting any basic silviculture are:

1) When modelling with unlimited silvicultural funding, the models always applied intensive treatments based on the priorities initially set.

2) The models were also trying to maximize the conifer harvest and the basic treatment options available, did not yield higher conifer volumes than the intensive treatment options available.

3) Silvicultural impacts and regeneration assumptions are limited when modelling for a 100 year planning horizon. This was necessary to make the comparison to FORMAN+1, which at present can only model up to that length of time. (The new release of FORMAN+1, expected in the summer of 1995, will be able to model for up to 200 years.)

To investigate the effects of different silvicultural intensities, additional runs were made using SFMM and FORMAN+1.

4.3.1 SILVICULTURAL INTENSITIES-FORMAN+1

Three runs were made with FORMAN+1, using the updated landbase with the successional paths described in Section 4.2. The first run was made with only basic treatments (unlimited) and the second run made was with only intensive treatments (unlimited). These runs were then compared to the third run that allowed the model unlimited basic and intensive treatments, but asked the model to minimize silvicultural costs. The results of the comparison are shown in Table 17.

4.2.1 OBSERVATIONS ON NATURAL SUCCESSION

TABLE 16 IMPACT OF NATURAL SUCCESSION ON HARVEST LEVELS

Model	Without Succession	With Succession	Increase
FORMAN+1	580,000	600,000	3%
SFMM	586,000	613,000	5%

Volumes in NM^3 per year

Both models showed an increase in the sustainable conifer harvest level with the use of natural succession. The slightly higher harvest level calculated by SFMM, is primarily due to the increased flexibility allowed in the harvest level (+ or - 10%) between ten year periods.

What was interesting between the two models was the difference in growing stock reported (Figure 4D) by the models with no harvest. With natural succession SFMM showed an increase in the conifer growing stock over much of the 100 year period and a drop in the poplar growing stock over the entire 100 year period. This was expected. What was not expected was the dramatic difference in conifer growing stock reported by FORMAN+1. FORMAN+1 only reports the growing stock between operable ages available for harvest. With no natural succession the growing stock is reduced by the mortality that occurs as stands mature and drop out of the picture at ages 200+. SFMM does not report mortality and volumes are held at the oldest age class, 201+ in this case. With natural succession, FORMAN+1 hides the volumes for the areas that have succeeded until they become available for harvest. Hence the sudden increase in growing stock between years 60 and 100.

4.2.2 CONCLUSIONS ON NATURAL SUCCESSION

a) The ability to model natural succession allows the resource manager to consider the impacts of stands growing older and succeeding. Changes in the forest structure and the growing stock are reported on by the models and can be analyses.

b) The ability to model natural succession resulted in a higher conifer sustainable harvest using the assumptions made on natural succession in this case study. This may not be true for all forests, especially if there is a large initial age class discrepancy and the successional path selected for these stands is one that moves them to mixedwood or hardwood composition.

4.4.0 HARVEST LEVEL/SILVICULTURAL COSTS/ Planning Horizon -SFMM

The 100 year planning horizon is not long enough to study the full impacts of the silvicultural assumptions used in modelling the forest . The planning period for SFMM was extended to 150 years and the model was re-run using the updated landbase and the assumptions used for natural succession. A comparison of the results is shown in Table 18.

4.4.1 OBSERVATIONS ON THE 150 YEAR PLANNING HORIZON USING SFMM

TABLE 18 SFMM- 150 YEAR PLANNING HORIZON

	100 Year Planning Horizon	First 100 Years of 150 Year Planning Horizon	150 Year Planning Horizon
Ave. Conifer Volume	619,000	543,500	567,900
Ave. Poplar Volume	391,000	255,200	414,400
Ave. Spruce Volume	302,000	271,700	259,900
Total Silvicultural Costs	$4.23	$2.94	$3.78
Cost/NM³	$6.83	$5.41	$6.66
Silvicultural Costs Basic	($0.29)	($1.27)	($0.85)

Volumes are in NM³/YR (both runs were made using "maximize conifer volumes harvested").
Amounts shown are in millions of dollars and represent the total average annual silvicultural cost for the planning horizon.
Cost/NM³ is the total silvicultural cost divided by the annual average conifer harvest.
Amounts shown in brackets are in millions of dollars, and represent the total average silvicultural costs for basic silvicultural treatments (these costs are included in the total silvicultural cost).

By extending the planning horizon to 150 years it was shown that the annual sustainable conifer harvest and the annual spruce harvest dropped by approximately 10%. The poplar harvest increased by 6% with the longer planning horizon. For both planning horizons there was a large increase in the poplar and conifer volumes harvested in the last 10 to 20 years.

4.3.2 OBSERVATIONS -SILVICULTURAL INTENSITIES (FORMAN + 1)

TABLE 17 SILVICULTURAL INTENSITIES-FORMAN + 1

Unlimited Intensive Only	Unlimited Basic Only	Minimize Silvicultural Costs Unlimited Basic & Intensive
600,000 ($422.2)	600,000 ($155.0)	600,000 ($422.2)

Volumes shown are in NM^3/year
Amounts shown are in millions of dollars, and represent the total silvicultural cost for the 100 year planning horizon.

All three runs were made with the harvest rule "minimize primary volume loss" and reported the sustainable confer harvest level at 600,000 m^3/year. The first two runs were made with the silvicultural rule "minimize time to operability" and the third run with the silvicultural rule "minimize silvicultural costs/ha". In the third run, the model did not do any basic treatments and elected to intensively treat everything. Thus the costs are exactly the same as the first run.

While not shown in Table 17, over the 100 year planning horizon, with natural succession in place, the sustainable harvest level can be maintained using basic silvicultural treatments only. This resulted in a total savings of $267.2 million dollars over the 100 year period. When another run was made using the harvest rule "minimize silvicultural cost", with unlimited silvicultural funding, the model could not sustain the 600,000 m^3/year harvest level.

4.3.3 CONCLUSIONS

a) The silvicultural rule "minimize silvicultural costs/ha", did not work well in combination with the harvest rule "minimize primary volume loss". On the other hand, the sustainable conifer harvest level could not be maintained if the harvest rule "minimize silvicultural cost" was used.

b) All of these results should be carefully considered by the resource manager, and a variety of options should be examined in order to determine silvicultural costs and treatment levels.

d) The longer planning horizon in this case, reduced the sustainable conifer harvest level. The question now becomes one of, what is the most appropriate length of time to model over? There are mixed opinions on this. Some resource managers feel, the longer period is required because it allows for the consideration of the silvicultural activities planned. Others feel, that there is insufficient knowledge about the success of the planned regeneration and the shorter planning horizon reduces the dependency on the assumptions made. Last but not least, are the resource managers who do not put a lot of faith in the inventory and think 100 years is even too long of a planning horizon.

By extending the planning horizon to 150 years, the average annual silvicultural expenditure also dropped 10%. Silvicultural expenditures were also significantly reduced in the first 100 years of the 150 year period. On a cost per cubic metre basis, costs were lower with the 150 year planning horizon.

With the 100 year planning horizon, the model only did a small amount of basic silviculture (all of it was in the first 20 year period). With the 150 year planning horizon, the model did more basic silviculture and carried it out over the first 70 years of the total 150 years.

4.4.2 CONCLUSIONS ON THE 150 YEAR PLANNING HORIZON USING SFMM

a) By lengthening the planning horizon to 150 years the overall sustainable conifer harvest dropped significantly (10%) and the overall poplar harvest level increased significantly (6%).

b) Silvicultural expenditures showed a savings with the longer planning horizon but this was also at the expense of a lower conifer harvest level. This trend of lower silvicultural costs with lower harvest levels is true for all the models.

c) The longer planning horizon smoothed out the increased harvest level for the 80 to 100 year period, and moved it to the 130 to 150 year period.

4.4.3 COMMENTS

a) It is difficult with SFMM to compare silvicultural costs between treatment scenarios because the harvest cannot be pegged down. The model kept coming up with "infeasible solution" as soon as you made the harvest targets binding.

b) While the financial analysis presented in this report is limited, it has become evident to the authors that determining silvicultural costs is very much a "game" with all the models. Resource managers should take the time and try different methods, such as setting planting and seeding targets (levels), rather than depending upon the model to "minimize silvicultural costs".

c) Further financial analysis is available with SFMM using some of the models unique targets and policy options such as determining the "greatest total stumpage value of timber harvested" and "greatest net present value of timber management". However, this was not possible in this case, due to the way that the files were set up. In retrospect the spruce volumes should have been subtracted from the conifer volumes so that the proper financial comparisons could be made. The way the files were set up caused SFMM to add the spruce volume to the overall harvest. While this was not a problem for reporting on what was harvested and treated, it was a problem when the model was trying to determine the total value of the products produced.

SUMMATION

5.3 FORMAN+1

FORMAN+1 is a model available for purchase from Pearson Timberline in Alberta. The model has many capabilities such as how it harvests, regenerates, and maintains the forest. It also has the ability to model natural succession. While it takes more time to understand and use this model, its extended capabilities are worth it. Currently the biggest draw back with this model is that it will only simulate forest activities for up to 100 years. A new version planned for release in the summer of 1995, will be upgraded and allow for modelling up to 200 years. Pearson Timberline also offers good support with their product and are very helpful in answering questions.

5.4 HSG

A qualitative, not quantitative, comparison between the FORMAN based and HSG is warranted because there are substantial differences in model design. The goal of this study is to determine the relative strengths and functionality of the available wood supply models. Although Table 4 compares the quantitative results of the various models, the purpose of this discussion is to highlight the design features which differ between the FORMAN based and HSG models.

Design Rationale and Inventory Inputs

The HSG design rationale is to (a) store Ontario inventory data at the stand level, (b) queue the harvest based upon individual species volumes, and c) produce a simulation answer which then can be classified into descriptive forest classes for the user. HSG requires that each stand description be stored and altered throughout the simulation according to a set of State table definitions. All assumptions regarding natural succession and regeneration must be explicit in the State table. This can be a formidable task on forests which are complex and diverse.

The FORMAN based models, on the other hand, are premised on the laws of averaging: accepting that an **aggregate description** of conceptual "forest classes" best describes an otherwise complex forest. Admittedly, any two stands, described by the same forest class may differ in timber, but when examining numerous stands of that same forest class, the average condition can be more readily measured. This average condition, and development assumptions, are expressed in the "class present yield curves".

Model Inputs

HSG requires Ontario FRI inventory format, to operate. An HSG module FRITTER is used to convert this FRI format into a HSG compatible format. A user must ensure that the input inventory file format complies with the FRI standards exactly, prior to using FRITTER. HSG uses fully stocked pure species yield curves to calculate volumes at a given age. A total stand volume is calculated by considering each species component within each unique stand, referencing each species yield curve, and prorating that value according to that stands stocking level. There is a maximum capacity of **five** species in a stand. A hypothetical stand of PJ5

5.0 SUMMATION

All of the models examined have assisted in their time, to increase the resource manager's understanding of forest dynamics. Each model added and contributed to better forest management.

To properly use these models a great deal of care and effort is required in the set up of the inventory. All of the models need accurate up-to-date inventory information. Using these models is not difficult, but it is very "precise work" and mistakes can be easily made and go unnoticed. When interpreting the results of the models it is necessary to be aware of the inherent and implied assumptions.

The following summation is an overall appraisal of the current status of each of the models relative to each another.

5.1 FORMAN 2.3, GLFC-FORMAN and NORMAN

All three of these models work basically in the same fashion and can be learned quickly. They are also in the public domain and available free of charge. FORMAN 2.3 is not used very much because of its poorer reporting abilities and the fact that it only handles two levels of regeneration treatments (extensive and intensive). GLFC-FORMAN has a certain advantage in that it is more user friendly and operates in a UNIX environment. However, as previously stated, development of this model ended in 1991 and, as such, it fails to include the corrections and improvements incorporated in the development of FORMAN Version 2.3. Of these three programs NORMAN is the best overall. It has good reporting abilities and for many situations can handle the task at hand. The model should be updated to handle 20 management units. It is understood that NORMAN has this capability, it just was never published because many personal computers could not handle the array size at that time.

5.2 CROPLAN (FORMANCP)

CROPLAN was developed to assist resource managers to better understand the financial implications of various levels of silvicultural treatments. It was also developed to assist in the preparation of the required input files. The model meets these goals. While not tested in this study, the model has the ability to examine thinning as a means to meet anticipated wood shortages.

Results from this project suggest that the result from CROPLAN may be less accurate than the results from the other models that use 10 year age classes for the yield curve input.

maturing stages (if desired) using a juvenile 'breakup' age. HSG allows the user to specify the maximum allowable area for silvicultural treatment throughout the simulation. If a user defined an upper budget limit for silviculture, this budget value could be translated into cost.

The other models require future class curves which contain silvicultural assumptions. These regeneration classes are assumed to develop (until the next rotation) with the same species composition and stocking levels, as described above. Simulation results are therefore sensitive to small variations in the regeneration class curves. The other models also contain cost curves which are commonly used to reflect silvicultural treatment costs. A target harvest level can be specified using the "Minimize Cost" queuing rule. This allows the user to consider silvicultural budgets in a manner different than HSG.

Data Storage

HSG controls the size of the simulation intervals using the STEP command. The step intervals can vary throughout the full simulation, and at each interval, a different harvest target and harvest rule can be specified. The landbase is adjusted and the volumes are recalculated at each step. A five year interval step was used to coincide with the FORMAN modelling. The step size can make a significant difference upon the long-term sustainable harvest level. The SNAPSHOT command records a copy of the inventory database for the current simulation with the (redescribed state, and) adjusted volumes. The SNAPSHOT file is as large as the original inventory file, therefore frequent use of SNAPSHOT may consume large amounts of disk space. If the user wishes to generate a map query of a particular time period, a snapshot must be taken at that time period.

In FORMAN based models, queries relating to any particular time period must be solved by interpreting the hardcopy tabular reports. Only one copy of the forest classes is stored for the FORMAN based models. This requires little disk space.

Outputs

Three forms of output are provided by HSG simulations; tabular, graphs, and maps (where a digital inventory exists).

The most significant difference between HSG and the other models is that diverse queries can be made of the HSG simulation results to enhance the interpretation of simulation activities. In contrast, the FORMAN based outputs are tabular only, and no queries of the simulation results are possible. The ability of HSG to query the simulation results (with or without a digital inventory) affords the user a tremendous ability to interpret simulation effects. Suitability matrices can be defined to classify output stand data into descriptive classes (analogous to FU's). The suitability matrix can be easily modified to reclassify the output differently. In contrast, with the other models, the entire inventory would require re-aggregation into new forest classes and the associated yield curves prepared, if the classification parameters changed.

If the goal of a modelling exercise is to explore the full range of simulation effects upon the forest, and the classification of output stand data into more readily interpreted classes, HSG is the preferred tool. Further, if these effects require a spatial context, HSG is better.

SB4 PO1, 60% stocked, would require three separate calculations to arrive at the total stand volume at any age. The stocking value unique to each three species is calculated by multiplying the stand total stocking by the each species percent composition within the stand. For the above example: PJ5 * 0.6 = 0.3 Thirty percent of the Pj (fully stocked) yield curve volume for the appropriate age is then determined. The stand area is then multiplied to calculate each species volume within a stand. The age of all species within an inventory FRI stand are considered equal.

The inventory can be simulated and redescribed according to the State table: the possibility of uneven-aged stand components exists. The complex scenarios of partial logging (where residual mature species succeed in community with even-aged regeneration) may be described. This however is not considered as a normal application of HSG, and would be quite complex. One other distinction between the design of HSG and the FORMAN based models is that HSG does not allow for an "Area Factor" (i.e. the net forest landbase to be included in the simulation after reserves have been excluded). FRI input can be altered using a database to reduce individual stand area, for example by 15%, prior to use in HSG if no other spatial means are available for coding reserves. Ideally, the FRI inventory can be coded spatially using a GIS to reflect these anticipated reserves, but a GIS is not always available. If an average riparian reserve is 50 metres wide, then the selected pixel size should ideally be 0.5 hectares to match this resolution. Small pixel sizes create very large data files which may overload small computers.

Simulation Queuing Mechanisms and Harvest Rules

HSG queues based on **species volume targets only**. Multiple species may contribute to one harvest target, as in the general case of 'conifer'. Timber volumes, by species, are calculated for each stand: if the stands volume components are sufficient to meet the harvest rule, the stand is then queued. An example harvest rule target would be Sb/Sw/Pj/B = 145000m3. No additional secondary targets can be defined.

Instantaneous Rates of Change: State Tables

The HSG model uses stand "breakup", as a mechanism to define dynamic succession, the stand stocking and species composition can be redescribed, by species (at periodic intervals), using the State table. With HSG the total inventory is constantly being redescribed, with or without any harvest activity. Natural successional pathways are defined in the State table. Of the FORMAN based models, only FORMAN+1 allows for natural succession. A breakup age can be defined and when this age is reached the area is directed to a new curve at a user defined age. SFMM also works in a similar fashion.

Silviculture

HSG and the other models provide the user with sufficient capacity to examine silvicultural treatments. All models provide equal resolution for the definition of assumptions relating to silvicultural succession. HSG uses a treatment table to priorize which inventory sites are referenced to intensive, extensive, basic or natural regeneration states. Each regeneration description is found in the State table. Regeneration can be redescribed after the juvenile and

Wildlife Habitat

HSG is effective at simulating wildlife habitat availability because it maintains the stand level inventory resolution, along with a spatial context. Suitability matrices can be designed to describe specific levels of habitat quality and store the value in a new category. This category can then be queried spatially, and examined for broad local or landscape patterns.
The suitability matrix can then be adjusted if warranted, an a second simulation will show how sensitive the description of habitat is in relation to this adjusted variable.

Decision Communication

HSG provides detailed simulation results and maps which help communicate these results to others. This is particularly important when potential land use conflicts exist. The ability to link a spatial component to otherwise abstract simulation results cannot be understated. The goal of this study is not to compare the mapping output of HSG to other mapping software, but to other wood supply software.

In reference to the questionnaire issued for this study, HSG is an effective tool in examining (a) timber harvest, by species, (b) forest succession, c) economic impacts, and (d) wildlife habitat issues. Although a 'secondary product' definition capacity is not available in HSG, most questionnaire respondents preferred to rely upon historic estimates and intuition for this, rather than upon simulation results.

5.5 SFMM

The testing of SFMM was incorporated into the project in the last two months of the study, and the authors readily admit that not all of capabilities of this model were examined. In many instances to make an even comparison to the other models, additional restrictions/constraints were placed on SFMM.

SFMM is an optimization model and how the model reacts to the assumptions and targets used takes a bit of time to get use to. The model is easy to use but it is harder to understand. When using this model it is important to start off with a basic run and slowly add assumptions one at a time to see how the model reacts. Overall the model is very flexible and can be used in a wide variety of situations. Support from Mr. Davis was excellent and he was constantly making improvements to the beta version being tested.

The AIMMS windows version tested provides an excellent user friendly interface and changes in assumptions can be made efficiently. Input graphs and tables allow the user to visualize the assumptions and identify and correct any input errors. Outputs in the form of graphs, tables and reports are excellent and options allow the user to save cases and make comparisons between runs without a lot of manual effort.

Overall the model stands head and shoulders above all the other models. The only drawback in the use of this model will be the price tag for the AIMMS linear program and the size of the PC that is required.

User Skill and Ease of Use

Generally speaking, HSG requires a higher degree of user skill to effectively operate the model and take advantage of output capacities. HSG requires the user to explicitly define forest development assumptions (the State table) in advance. This can be timely, as all possible states must be identified. Casual users of modelling software may find this difficult. In contrast, the other models require the user to define generalized forest classes and yield curves. The querying capacity of HSG is a tremendous advantage, but also requires *skill* and experience to utilize.

HSG FUNCTIONALITY IN APPLICATIONS

HSG functions as a wood supply tool without the need for a digital forest inventory. However, a digital inventory should be used to augment the interpretive capacity of the model. Although the quality of spatial output provided by HSG/IDRISI is inferior to that produced by workstation-based GIS software, it is nonetheless valuable to the analyst. Further, spatial output is an asset when communicating results to others.

A digital inventory can be rasterized using other available software, including ARC/INFO. Techniques to complete this rasterization process will differ with each package. A unique record number must first be assigned to each stand in the forest prior to rasterization. This unique record number will relate to the inventory file containing the stand FRI attributes. The HSG GRIDDER module is then used to reformat a non-compressed ASCII grid file into IDRISI raster file format. IDRISI is limited to 32767 unique stand records. Dependent upon the forest area and the selected raster cell size, this may be a limiting factor. These stages should be performed by computer literate individuals.

Adaptive Management and Tradeoff Analysis

HSG is designed to be a simulation tool used in the context of adaptive resource management . Source data is input, harvest targets are specified, and then queries are made of the simulation results to determine future simulation modifications. The user can examine the simulation results and determine if these results are compatible with defined forest objectives. Common forest objectives can be expressed in terms of sustainability, industrial opportunities, and costs. A 'selected' simulation result will be determined after various tradeoff analyses.

Economics

Unlike the other models, HSG cannot queue the harvest using cost as a factor. It can however fully analyse the economic implications of the simulation results, and classify the output in terms of cost. HSG links a rule file (containing economic parameters) to the schedule of harvest and silvicultural treatments to calculate, economic values and costs. These cost rule files can be defined as either broad or fine resolution depending upon the circumstances. Simple HSG menus allow the user to calculate and query the Net Present Value (NPV) of simulation results. More complicated harvesting and transportation cost analysis is possible but this was not explored as the required Case Study forest input was not fully available.

This would allow the user to further refine the definition, between up and lowland black spruce sites, which in this case is a primary species and requires quite different silvicultural treatments.

Yield Curve Development

This stage involves the entering of the information required for the: silvicultural cards, pure species curves, product percent table, and site-class cross reference table. The format for this data entry has been well thought out and is user friendly. If the user is not satisfied with the silvicultural card setup developed in the aggregation stage the user has to back-up, and re-enter and run the aggregation criteria. It would have been nice to have, a "bank" of silvicultural treatment cards that could be re-used for different aggregation runs, avoiding the need to re-enter the information each time (i.e. similar to the cross reference table and pure species curves and product percent tables).

File Export

The last stage of the program involves the preparation of files required by NORMAN, FORMAN CP and FORMAN 2.3. Note: because FORMAN+1 has a built in conversion program to accept FORMAN 2.1 files, PCNFCS can also be used to prepare, in part, some of the curve information required by FORMAN+1. File export is straight forward.

Note: In the March 31,1994 version of PCNFCS there were two problems encountered in the file export stage:

1. In the NORMAN cost files there are two places where a space is missing in the file. These required manual editing before the program would accept the file.

2. In the transfer of information for CROPLAN the cost data did not transfer to the FORMAN CP files (it did however on earlier versions)

Comment

PCNFCS is very handy for a wide variety of purposes and should be supported. It is recommended that the program be upgraded to handle the required inputs for FORMAN+1 and SFMM (some work has been started on SFMM inputs).

5.6 PCNFCS

In general to the new user, this program offers a wide variety of options to prepare the required inputs for modelling. The program is set up in four stages: file check and preparation, forest class aggregation, yield curve development and file export. The following comments on the program deal specifically with each stage.

File Check and Preparation

This stage of the program is easy to use, works well and can be useful for a variety of purposes. The error check capability identified mistakes in the original FRI database that had gone unnoticed for years. The search and edit features allow the user to easily search out errors and make the required changes.

There is a wide variety of reports and summaries available and the author has taken the time to assist the user by formatting some of the reports for inclusion into Timber Management Plans. Reports can be saved in a file or exported directly to a printer. Reports sent directly to a printer have been formatted for a wide page printer. This is a drawback with the program, but the user may be able to avoid this by: sending the report files to some other software program and printing from there, or by setting up the printer to print small and wide from DOS.

The option of exporting the corrected Stanf file in the proper format avoids the necessity of making corrections in more than one database. While not the fault of the program the user should be cautioned that in order to incorporate free to grow and cutover information into the stanf database, the required format must be followed. For example larch and balsam fir should be identified by "L" and "B", and the correct number of spaces left between the working group and percent composition (B_ _6BW_3L_ _1).

Forest Class Aggregation

The forest class aggregation stage of the program allows the user to define the parameters needed to model the required scenarios. There is great flexibility in setting these parameters but caution and planning are required to avoid creating too many curves. When setting the number of Forman Managements Units (FMU's) and setting the aggregation criteria for the working groups and site classes, the total number of curves generated by the program is almost exponential. Even some of the simplest scenarios can generate 200 to 300 curve sets which is greater than the capacity of most models.

The selection and running of aggregation criteria also sets up the silvicultural cards (silvicultural treatment regimes) for the next step of the program. Again it is cautioned that planning is required to avoid creating too many silvicultural cards. If there are no real differences between silvicultural treatments required to regenerate the sites, and the user feels comfortable with averaging the volumes between site classes, it is advisable to group whenever possible. This will free up a number of curves and gives the user enough flexibility to better model more important criteria. For example, the user may decide to group all three site classes for the white birch working group because the silvicultural treatment required to regenerate these stands (i.e. leave for natural) are similar and white birch is not usually a primary or secondary product.

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5.7 FORESTRY CANADA'S FRONT END PROGRAM FOR FORMAN + 1

Alpha copies of the "DATA GENERATOR, Version 1.0" have been completed to date. Decisions with respect to the development and distribution of beta copies are pending. However, information and a copy of the draft user's guide may be obtained by contacting the author, Stig Andersen.

The FORMAN + 1 data generator was developed with the intent of facilitating FORMAN + 1 simulations by the process of automating much of the "input files" data preparation process. The data generator was developed within the context of a specific simulation design. The intent of the simulation was to provide spatial representation at the level of compartments (e.g. map sheet aggregates) or working circles within a designated management unit (or group of management units). Temporal projection was envisioned as encompassing a 20 to 30 year planning horizon. Representation of forest cover type was designed to allow for differentiation by selected working group, site class and age class categories. (Note: in order to process cover type aggregations comparable to PCNFCS- generated data files, the prospective user will require a compatible FORTRAN compiler, must be familiar with Fortran programming and, ultimately, be prepared to undertake the task of modifying the source code).

APPENDIX 1

RESULTS OF THE SCOPING SURVEY

Please provide a generalized profile of the person or persons using or likely to be using forest management planning models (e.g. title, educational background, work experience, etc.).

Currently, a variety of professional foresters, forestry technicians and wildlife biologists are using simulation models to assist in resource management planning. The need for resource managers and planners to access models on a regular basis is recognized and as such there is a request to make the models more user friendly (easier to learn and understand).

Please list the forestry planning models that you currently use?

MADCALC
FORMAN 2.3
NORMAN
CROPLAN
FORMAN+1
HSG (Harvest Schedule Generator)

While all of the models examined in this study are being used in the province, there is a strong reliance on the provincial standard model, MADCALC. Historically most of the users started out with FORMAN 2.1 and as improvements were made, users switched to the most advanced model available, FORMAN+1, HSG and most recently, SFMM. Model users were also anticipating the availability of new front end generators that were coming on stream at the time of the questionnaire.

Briefly what benefits have you achieved and/or what problems have you encountered with the use of these model(s)? i.e what are your likes and dislikes?

In the past, obtaining up-to-date land base information was one of the most difficult tasks in modelling. With more users having access to a geographic information system and with recent releases of more user friendly database software, preparing land base information for input into the models has become less problematic.

Limitations on the acceptance of model outputs stem from two main concerns. Reliance on FRI (forest resource inventory), and the current lack of quality growth and yield information needed to develop the required curve information (especially for over-mature stands).

Respondents reported success in using models for conducting wood supply analysis. Many commented on achieving a greater understanding of forest level responses to silvicultural activities. It was also noted that the public and other stakeholders acknowledge the reliability of volume-based simulation models over area based models such as MADCALC.

What are your expectations from the models?

Resource planners generally fall into two categories when it comes to their expectations on how models should function. The first group knows how they want to manage the forest, and use the model(s) to prove or justify what they want to do. This group looks for improved flexibility in how models operate to allow them to keep their options open. The second group of resource planners use modelling to direct their harvesting and silvicultural plans. This group is generally more concerned with input requirements and the quality of the information being modelled.

One concept of testing how useful models are, is to test the model's ability to explain or handle current forestry issues.

Resource managers currently look to models to assist in decision making with respect to a number of issues, such as; silvicultural options, economic timber allocations, and land use (withdrawals for parks, reserves, other users). Resource managers generally do not look to models to assist with decisions that are more political in nature, such as those concerning social/cultural values, non-market valuation, and old growth forests. Resource managers would like to have available or use models that with spatial capabilities could assist with decisions concerning wildlife habitat, landscape management and road access options.

Approximately what percent of your landbase has historically been regenerated using the following silvicultural systems? What changes do you expect in these trends in the future?

When asked about future trends in silvicultural treatments, resource managers predicted that while the reliance on natural regeneration will increase from 5% to 40% of the total area harvested, the majority of the areas will continue to be site prepared and planted or site prepared and aerial seeded. Alternate strip cutting for natural regeneration and thinning are predicted to remain at less than 5% of the total area treated. One change that is being noticed is the switch from using aerial herbicides to ground herbicide application. However, the total area receiving herbicide treatments is expected to remain at approximately 40% of the harvested area. It should be noted that these are averages, in fact there is a high reliance on natural regeneration and planting in the northeastern Ontario and a high reliance on site preparation and aerial/ground seeding in northwestern Ontario .

In modelling post-harvest forest development, what growth and yield conventions do you use (e.g. Plonski's Normal Yield Tables, localized volume tables, etc.)?

The majority of model users depend on Plonski's yield curves to form the basis for the curves used in modelling pre and post-harvest forest development. Minor adjustments to Plonski's curves are based on local volume tables and professional judgement. These adjustments tend to be conservative. Only one respondent had sufficient growth and yield information to develop their own curves.

In estimating timber growing stock volumes and in projecting yield predictions, is Site Class a significant parameter in your determination?

Most resource managers believe that site class is a significant factor in determining growing stock volumes and projecting yields. However concern was raised on the FRI interpretation of site class, and as a result, many do not always rely on site class.

Do you assign a different rotation age (operability limit) to those stands regenerated by planting, or to those treatment types/site classes which will likely be released/thinned?

While rotation ages are thought to be lower for managed stands regenerated by planting when compared to natural or un-managed stands, a note of caution was given by resource managers that they lack the information required to prove this.

Do you or would you consider using financial analyses (e.g., determination of present net worth, return on investment, benefit-cost ratios, etc.), as an integral component of timber production (and/or silvicultural investment) planning?

Resource managers in general believe that using financial analysis is "an integral component of timber production planning". However, very few managers are presently doing any financial analysis. Many managers expressed dissatisfaction with the current tools available. Others find the current situation where harvest and access costs are borne by the company, and silvicultural cost, are for the most part paid for by the crown, complicated and difficult to analyse. Planned changes in silvicultural funding are expected to result in the need for more financial analysis.

Please rate the degree to which you agree with the following statement." In general, to examine the overall cost of harvesting a given stand; access costs, harvesting costs, hauling costs and silvicultural costs (discounted) should be considered".

Resource managers believe that to examine the cost of harvesting a stand; access costs, harvesting costs, haul costs, and silvicultural costs (discounted), should be considered. It was noted by one of the respondents that as resource managers it must be remembered that the lowest costs may not necessarily be the best overall management approach.

What wildlife habitat requirements do you need to model?

While current forest resource information is helpful in modelling wildlife habitat, almost all the respondents believed that unless spatial information is considered, there is limited benefits in doing so. In general, more of a landscape approach to modelling wildlife habitat was recommended.

Do you require a timber species breakdown explicitly for your wood supply modelling?

All but one of the respondents identified the need for a species breakdown for the areas scheduled for harvest by the models. Many users were dissatisfied with the abilities of the current models in this regard.

Do you require a product (pulpwood, sawlog, veneer) breakdown? If so, how would you use existing FRI data to make inference / parameters which define the likely availability of each product?

For a product breakdown, many of the users were sceptical of using models and actually preferred to rely on historical volume information to apply a percent to projected volumes. In general this reluctance to project product volumes, is more a reflection on the original inventory than the capabilities of the models.

A BRIEF HISTORY FOR EACH OF THE MODELS BEING TESTED

FORMAN 2.3

FORMAN (FORest MANagement) is a sequential inventory projection model useful in evaluating forest management activities and strategies. It is a simulation rather than a statistical or optimization model. It serves as a bookkeeping device that tracks changes in the forest inventory in response to activities such as harvesting and silviculture. Version 2.1 was released in April 1987 by the New Brunswick Department of Natural Resources and Energy. The original FORMAN model was developed by: E. Wang, T. Erdle and T. Roussell. The approach used in the development of FORMAN follows that used in the Wood Supply and Forest Productivity model (WOSFOP) (Hall,1977). Minor program changes have been made since 1987 and the current version is FORMAN 2.3. FORMAN 2.1 has been used as the basis for many of the other simulation models that have been since developed over the years.

GLFC FORMAN version 1.0

GLFC FORMAN (Great Lakes Forestry Centre FORest MANagement model) is a VAX-11 FORTRAN / SUN FORTRAN conversion and a progressive adaptation of the inventory projection model, FORMAN Version 2.1 (1987 Wang, Erdle and Roussell). The basic computational algorithms inherent to FORMAN Version 2.1 remain unchanged. It incorporates a number of internal data validation routines; provides for a user interactive "help" query; incorporates significant changes in the manner of presenting interactive data input prompts and, in the generated output reports. However it should be noted that ongoing development of GLFC FORMAN was terminated in 1991 and, as a result, GLFC FORMAN was not updated to include any of the subsequent improvements or revisions inherent to FORMAN Version 2.3. For example, GLFC FORMAN was not updated to incorporate the (FORMAN Version 2.1) correction to harvest rule #5 which maximizes product volumes.

NORMAN VERSION 2

The NORMAN (NOrthern Region Forest MANagement)wood supply model was developed by Grant Hauer, Ontario Ministry of Natural Resources in November 1989. The model is an adaptation from the original FORMAN 2.3 model (Wang, 1987). Changes to the model were meant to make it more applicable to Northern Ontario forest management situations. Specifically improvements were made to allow for: additional future treatment options (intensive, basic and future), treatments for Non-Sufficiently Regenerated (NSR) areas, and better report options.

CROPLAN

The CROPLAN model was developed in 1991 by Dr. Jeremy Williams under contract with the Northwestern Ontario Technology Development Unit (now, S &T Unit). The development of CROPLAN was in response to the need for a model that could assist resource managers in planning at both the stand and forest level. This process was earlier identified and outlined in the NWOFTDU publication "A Crop Planning Process for Northern Ontario Forests" (Willcocks et al. 1990).
CROPLAN is actually two software programs, FORMANCP and a LOTUS-based program, called

CROPLAN.WK1. FORMANCP is an adaptation of FORMAN 2.3 and displays graphically selected simulation results, has more detailed short reports and calculates net worth statistics at the forest level. CROPLAN.WK1 is designed for forest unit level analysis. It enables the user to; develop, format, select management regimes (or ground rules), and incorporate them into FORMANCP files. The basic types of data required in CROPLAN are economic parameters, growth and yield data and forest class parameters.

FORMAN+1 version 2.0

FORMAN+1 is a sequential forest projection model developed by VANGUARD Forest Management Services Ltd. in 1991 (Vanguard 1991). FORMAN+1 is registered as a trademark of Timberline Forest Inventory Consultants Ltd. Timberline claims copyright to Forman+1 and all associated material, including software and manuals.

Significant functional improvements have been incorporated into the program over its predecessors, namely, FORMAN (Wang et al. 1987) and WOSFOP (Hall, 1977). Although FORMAN+1 retains the general principals and approaches used in the earlier models, some of the features which are unique to the model include:

-more stand treatment options,
-a method to rank stands for harvesting and silvicultural treatments,
-a broad set of forest performance indicators including inventory status, habitat supply, treatment levels and costs, products, and volume summaries,
-treatment control using area or volume parameters,
-treatment control by user defined areas,
-improved output reports.

Harvest Schedule Generator HSG (PC Version)

HSG is a spatially referenced simulation model. HSG was developed by T. Moore and C. Lockwood, Petawawa National Forestry Institute of Forestry Canada for use in a UNIX- based work station environment (Lockwood and Moore 1993). The PC version was developed by a consortium of researchers and consultants led by Dendron Resource Surveys Inc. of Ottawa. The PC version and manual is held under copyright to Dendron Resource Surveys Inc. 1994. This PC version was designed to link with the IDRISI Geographical Information System developed by Clark University.

Unlike the other models tested in this project, HSG maintains the identity of individual stands as the forest is projected over time. The other models operate on an aggregation of stands with similar forest characteristics. Some of the features which are unique to this model include:

-the ability in the "state table" to allow for forest succession and post harvest and post silvicultural responses,
-harvest targets can be set for individual species and adjusted over time.
-harvest priority rules can assigned independently to species-volume components.
-silvicultural activities can be specified over time with each iteration.
-the ability to build queries, to report the results of the simulation and view these queries in a table, graph or map format.

Strategic Forest Management Model-SFMM

SFMM (affectionately called "SFUM") was developed by Rob Davis, Ontario Ministry of Natural Resources in 1994-1995. SFMM is derived from a decision support system called SilviPlan (Davis and Martell 1993) devised at the University of Toronto. SFMM is based on linear programming and is written for AIMMS (Advanced Interactive Mathematical Modelling Software). SFMM and all associated material, including software and manuals is under copyright to the Queen's Printer for Ontario 1995. AIMMS is under copyright to Paragon Decision Technology 1995.

SFMM is an optimization model and its approach is significantly different than the simulation approach taken by the other models. SFMM allows the user to define management objectives, targets and constraints. The model then identifies a strategy or options that most efficiently meets these criteria. One of five separate management objectives can be used for a run of the model: minimize silvicultural costs, maximize volume production, minimize area harvested and regenerated, or maximize the value of timber harvested.

The model has great flexibility and allows the user a wide range of options for growing and renewing the forest. Some of the features which are unique to this model include:

-complete flexibility in defining species, products, forest units and management units,
-the ability to model over any time horizon (normally 160 years),
-the ability to control the area lost to fire and a variety of timber reserves through time,
-the ability to allow for shifts in the landbase between productive and non productive forest lands (i.e. the area lost due to roads or the area of abandoned agricultural and land being rehabilitated back to productive forest),
-the ability to describe natural forest succession and succession for silvicultural treatments,
-the ability to direct silvicultural treatments by intensities to a number of future forest units,
-improved flexibility in creating desired output reports.

PCNFCS NORMAN FILE CREATION SYSTEM-PC VERSION

PCNFCS was developed by Kevin Linquist, Forest Computer Consulting, as a project funded through Forestry Canada's Northern Ontario Development Agreement (Linquist, 1994). The PCNFCS program was released to the public in February 1994, and is based on an earlier program titled "Norman File Creation System" which operates on the VAX/VMS platform. "The PCNFCS program is comprised of four main components:

1. FRI File Check and Preparation,
2. Forest Class Aggregation,
3. Yield Curve Development, and
4. Forest Model File Export." (K. Linquist.1994)

This program assists the resource manager with the inputs required to run FORMAN version 2.1, Norman, FORMANCP, and parts of FORMAN+1. In addition, PCNFCS can also be used to do volume runs and edit StanF files (FRI inventory attributes). A version of PCNFCS has also been modified to produce inputs in SFMM format.

FORESTRY CANADA'S DATA GENERATOR FOR FORMAN+1 (GLFC-F+1)

This program assists in the development of present yield curves for input into the FORMAN+1 model. The program was written by Mr. Stig Andersen (Forestry Canada, Sault St. Marie, Ontario), in conjunction with in-kind support from Mr. J. Lawson, Avenor Inc. (Andersen 1995). The data generator allows the user to aggregate the standard Ontario FRI StanF information into forest units based on working groups and site classes. The program also allows the user to define upland and lowland spruce treatment units. The aggregation is assisted with the help of user friendly prompts and the program is laid out in such a fashion that the user can easily follow the progression of the aggregation. Work on this program is ongoing and the current focus of the work is to prepare the necessary future curves required by the model.

SYSTEM APPLICATION SUPPORT AND DOCUMENTATION

FORMAN 2.3

Forman 2.3 is written in FORTRAN 77. Both source code and executable codes are available. The program was originally compiled with a Microsoft FORTRAN compiler. The program will run on IBM compatible computers with MS-DOS version 2.11 and higher.

FORMAN21.EXE is contained on one diskette. The balance of the files are contained on separate diskettes.

-FORMAN21.FOR	source code
-FORMAN21.EXE	executable code
-YIELD.MAN	sample curve set data file
-COST.MAN	sample silvicultural cost data file
-CLASS.MAN	sample forest class data file

The manual gives the basic instructions required to run the model and provides a set of cases for the user to become more familiar with modelling different harvest scenarios. Copies of the program and manual are usually provided free of charge, and can be obtained from:

New Brunswick Department of Natural Resources & Energy
Forest Management Branch
P.O. Box 6000
Fredericton, N.B.
E3B 5H1

In Ontario, usually copies can also be obtained from the local Ministry of Natural Resources District offices.

GLFC FORMAN

GLFC FORMAN, as developed to date, has been installed on a SUN workstation and on a DEC VAX minicomputer under UNIX and VMS operating systems, respectively. The GLFC FORMAN source code conforms to FORTRAN 77 and has been processed using both SUN FORTRAN and VAX-11 FORTRAN compilers. The source code is in the public domain and while available from Natural Resources Canada, is not supported and there are no plans to upgrade the product.

The supporting computer program is in the public domain. A copy of the source code and draft user's guide is available upon request from:

Mr. Stig Andersen
Natural Resources Canada
1219, Queen Street East
P.O. Box 490
Sault Ste Marie,
ONT P6A 5M7

NORMAN VERSION 2

Similar to FORMAN 2.3, the program was compiled with a Microsoft FORTRAN compiler. The program will run on IBM compatible computers with MS-DOS version 2.11 and higher. The array sizes in the NORMAN program are set to the maximum allowable for the program to fit on one diskette but can be increased using a FORTRAN compiler. The manual provides clear instructions on how to use the model and provides the user with a sample set of data and analysis. The program and manual are usually made available free of charge. A sample set of data and an example of a wood supply analysis based on the sample data is also available.

Any questions concerning the availability and use of the NORMAN model can be directed to:

Mr. David Hayhurst
Regional Planning Analyst
Ontario Ministry of Natural Resources
Site Region and Planning
60 Wilson Ave. , 2nd Floor
Timmins, Ontario
P4N 2S7

CROPLAN

CROPLAN will run on IBM compatible micro-computers (PC's) with DOS versions 2.11 or higher, and at least 580K of available RAM. Similar to FORMAN 2.3, the program was compiled with a Microsoft FORTRAN compiler. To make program changes, a FORTRAN 77 compiler is required. The manual warns that some users have reported difficulties with CROPLAN's macros in version 3.0 LOTUS 1-2-3, and suggests using an earlier version of LOTUS (i.e version 2.1).

In general the manual is well written and leads the new user through the steps required to learn and operate the program. The case study of the Port Arthur Crown Management Unit provides an excellent example of one approach to a wood supply study and how to interpret the economic indicators produced by the program. Some readers may be sceptical of some of the assumptions made concerning spacing levels for plantations and the effects from thinning.

A copy of the CROPLAN model and manual (Technical Report #65) is available from:

Ontario Ministry of Natural Resources
Northwest Region Natural Resource Centre
RR#1, 25th Side Road
Thunder Bay, Ontario
P7C 4T9

FORMAN+1

FORMAN+1 was programmed in FORTRAN 77 and compiled with the MICROSOFT 1 FORTRAN compiler (version 5.1). Two versions of FORMAN+1 are available. The DOS version will run on IBM compatible micro-computers (PC's) with DOS versions 2.11 or higher, having at least 580K of available RAM. The WINDOWS version of FORMAN+1 will run on IBM compatible micro-computers with MICROSOFT WINDOWS version 3.0 or higher. Availability of at least 1.5 MB of available Ram when using FORMAN+1 under WINDOWS will prevent paging to disk and minimize execution time.

FORMAN+1 is contained on one diskette and contains input and output example files for training purposes. The manual is well written and provides the user with step by step instructions.

An updated version of Forman+1 is expected in the summer of 1995 and can be purchased from:

Pearson Timberline
Suite 315
10357 -109th Street
Edmonton Alberta
T5J 1N3

HSG

The HSG Forest Modelling System runs on the MS-DOS operating system version 5.0 or greater. The software runs on an 80386 PC or higher and it is recommended that you have at least 1Mb of memory and 5 Mb of free disk space to run the programs. A math co-processor is also recommended and a mouse is required to operate HSG's graphical features.

The manual is well written and provides the user with an excellent introduction to forest modelling at the stand level. The technical section of the manual, on how to use the model, could be improved. For example, the manual states that the model can only handle stand descriptions for up to five species, but what the manual fails to state is that the model truncates the remaining species from the description. In some cases, FRI stand descriptions are not sorted in numerical order, therefore major errors can occur in the results of the simulation.

A copy of HSG can be purchased from:

Dendron Resource Surveys Inc.
206-880 Lady Ellen Place,
Ottawa, Ontario K1Z 5L9

IDRSI is a set of programs that can be used to map the results of the HSG simulations. IDRSI requires 3.6 Mb of memory and 5 Mb of free disk space to store the tutorial exercises. Because raster based systems are data intensive, IDRSI recommends using a system running at 25 MHz or better. The manual is well written and many excellent examples of how the software operates are given in the tutorial. Users should be aware that IDRSI operates on its own computer language which will require considerable time and effort to learn.

STRATEGIC FOREST MANAGEMENT MODEL - SFMM

To run SFMM (windows version), a PC 80386/80486 with a math copressor is needed. At least 8 Mb of extended memory is required but 16 Mb or more is preferred. Greater memory allows for the operation of more detailed model formulations, although you can substitute space on your hard drive for additional extended memory. SFMM and the supporting software AIMMS, requires a minimum of 20 Mb of hard drive space.

The manual for SFMM is well written but because the program is constantly being improved, it may be out of date for the version of SFMM you are presently using. The author is trying to keep the manual as current as possible, but the user should also refer to the "read me" file, with their copy of the program for the latest changes. SFMM comes with sample input files and AIMMS "cases" with all input and output information stored.

For more information on the purchase of AIMMS and SFMM contact:

Mr. R. Davis, R.P.F.
Forest Analyst
Ministry of Natural Resources
70 Foster Drive, Suite 400
Sault Ste. Marie, Ontario
P6A 6V5

PCNFCS -NORMAN FILE CREATION SYSTEM

The PCNFCS program runs on the MS-DOS operating system version 5.0 or greater and uses Windows 3.1 (optional but preferred). The program was written in dBASE IV version 2.0 and compiled using Borland's DOS Compiler. "The program operates across three directories under the main PCNFCS directory:

1. PROGRAM- contains the PCNFCS.EXE compiled program file, data reference files and data file templates,

2. DATA- contains all of the data files which are created and/or modified throughout the life of the program, and

3. REPORTS- contain all text reports which are written to file from the program and all volumetric model file sets which are exported by the program" (Linquist, 1994)

In general the manual is well laid out and leads the new user through the set-up and use of the program. One thing lacking in the manual, is a list of error messages and the steps required to correct the error. It should be recognized that this is a fairly new product and as comments concerning the program and manual are received there will likely be some revisions.

A copy of the PCNFCS program and manual is available from:

Ontario Ministry of Natural Resources
Site Region and Planning
60 Wilson Ave. , 2nd Floor
Timmins, Ontario
P4N 2S7

FORESTRY CANADA'S DATA GENERATOR FOR FORMAN+1

The data generator (as an adjunct to FORMAN+1 Version 2.0) was developed for intended application on a UNIX-based SUN (or SUN-comparable workstation. The source code conforms to FORTRAN 77 and has been developed using a SUN FORTRAN compiler. The data generator derives user-prescribed FORMAN+1 yield curve, forest class and treatment input data files direct from OMNR standard forest resource inventory data files. Development of the data generator is on-going. Information and a draft user's guide may be obtained by contacting the author:

Mr. Stig Andersen
Natural Resources Canada
1219, Queen Street East
P.O. Box 490
Sault Ste Marie,
ONT P6A 5M7

SUMMARY OF MODEL INPUT REQUIREMENTS

A summary of the input requirements for the each of the models is shown in Table 19. PCNFCS and the front end program for FORMAN+1 (developed by Forestry Canada), are shown in Table 2. Because HSG and SFMM also prepare curve information, these two models are also shown in Table 2.

SUMMARY OF MODEL OUTPUTS

A summary of the outputs for the models and front end loaders is shown in Table 20 and 21.

TABLE 19 SUMMARY OF MODEL INPUT REQUIREMENTS/CAPABILITIES

TYPE OF INPUT	FORMAN 2.3	GLFC-FORMAN	NORMAN	CROPLAN	FORMAN+1	HSG	SFMM
Max. No. of Management Units	12	12	12*	12	20**	One	INF.
Forest Units	Yes	Yes	Yes	Yes	Yes	WG Only	Yes
Max. No. of Iterations (5 year periods)	40	40	40	40	20	INF.	INF.
Scale Factor -Y Axis	Yes	Yes	Yes	Yes	Yes	No	Built in
Harvest Rules	6	6	6	6	6	3	Targets & Policies
Silvicultural Rules	No	No	No	No	6	No	**
Silv. Treatment Levels	2	2	3	3	3	3	INF.
Succession	No	No	No	No	Yes	Yes	Yes
Yield Curves						By Species	By Species Or User Defined
-Primary	Yes	Yes	Yes	Yes	Yes		
-Secondary	Yes	Yes	Yes	Yes	Yes		
-Product	Yes	Yes	Yes	Yes	Yes		
-User defined	Yes	Yes	Yes	Yes	Yes		
Max. No. of Yield Curve Sets	200	200	200	200	400	NA	INF.
Operability Limits	Volume	Volume	Volume	Volume	Age	Age	Age
Economic Data							
-Harvest Costs	Yes	Yes	Yes	Yes	Yes	Yes	Yes
-Silvicultural Costs	Yes	Yes	Yes	Yes	Yes	Yes	Yes
-Product Value	No	No	No	Yes	Yes	No	Yes
-Other***	No	No	No	Yes	Yes	No	Yes

* Can be increased to 20 with a FORTRAN COMPILER

** With WINDOWS VERSION , 10- With DOS VERSION

*** Includes information such as rate of return etc.

TABLE 20 SUMMARY OF INPUT REQUIREMENTS/CAPABILITIES FROM THE FRONT END LOADERS AND THE MODELS THAT PREPARE THEIR OWN CURVES

TYPE OF INPUT	PCNFCS	GLFC-F+1	HSG	SFMM*
Standard Stanf File	Yes	Yes	Yes**	No***
Pure Species Curve Information	Yes	Yes	Yes	Yes
Site Class Cross Reference	Yes	Yes	Yes	Yes
Silvicultural Information	Yes	No	Yes	Yes
Stand Succession Information	No	No	Yes	Yes
Wildlife Information	Yes	No	Yes	Yes
Aggregation by WG	Yes	Yes	Yes	Yes
Aggregation by Forest Units	Yes	No****	No*****	No
Economic Information	Yes	No	Yes	Yes

* SFMM has two options for entering information -Option 2, uses this information to prepare the required curves.

** Also requires one field to link to spatial information (Key-Basemap & Stand Number)

*** Requires a summary of area and weighted ave. species composition and stocking levels for each working group or forest unit.

**** "hard wired" To separate upland and lowland spruce.

***** Aggregation by forest unit can be done by writing a program to interpret the output information only.

Note: The SFMM Toolbox (under development) will accept input items listed in the table and allow users to interactively prepare area and yield information for input into SFMM.

TABLE 21 SUMMARY OF MODEL OUTPUTS

TYPE OF OUTPUT	FORMAN 2.3	GLFC-FORMAN	NORMAN	CROPLAN	FORMAN+1	HSG	SFMM
Tables	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Graphs	No	No	No	Yes-SCREEN	No	Yes-SCREEN	Yes-SCREEN
Maps	No	No	No	No	No	Yes	No
Input Data	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Reports on the Forest	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Statistics							
-Volume Harvested	Yes	Yes	Yes	Yes	Yes	Yes	Yes
-Area Harvested	Yes	Yes	Yes	Yes	Yes	Yes	Yes
-Area Treated	Yes*	Yes*	Yes	Yes	Yes	Yes	Yes
-Costs	Yes	Yes	Yes	Yes	Yes	Yes	Yes
-Mortality	Yes	Yes	Yes	Yes	Yes	No**	No***

* Only two levels of silvicultural intensities.
** Stands succeed onto new curves.
*** Stands succeed onto new curves or are held at the oldest age class.

TABLE 22 SUMMARY OF OUTPUTS FOR THE FRONT END LOADERS AND THE MODELS THAT PREPARE THEIR OWN CURVES

Type of Output	PCNFCS	GLFC-F+1	HSG	SFMM
For which Models	FORMAN 2.1 CROPLAN NORMAN FORMAN+1	FORMAN+1	HSG	SFMM
Present Curves	Yes	Yes	Yes	Yes
Future Curves	Yes	No	Yes	Yes
Cost Curves	Yes	No	Yes	Yes
Other Tables/Reports				
-Area Summary	Yes	No	Yes	Yes
-Age Class	Yes	No	Yes	Yes
-Stand Volumes	Yes	No	Yes	No
-Wildlife Habitat	Yes	No	Yes	Yes
-Species Composition	Yes	No	Yes	No
-Forest Diversity Indices	No	No	No	Yes

APPENDIX 2

FIGURE #2A AGE-CLASS DISTRIBUTION

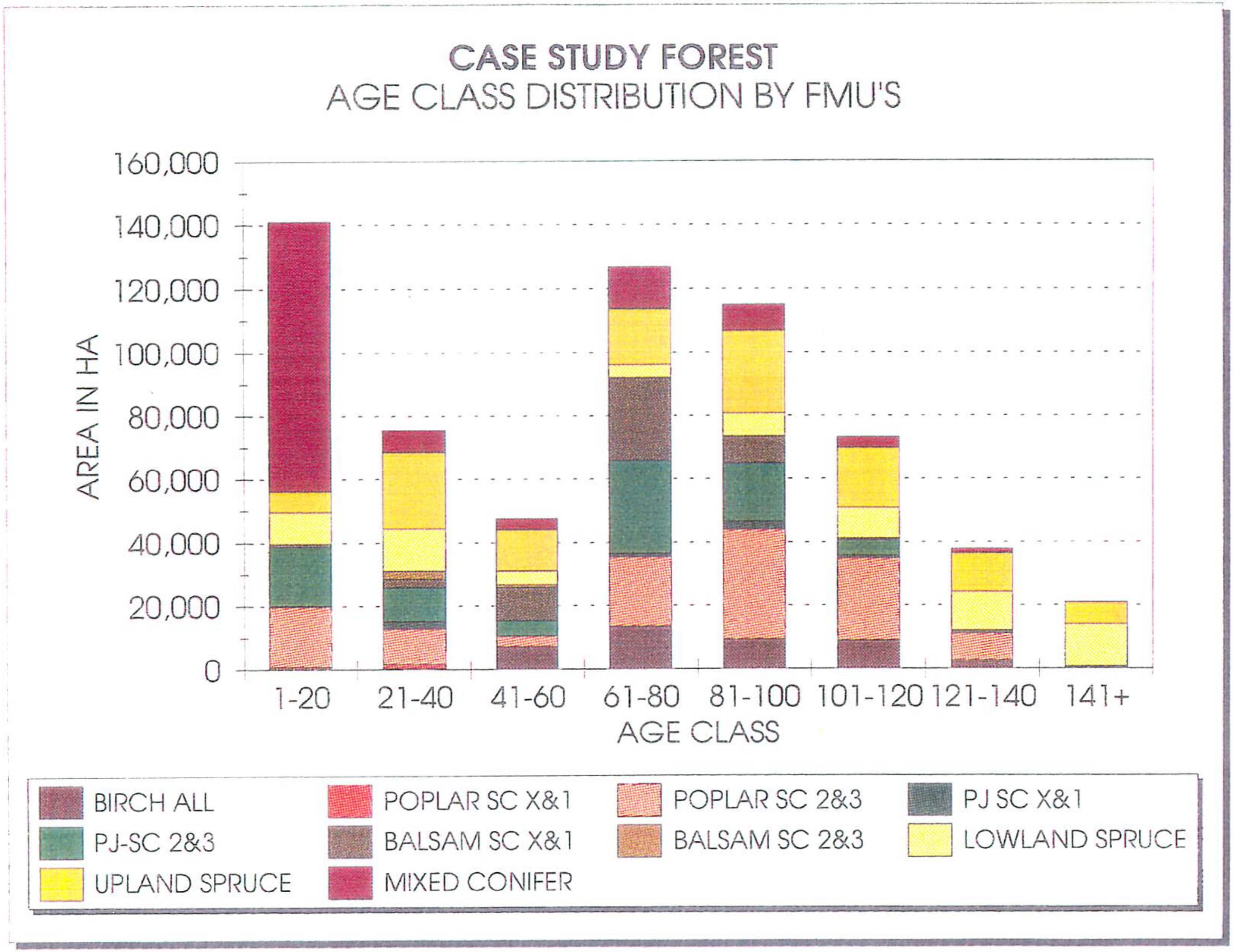
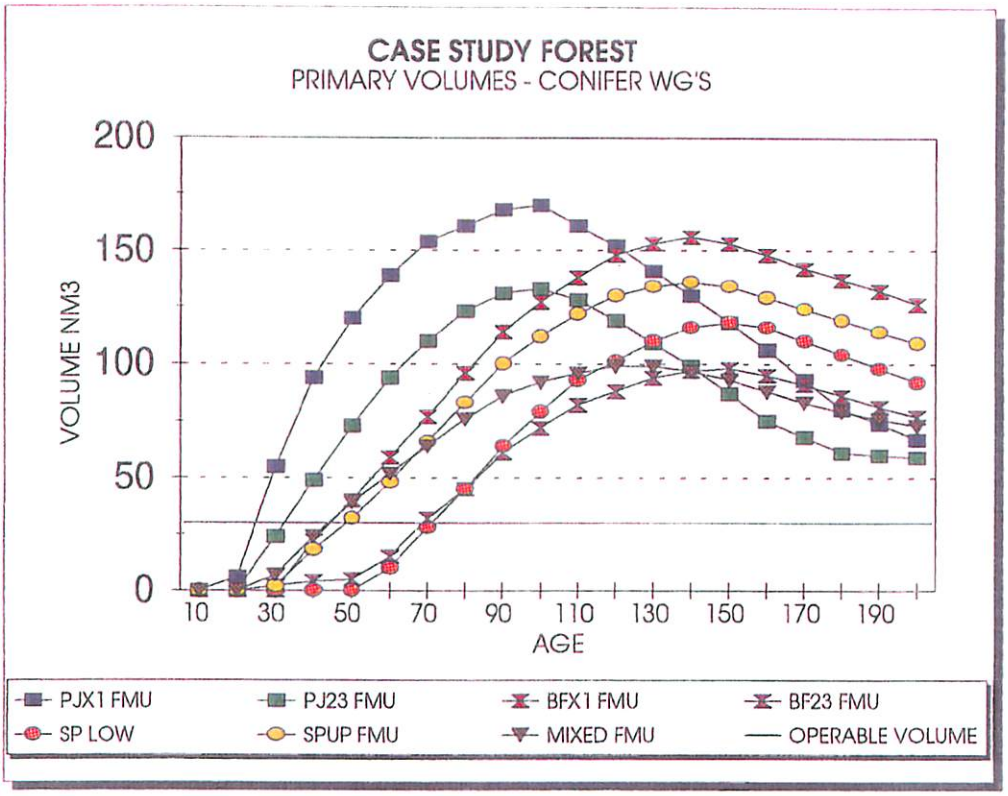


FIGURE #2B CONIFER PURE SPECIES CURVES



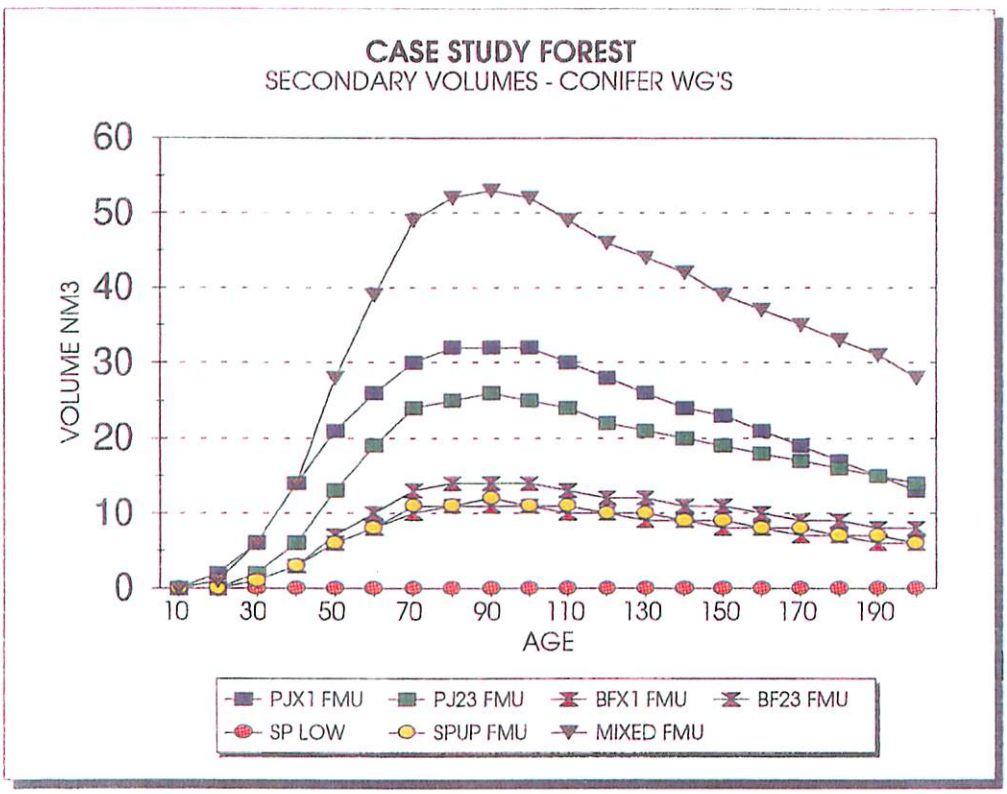
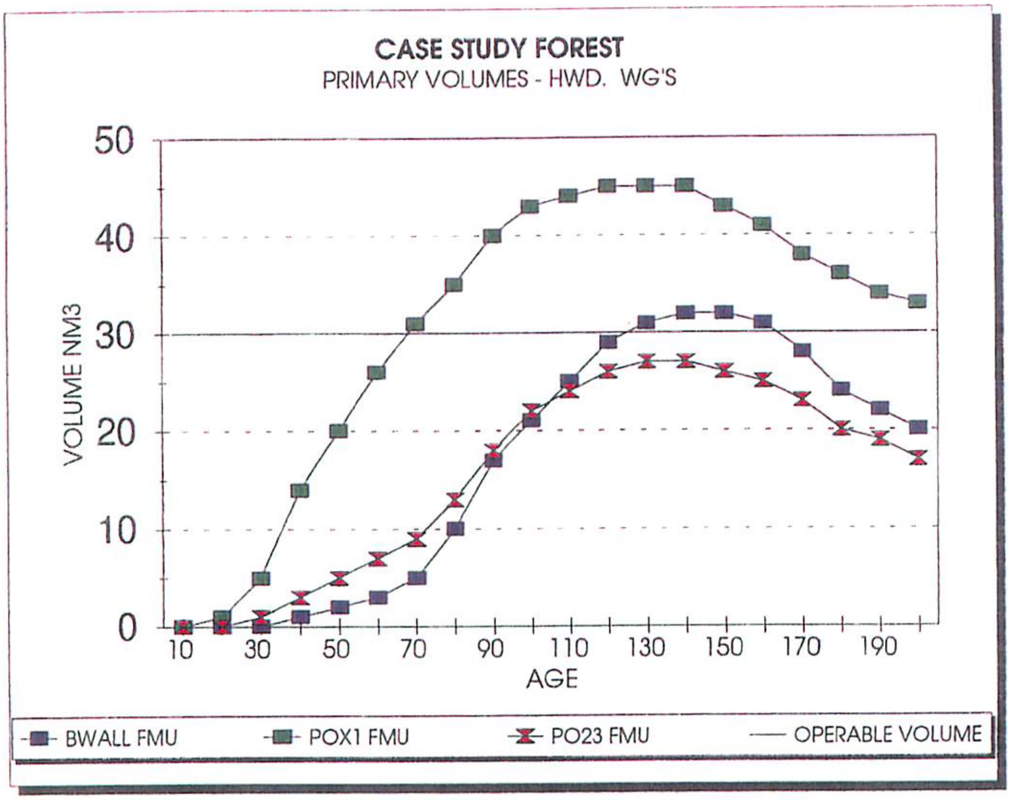
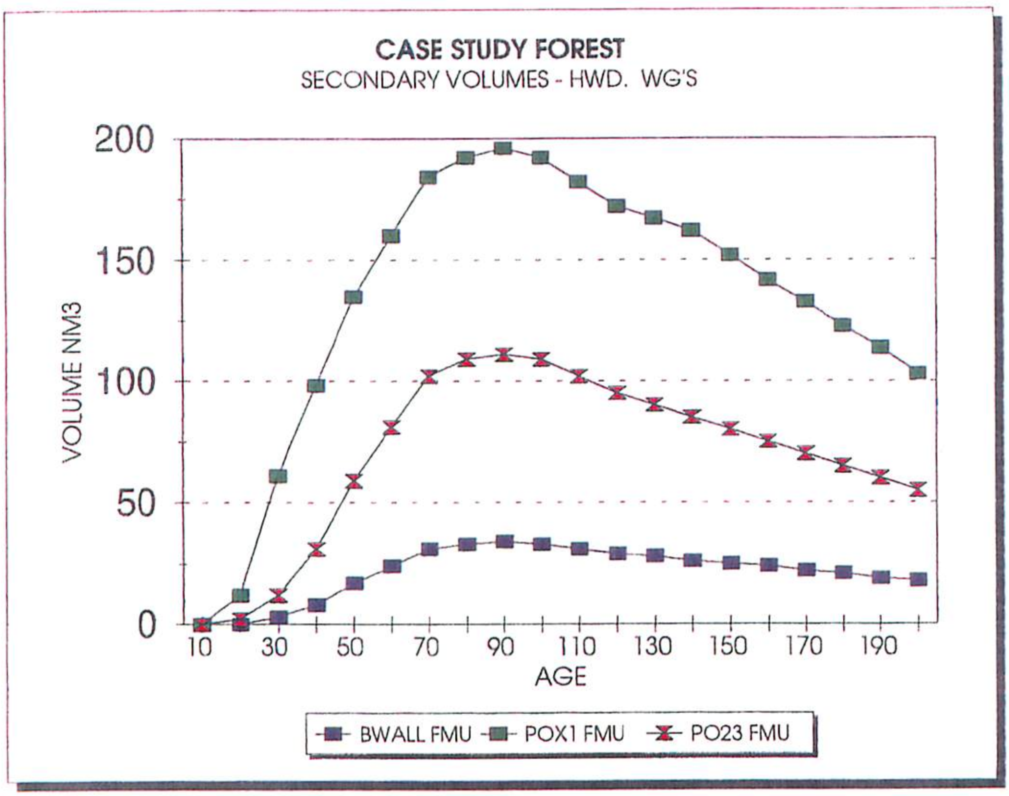


FIGURE #2C HARDWOOD PURE SPECIES CURVES





FOREST CLASS VOLUME SUMMARY (m3/Ha)

MANAGEMENT UNIT: 777 FOREST CLASS FILE: CLWIN.DBF YEAR: 1995

05/02/94

Own 1 · Polygon 20 - 28 · FMU Label BWALL · Stocking

Age Class	Age	Area	Sb	Sw	Pj	Bf	Ce	Pw	Pr	Oc	Po	Bw	Oh	SWD	HWD	TOTAL	FMU	CLASS
1- 20	18	784	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
21- 40	32	287	0	0	0	0	0	0	0	0	1	7	0	0	8	8	1	2
41- 60	57	7099	0	0	3	0	0	0	0	0	23	34	0	3	57	59	1	3
61- 80	70	13008	0	0	8	1	0	0	0	0	38	39	0	9	78	87	1	4
81-100	92	9177	6	1	3	6	0	1	0	0	29	30	0	16	59	76	1	5
101-120	109	8515	9	3	2	9	0	1	0	0	29	23	0	24	52	76	1	6
121-140	131	2040	8	6	0	9	0	1	0	0	23	17	0	24	40	65	1	7
141-160	145	115	6	3	0	16	0	0	0	0	11	46	5	24	62	86	1	8
TOT/AVG	83	41025	3	1	4	4	0	1	0	0	30	31	0	13	61	74		

Own 1 · Polygon 20 - 28 · FMU Label POX1 · Stocking

Age Class	Age	Area	Sb	Sw	Pj	Bf	Ce	Pw	Pr	Oc	Po	Bw	Oh	SWD	HWD	TOTAL	FMU	CLASS
1- 20	19	88	0	0	0	0	0	0	0	0	9	0	0	0	9	9	2	9
21- 40	29	1335	0	0	10	0	0	0	0	0	48	0	0	10	49	58	2	10
41- 60	53	20	3	0	0	16	0	0	0	0	148	9	0	19	158	177	2	11
61- 80	67	352	4	0	7	4	0	0	0	0	135	20	6	15	160	175	2	12
81-100	88	50	24	9	0	11	0	0	0	0	179	8	0	44	187	231	2	13
101-120	112	367	9	8	0	5	0	0	0	0	252	6	0	22	258	280	2	14
121-140	134	587	11	16	2	4	0	0	0	0	214	9	0	32	223	255	2	15
141-160	149	94	0	4	0	9	0	0	0	0	126	24	0	13	150	163	2	16
TOT/AVG	70	2893	4	5	6	2	0	0	0	0	122	6	1	17	129	146		

Own 1 · Polygon 20 - 28 · FMU Label PO23 · Stocking

Age Class	Age	Area	Sb	Sw	Pj	Bf	Ce	Pw	Pr	Oc	Po	Bw	Oh	SWD	HWD	TOTAL	FMU	CLASS
1- 20	13	18910	0	0	0	0	0	0	0	0	3	0	0	0	3	3	3	17
21- 40	27	11036	0	0	1	0	0	0	0	0	5	0	0	1	5	6	3	18
41- 60	55	3322	0	0	4	0	0	0	0	0	60	10	0	4	71	75	3	19
61- 80	73	21852	1	0	12	0	0	0	0	0	105	10	0	13	116	129	3	20
81-100	93	34597	6	1	9	3	0	0	0	0	96	8	0	18	104	122	3	21
101-120	109	25879	9	2	5	6	0	0	0	0	91	6	0	21	98	119	3	22
121-140	133	8349	8	6	1	6	0	0	0	0	69	5	0	22	74	95	3	23
141-160	146	146	3	9	2	14	3	0	0	0	59	3	0	30	63	92	3	24
161-180	169	35	20	10	0	10	0	0	0	0	40	6	0	40	46	87	3	25
181-200	194	66	8	4	0	0	0	0	0	0	27	5	0	12	32	44	3	26
TOT/AVG	77	124192	4	1	6	2	0	0	0	0	72	6	0	14	78	91		

Own 1 · Polygon 20 - 28 · FMU Label PJX1 · Stocking

Age Class	Age	Area	Sb	Sw	Pj	Bf	Ce	Pw	Pr	Oc	Po	Bw	Oh	SWD	HWD	TOTAL	FMU	CLASS
1- 20	14	273	0	0	2	0	0	0	0Page	0	1 1	0	0	2	1	3	4	27

FOREST CLASS VOLUME SUMMARY (m3/Ha)

MANAGEMENT UNIT: 777 FOREST CLASS FILE: CLWIN.DBF YEAR: 1995 05/02/94

Age Class	Age	Area	Sb	Sw	Pj	Bf	Ce	Pw	Pr	Oc	Po	Bw	Oh	SWD	HWD	TOTAL	FMU	CLASS
21- 40	25	2513	0	0	25	0	0	0	0	0	5	0	0	25	5	30	4	28
41- 60	54	24	17	0	84	0	0	0	0	0	0	0	0	101	0	101	4	29
61- 80	73	1053	23	0	160	1	0	0	0	0	23	2	0	183	25	208	4	30
81-100	90	2477	22	0	175	1	0	0	0	0	28	2	0	197	30	227	4	31
101-120	109	674	27	0	134	2	0	0	0	0	30	2	0	163	32	194	4	32
121-140	133	347	42	2	80	4	0	0	0	0	21	2	0	128	23	151	4	33
141-160	147	231	29	0	44	18	5	0	0	0	21	2	0	97	23	120	4	34
TOT/AVG	69	7592	16	0	105	1	0	0	0	0	18	1	0	122	19	141		

Own Polygon FMU Label Stocking
1 20 - 28 PJ23

Age Class	Age	Area	Sb	Sw	Pj	Bf	Ce	Pw	Pr	Oc	Po	Bw	Oh	SWD	HWD	TOTAL	FMU	CLASS
1- 20	14	18557	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	35
21- 40	27	10331	0	0	3	0	0	0	0	0	2	0	0	3	2	5	5	36
41- 60	58	4985	3	0	70	0	0	0	0	0	16	1	0	73	17	90	5	37
61- 80	70	29420	6	0	121	0	0	0	0	0	20	2	0	127	22	150	5	38
81-100	90	18441	21	0	117	0	0	0	0	0	28	3	0	138	31	169	5	39
101-120	108	4919	29	1	85	2	0	0	0	0	25	4	0	117	29	146	5	40
121-140	135	489	36	0	48	5	0	3	0	0	17	3	0	92	21	112	5	41
141-160	151	41	61	0	37	0	0	0	0	0	8	0	0	97	8	105	5	42
161-180	169	6	24	0	20	0	0	0	0	0	0	0	0	44	0	44	5	43
TOT/AVG	59	87189	9	0	75	0	0	0	0	0	16	2	0	84	17	101		

Own Polygon FMU Label Stocking
1 20 - 28 BFX1

Age Class	Age	Area	Sb	Sw	Pj	Bf	Ce	Pw	Pr	Oc	Po	Bw	Oh	SWD	HWD	TOTAL	FMU	CLASS
1- 20	19	762	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	44
21- 40	33	2953	2	0	0	4	0	0	0	0	1	1	0	6	3	9	6	45
41- 60	55	10157	14	1	1	38	0	0	0	0	6	7	0	54	13	67	6	46
61- 80	72	26040	20	4	1	57	0	2	0	0	11	12	0	84	24	108	6	47
81-100	89	8388	24	8	1	66	0	3	0	0	10	10	0	102	20	122	6	48
101-120	109	709	23	16	1	72	1	3	0	0	10	11	0	117	20	138	6	49
121-140	130	138	34	12	1	102	0	0	0	0	4	5	0	150	9	159	6	50
141-160	143	45	68	0	0	109	0	0	0	0	2	6	0	177	9	185	6	51
TOT/AVG	69	49192	18	4	1	51	0	2	0	0	9	10	0	76	19	95		

Own Polygon FMU Label Stocking
1 20 - 28 BF23

Age Class	Age	Area	Sb	Sw	Pj	Bf	Ce	Pw	Pr	Oc	Po	Bw	Oh	SWD	HWD	TOTAL	FMU	CLASS
1- 20	11	271	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	52
21- 40	32	2404	0	0	3	0	0	0	0	0	2	0	0	3	2	5	7	53

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FOREST CLASS VOLUME SUMMARY (m3/Ha)

MANAGEMENT UNIT: 777 FOREST CLASS FILE: CLWIN.DBF YEAR: 1995

05/02/94

Age Class	Age	Area	Sb	Sw	Pj	Bf	Ce	Pw	Pr	Oc	Po	Bw	Oh	SWD	HWD	TOTAL	FMU	CLASS
41- 60	55	957	1	0	1	3	0	0	0	0	6	2	0	6	8	14	7	54
61- 80	69	461	7	0	1	25	0	0	0	0	9	4	0	32	12	45	7	55
81-100	94	316	13	2	2	38	0	0	0	0	13	9	0	57	22	79	7	56
101-120	110	52	18	0	0	44	1	0	0	0	0	1	0	63	1	65	7	57
121-140	133	13	12	0	0	73	7	0	0	0	24	0	0	93	24	116	7	58
TOT/AVG	45	4474	2	0	2	7	0	0	0	0	4	2	0	11	6	17		

Own Polygon FMU Label Stocking
1 20 - 28 SPLOW

Age Class	Age	Area	Sb	Sw	Pj	Bf	Ce	Pw	Pr	Oc	Po	Bw	Oh	SWD	HWD	TOTAL	FMU	CLASS
1- 20	19	10109	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	59
21- 40	29	13611	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	60
41- 60	50	4299	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	61
61- 80	73	3896	50	0	0	0	0	0	0	0	0	0	0	51	0	51	8	62
81-100	93	7439	87	0	0	0	0	0	0	1	0	0	0	88	0	88	8	63
101-120	110	9540	117	0	0	0	0	0	0	1	0	0	0	118	0	118	8	64
121-140	135	12188	140	0	0	0	1	0	0	1	0	0	0	142	0	142	8	65
141-160	154	10137	77	0	0	0	2	0	0	1	0	0	0	80	0	80	8	66
161-180	169	3028	95	0	0	0	2	0	0	1	0	0	0	98	0	98	8	67
TOT/AVG	88	74247	64	0	0	0	1	0	0	1	0	0	0	65	0	65		

Own Polygon FMU Label Stocking
1 20 - 28 SPUP

Age Class	Age	Area	Sb	Sw	Pj	Bf	Ce	Pw	Pr	Oc	Po	Bw	Oh	SWD	HWD	TOTAL	FMU	CLASS
1- 20	14	6415	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	68
21- 40	30	24106	0	0	2	0	0	0	0	0	1	1	0	2	2	4	9	69
41- 60	51	13208	1	0	2	0	0	0	0	0	3	2	0	3	5	9	9	70
61- 80	74	17498	72	1	14	11	0	0	0	0	10	5	0	99	15	114	9	71
81-100	93	25765	102	1	18	13	0	0	0	0	11	4	0	135	15	150	9	72
101-120	110	19064	99	2	9	17	0	1	0	0	10	4	0	129	15	143	9	73
121-140	134	12111	78	5	3	17	1	1	0	0	7	2	0	105	10	115	9	74
141-160	153	6204	70	3	2	13	2	1	0	0	4	2	0	91	6	97	9	75
161-180	168	667	58	2	1	6	1	1	0	0	4	1	0	69	5	74	9	76
181-200	190	19	50	0	2	1	0	0	0	0	11	0	0	54	11	64	9	77
TOT/AVG	80	125057	58	1	8	9	0	0	0	0	7	3	0	77	10	87		

Own Polygon FMU Label Stocking
1 20 - 28 MIXED

Age Class	Age	Area	Sb	Sw	Pj	Bf	Ce	Pw	Pr	Oc	Po	Bw	Oh	SWD	HWD	TOTAL	FMU	CLASS
1- 20	9	84908	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	78
21- 40	26	7133	0	0	1	0	0	0	0	0	3	0	0	1	3	4	10	79

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FOREST CLASS VOLUME SUMMARY (m3/Ha)

MANAGEMENT UNIT: 777 FOREST CLASS FILE: CLWIN.DBF YEAR: 1995

05/02/94

Age Class	Age	Area	Sb	Sw	Pj	Bf	Ce	Pw	Pr	Oc	Po	Bw	Oh	SWD	HWD	TOTAL	FMU	CLASS
41- 60	55	3484	15	1	9	15	0	0	0	0	24	13	0	40	36	76	10	80
61- 80	72	13269	21	2	35	24	0	1	0	0	72	29	0	83	101	184	10	81
81-100	91	8477	43	3	16	23	0	0	0	0	41	17	0	86	58	144	10	82
101-120	109	3450	62	3	14	19	0	0	0	0	39	14	0	98	53	151	10	83
121-140	133	1422	62	12	4	19	0	0	0	0	26	10	0	99	36	135	10	84
141-160	153	233	49	5	2	25	0	2	0	0	18	7	0	81	25	106	10	85
TOT/AVG	28	122376	8	1	6	5	0	0	0	0	13	5	0	20	18	38		

SILVICULTURE CARD LISTING

CRITERIA NAME - ORIGIN

FOREST CLASS FILE: CLORIGIN.DBF YIELD FILES: PRORIGIN.DBF, FCORIGIN.DBF COST FILE: CSORIGIN.DBF

12/28/94

CARD # 0001

AGGREGATION CRITERIA

FormanMU Label
BF23

PRESENT CURVE INFO

Operability Limits (Age): Min - 50 Max - 90 % Available: 100.00 Y-Factor: 100.00

FUTURE CURVE INFO

Future Curve	Species Composition	Stk	Site Class	Plt Crv	COST / HA S/P	Regen	Tend	Priority	Age/Time Reference	Operability Ages Min	Max
INTENSIVE	SB 6PO 2BF 1BW 1	0.8	2	N	255	540	120	4	10	70	140
BASIC	PJ 6PO 2SB 1BW 1	0.7	2	N	255	100	120	8	10	70	120
NATURAL	PO 4BW 3BF 2SB 1	0.6	2	N					10	65	120
NSR / B&S											
SPACING											

CARD # 0002

AGGREGATION CRITERIA

FormanMU Label
BFX1

PRESENT CURVE INFO

Operability Limits (Age): Min - 50 Max - 90 % Available: 100.00 Y-Factor: 100.00

FUTURE CURVE INFO

Future Curve	Species Composition	Stk	Site Class	Plt Crv	COST / HA S/P	Regen	Tend	Priority	Age/Time Reference	Operability Ages Min	Max
INTENSIVE	SB 6PO 2BF 1BW 1	0.8	1	N	255	540	120	3	10	70	140
BASIC	PJ 6PO 2SB 1PO 1	0.7	1	N	255	100	120	7	10	70	120
NATURAL	PO 4BW 3BF 2SB 1	0.6	1	N					10	65	120
NSR / B&S											
SPACING											

SILVICULTURE CARD LISTING

CRITERIA NAME - ORIGIN

FOREST CLASS FILE: CLORIGIN.DBF YIELD FILES: PRORIGIN.DBF, FCORIGIN.DBF COST FILE: CSORIGIN.DBF 12/28/94

CARD # 0003

AGGREGATION CRITERIA FormanMU Label
BWALL

PRESENT CURVE INFO
Operability Limits (Age): Min - 65 Max - 101 % Available: 100.00 Y-Factor: 100.00

FUTURE CURVE INFO

Future Curve	Species Composition	Stk	Site Class	Plt Crv	COST / HA S/P	Regen	Tend	Priority	Age/Time Reference	Operability Ages Min	Max
INTENSIVE											
BASIC											
NATURAL	PO 5BW 3SB 1PJ 1	0.7	2	N					10	65	120
NSR / B&S											
SPACING											

CARD # 0004

AGGREGATION CRITERIA FormanMU Label
MIXED

PRESENT CURVE INFO
Operability Limits (Age): Min - 70 Max - 140 % Available: 100.00 Y-Factor: 100.00

FUTURE CURVE INFO

Future Curve	Species Composition	Stk	Site Class	Plt Crv	COST / HA S/P	Regen	Tend	Priority	Age/Time Reference	Operability Ages Min	Max
INTENSIVE	SB 6PO 3BW 1	0.7	1	N	255	540	240	12	10	70	140
BASIC	PJ 5PO 3BW 1SB 1	0.8	2	N	255	100	120	10	10	70	120
NATURAL	PO 5BW 3SB 1BF 1	0.8	2	N					10	65	120
NSR / B&S											
SPACING											

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SILVICULTURE CARD LISTING

CRITERIA NAME - ORIGIN

FOREST CLASS FILE: CLORIGIN.DBF   YIELD FILES: PRORIGIN.DBF, FCORIGIN.DBF   COST FILE: CSORIGIN.DBF   12/28/94

CARD # 0005

AGGREGATION CRITERIA   FormanMU Label
PJ23

PRESENT CURVE INFO   Operability Limits (Age): Min - 70 Max - 120   % Available: 100.00   Y-Factor: 100.00

FUTURE CURVE INFO

Future Curve	Species Composition	Stk	Site Class	Plt Crv	COST / HA S/P	Regen	Tend	Priority	Age/Time Reference	Operability Ages Min	Max
INTENSIVE	PJ 7PO 2BW 1	0.8	2	N	255	70	120	7	5	70	120
BASIC	PJ 6PO 3SB 1	0.7	2	N	255	70	120	3	5	70	120
NATURAL	PO 6BW 3SB 1	0.8	2	N					5	65	120
NSR / B&S											
SPACING											

CARD # 0006

AGGREGATION CRITERIA   FormanMU Label
PJX1

PRESENT CURVE INFO   Operability Limits (Age): Min - 70 Max - 120   % Available: 100.00   Y-Factor: 100.00

FUTURE CURVE INFO

Future Curve	Species Composition	Stk	Site Class	Plt Crv	COST / HA S/P	Regen	Tend	Priority	Age/Time Reference	Operability Ages Min	Max
INTENSIVE	PJ 7PO 2BW 1	0.8	1	N	255	500	120	5	5	70	120
BASIC	PJ 7PO 2SB 1	0.6	1	N	255	70	120	2	5	70	120
NATURAL	PO 6BW 3SB 1	0.7	1	N					5	65	120
NSR / B&S											
SPACING											

SILVICULTURE CARD LISTING

CRITERIA NAME - ORIGIN

FOREST CLASS FILE: CLORIGIN.DBF YIELD FILES: PRORIGIN.DBF, FCORIGIN.DBF COST FILE: CSORIGIN.DBF 12/28/94

CARD # 0007

AGGREGATION CRITERIA FormanMU Label
P023

PRESENT CURVE INFO
Operability Limits (Age): Min - 65 Max - 120 % Available: 100.00 Y-Factor: 100.00

FUTURE CURVE INFO

Future Curve	Species Composition	Stk	Site Class	Plt Crv	COST / HA S/P	COST / HA Regen	COST / HA Tend	Priority	Age/Time Reference	Operability Ages Min	Operability Ages Max
INTENSIVE BASIC NATURAL NSR / B&S SPACING	PO 6BW 2SB 1BF 1	0.7	2	N					5	65	120

CARD # 0008

AGGREGATION CRITERIA FormanMU Label
POX1

PRESENT CURVE INFO
Operability Limits (Age): Min - 65 Max - 120 % Available: 100.00 Y-Factor: 100.00

FUTURE CURVE INFO

Future Curve	Species Composition	Stk	Site Class	Plt Crv	COST / HA S/P	COST / HA Regen	COST / HA Tend	Priority	Age/Time Reference	Operability Ages Min	Operability Ages Max
INTENSIVE BASIC NATURAL NSR / B&S SPACING	PO 7BW 2BF 1	0.8	1	N					5	65	120

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SILVICULTURE CARD LISTING

CRITERIA NAME - ORIGIN

FOREST CLASS FILE: CLORIGIN.DBF YIELD FILES: PRORIGIN.DBF, FCORIGIN.DBF COST FILE: CSORIGIN.DBF 12/28/94

CARD # 0009

AGGREGATION CRITERIA FormanMU Label
SPLOW

PRESENT CURVE INFO
Operability Limits (Age): Min - 100 Max - 140 % Available: 100.00 Y-Factor: 100.00

FUTURE CURVE INFO

Future Curve	Species Composition	Stk	Site Class	Plt Crv	COST / HA S/P	Regen	Tend	Priority	Age/Time Reference	Operability Ages Min	Max
INTENSIVE											
BASIC											
NATURAL	SB 90C 1	0.7	3	N					15	100	140
NSR / B&S											
SPACING											

CARD # 0010

AGGREGATION CRITERIA FormanMU Label
SPUP

PRESENT CURVE INFO
Operability Limits (Age): Min - 70 Max - 140 % Available: 100.00 Y-Factor: 100.00

FUTURE CURVE INFO

Future Curve	Species Composition	Stk	Site Class	Plt Crv	COST / HA S/P	Regen	Tend	Priority	Age/Time Reference	Operability Ages Min	Max
INTENSIVE	SB 6PO 3BW 1	0.9	2	N	255	540	120	1	10	55	140
BASIC	PJ 5PO 4BW 1	0.8	2	N	255	540	120	1	10	70	120
NATURAL	PO 3BW 2SB 2BF 2PJ 1	0.7	2	N					10	65	120
NSR / B&S											
SPACING											

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APPENDIX 3

FIGURE #3A RESIDUAL GROWING STOCK

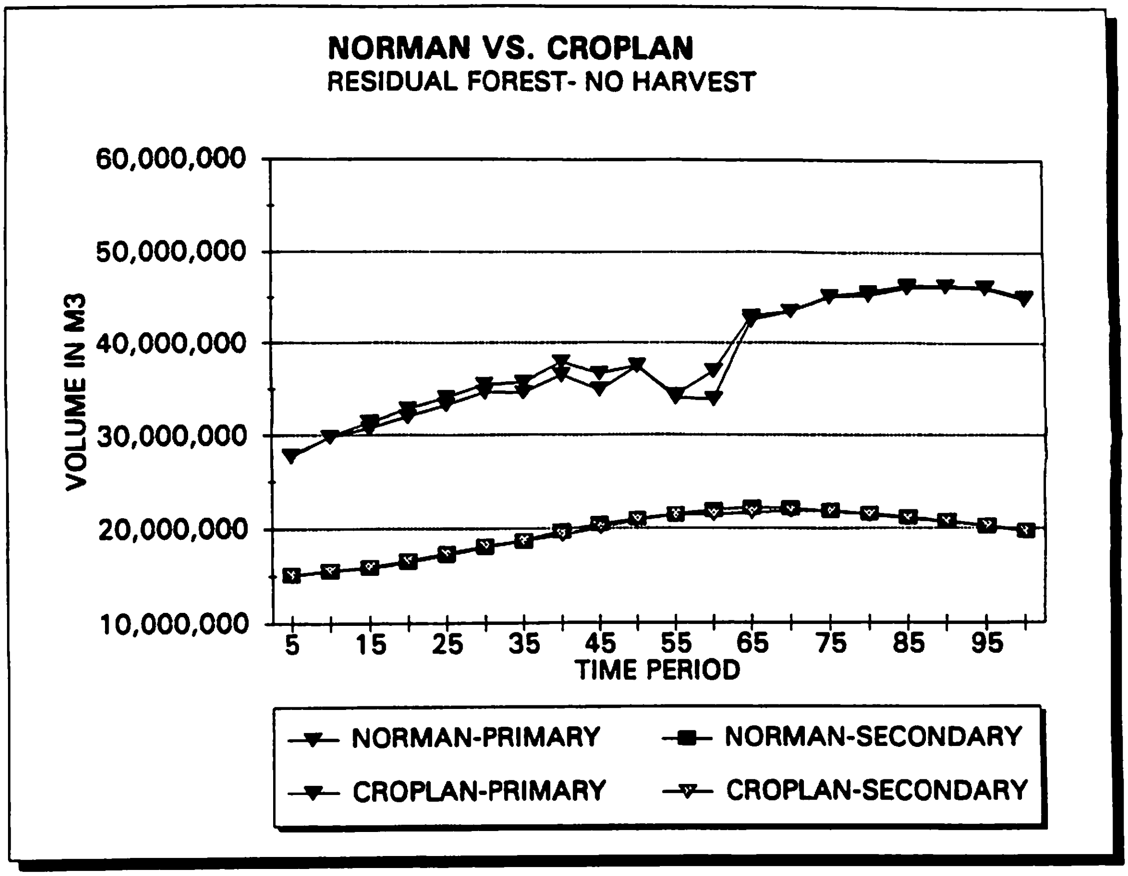
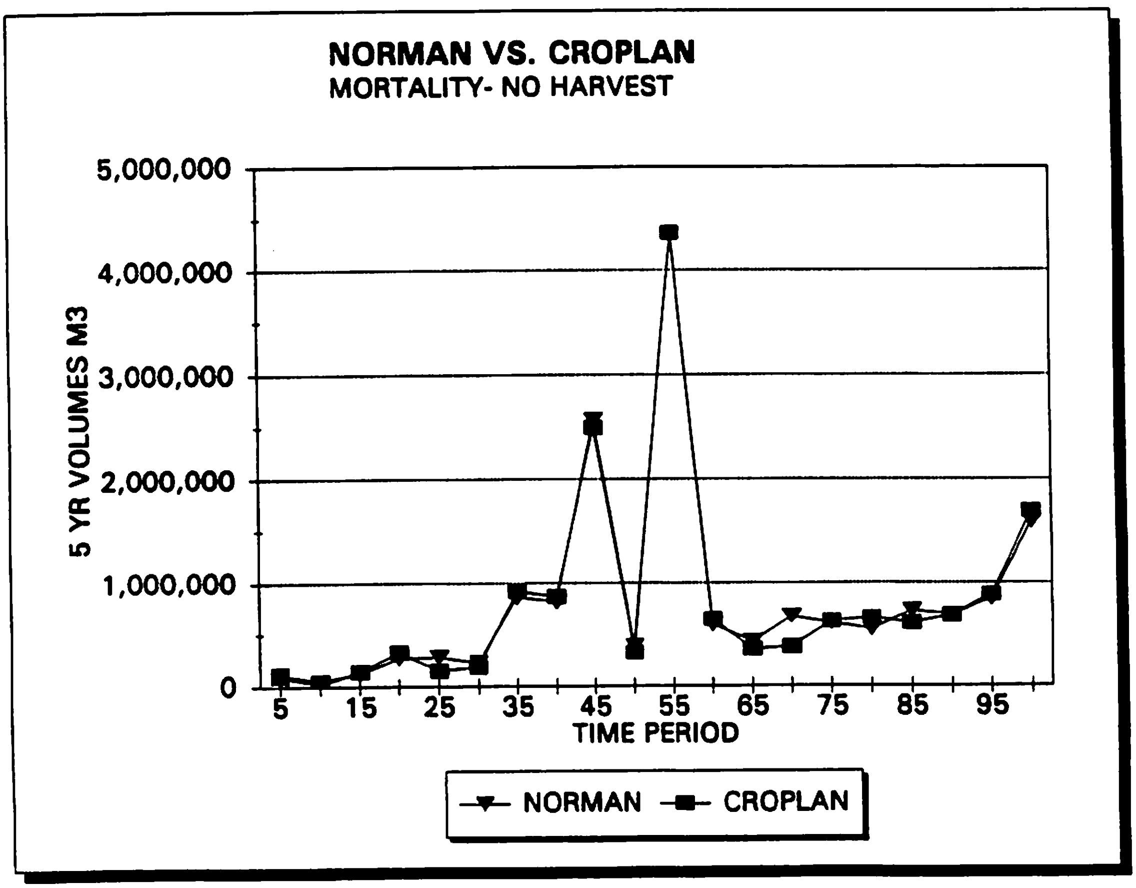
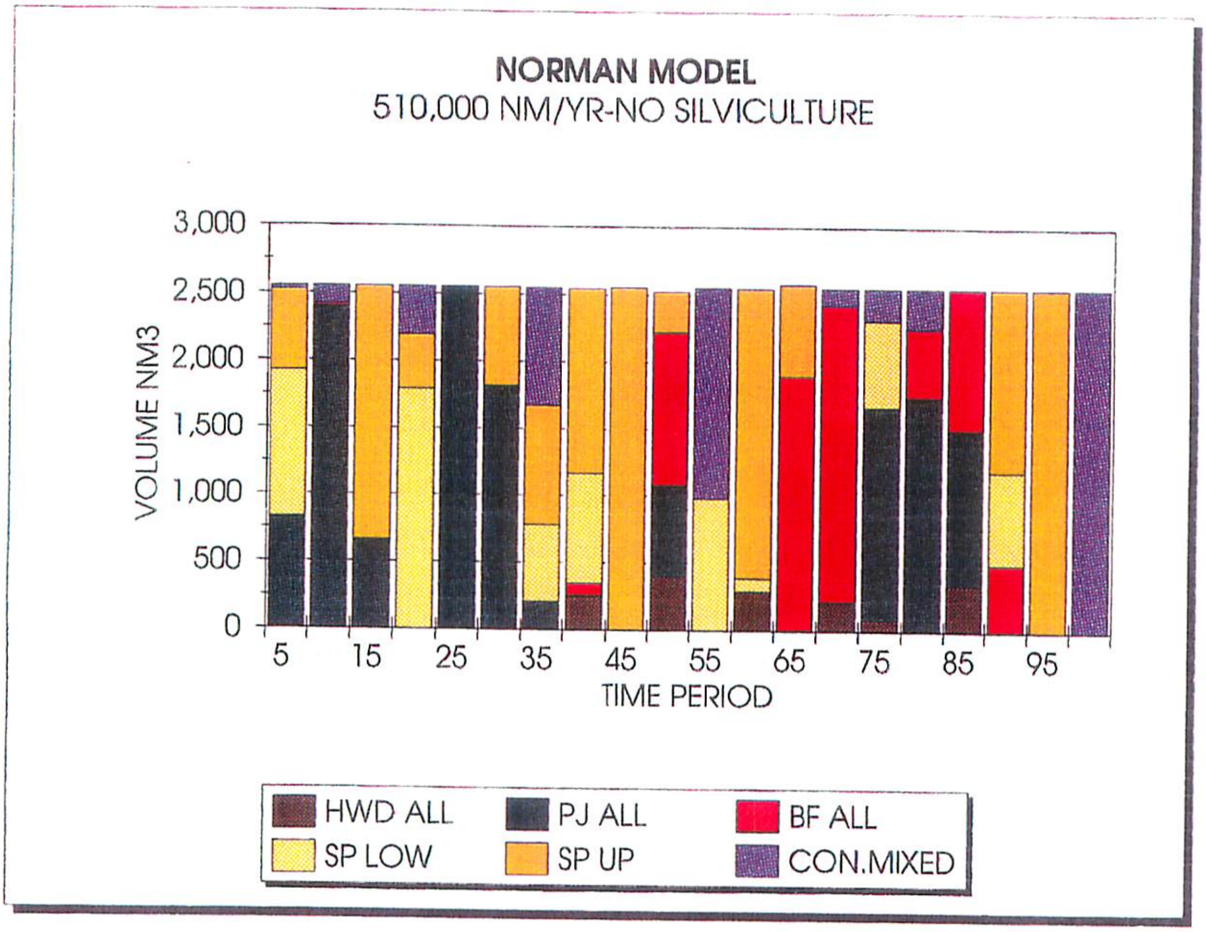


FIGURE #3B MORTALITY WITH NO HARVEST




NORMAN MODEL
510,000 NM/YR-NO SILVICULTURE
3,000
2,500
2,000
1,500
1,000
500
0
VOLUME NM3
5
15
25
35
45
55
65
75
85
95
TIME PERIOD
HWD ALL
PJ ALL
BF ALL
SP LOW
SP UP
CON.MIXED

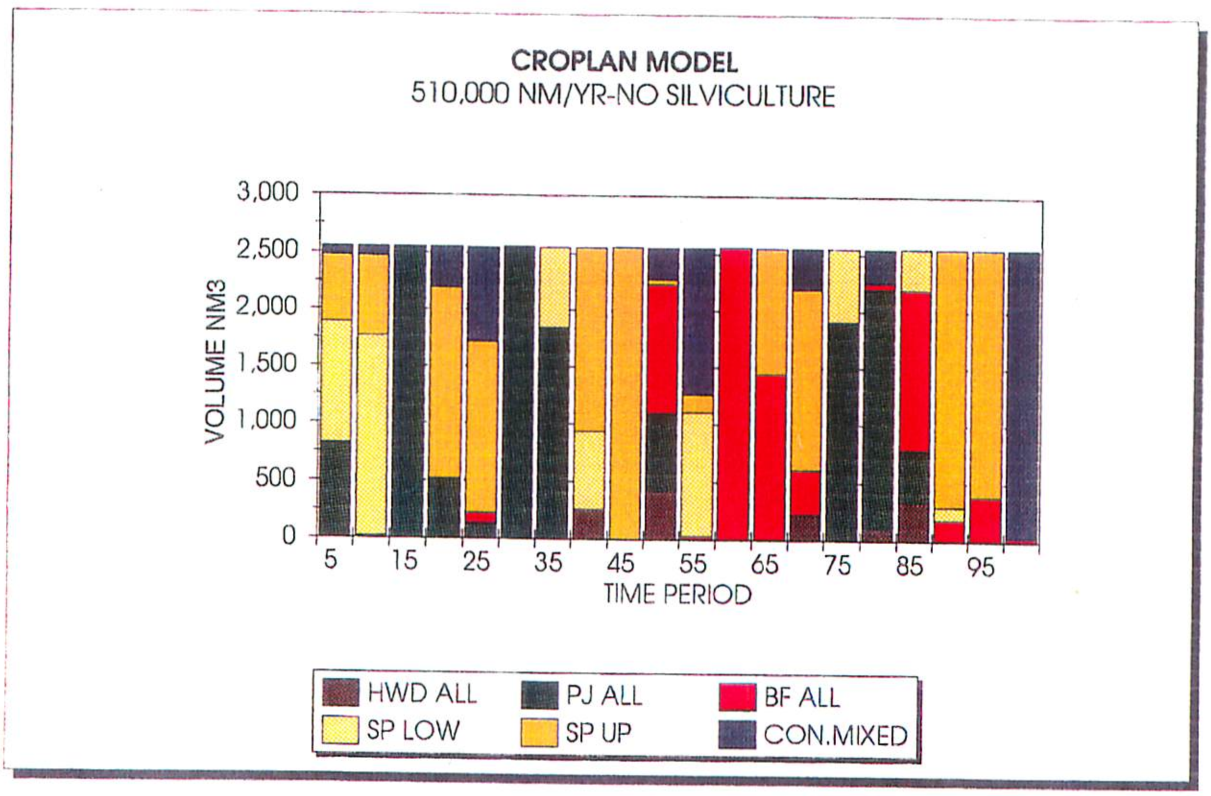
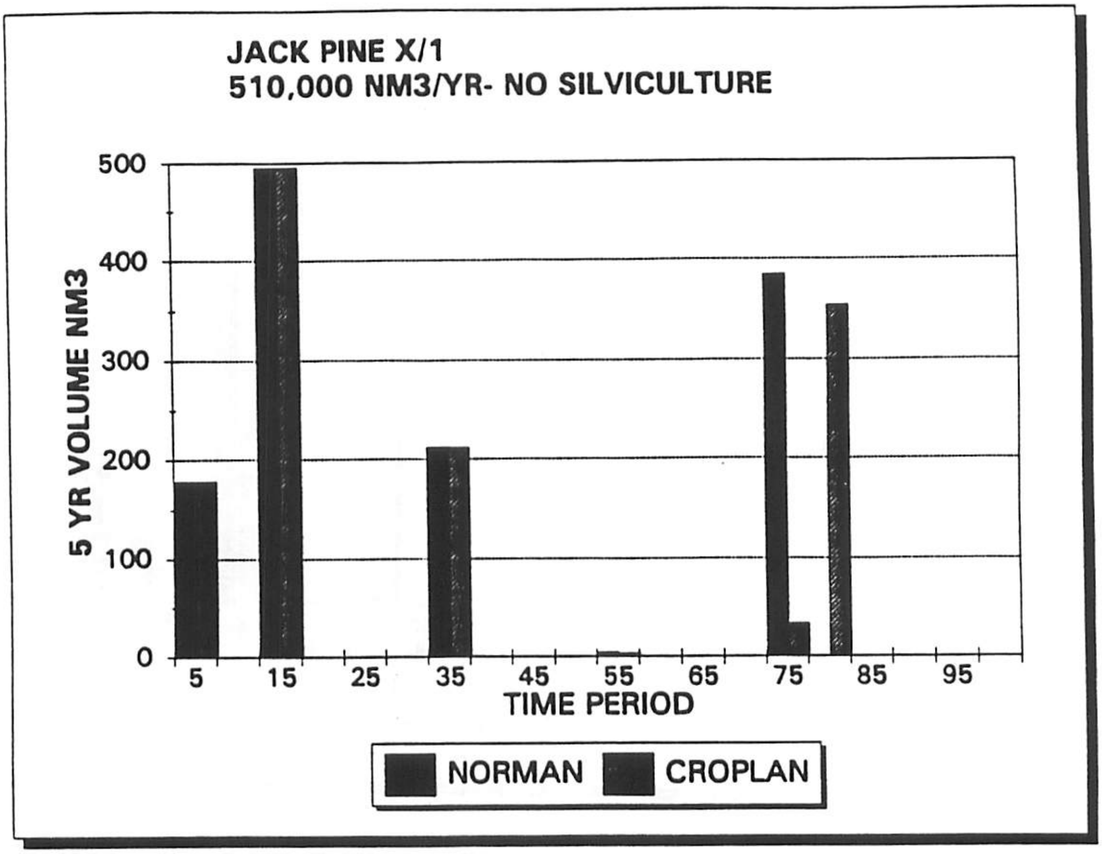

CROPLAN MODEL
510,000 NM/YR-NO SILVICULTURE
3,000
2,500
2,000
1,500
1,000
500
0
VOLUME NM3
5
15
25
35
45
55
65
75
85
95
TIME PERIOD
HWD ALL
PJ ALL
BF ALL
SP LOW
SP UP
CON.MIXED

FIGURE #3D HARVEST BY FMU'S DETAILED



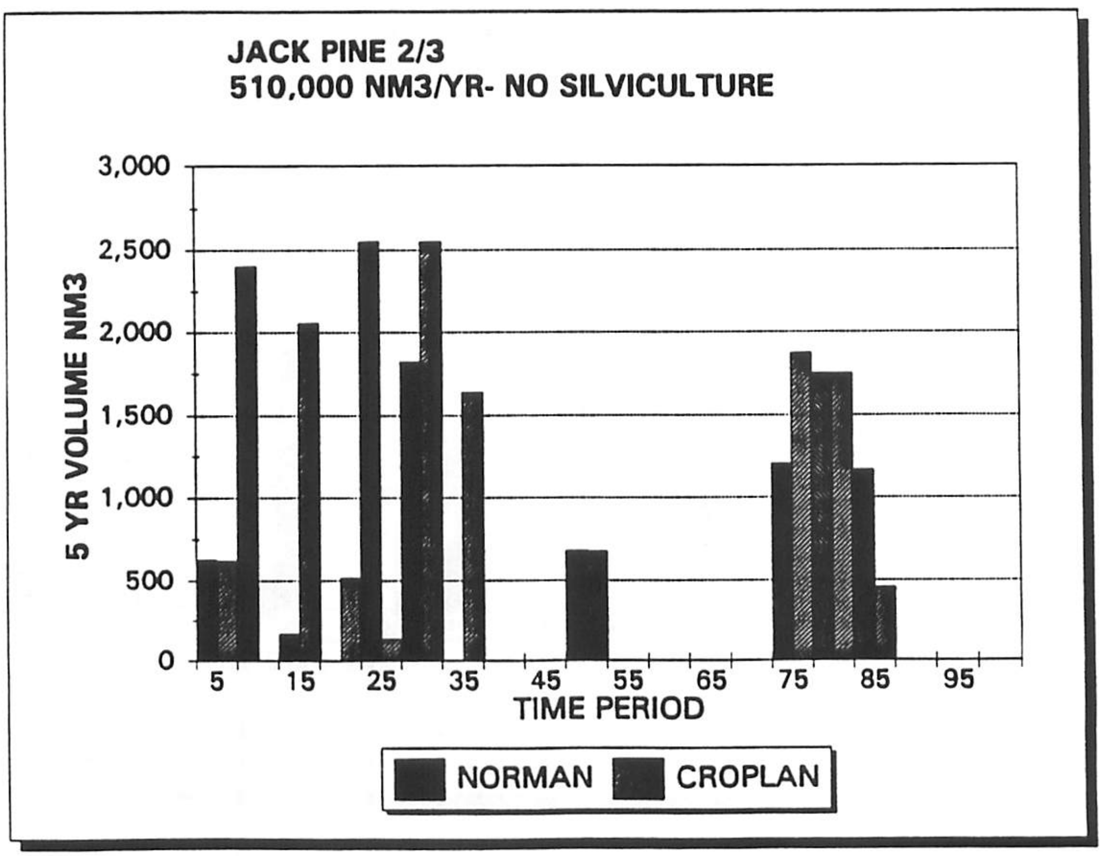
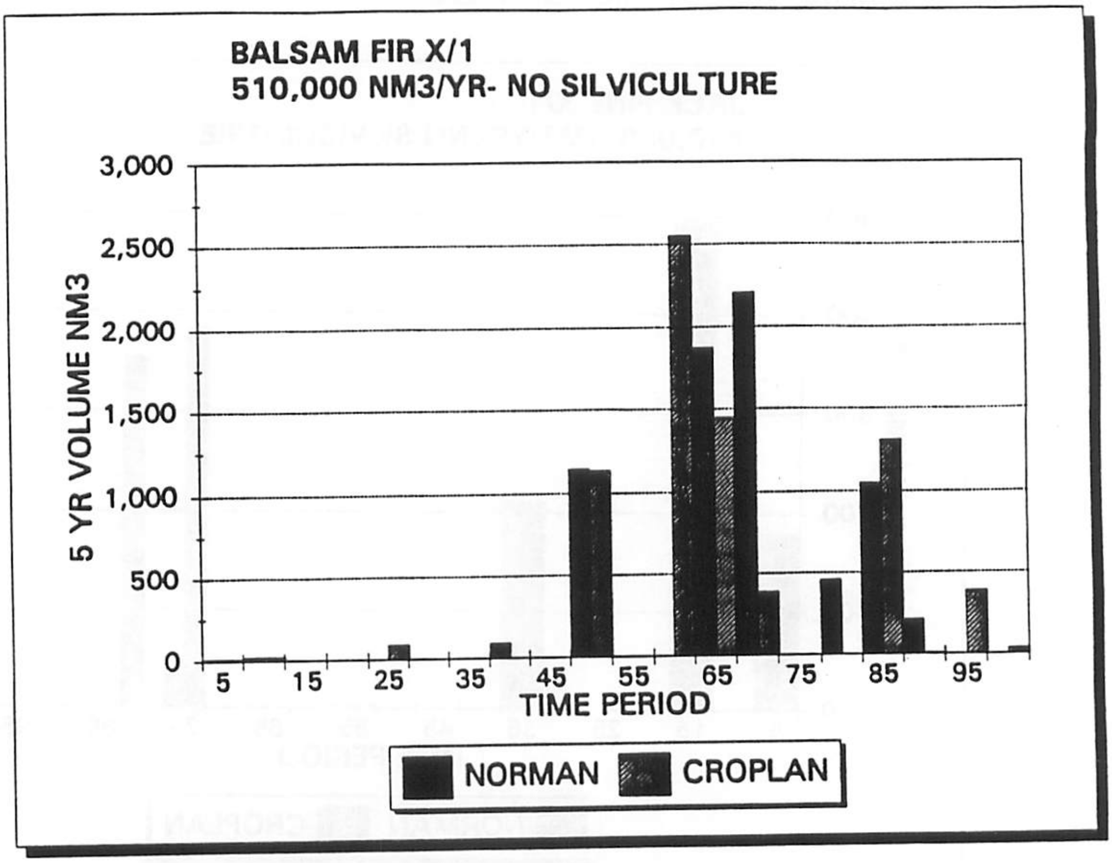


FIGURE #3E HARVEST BY FMU'S DETAILED



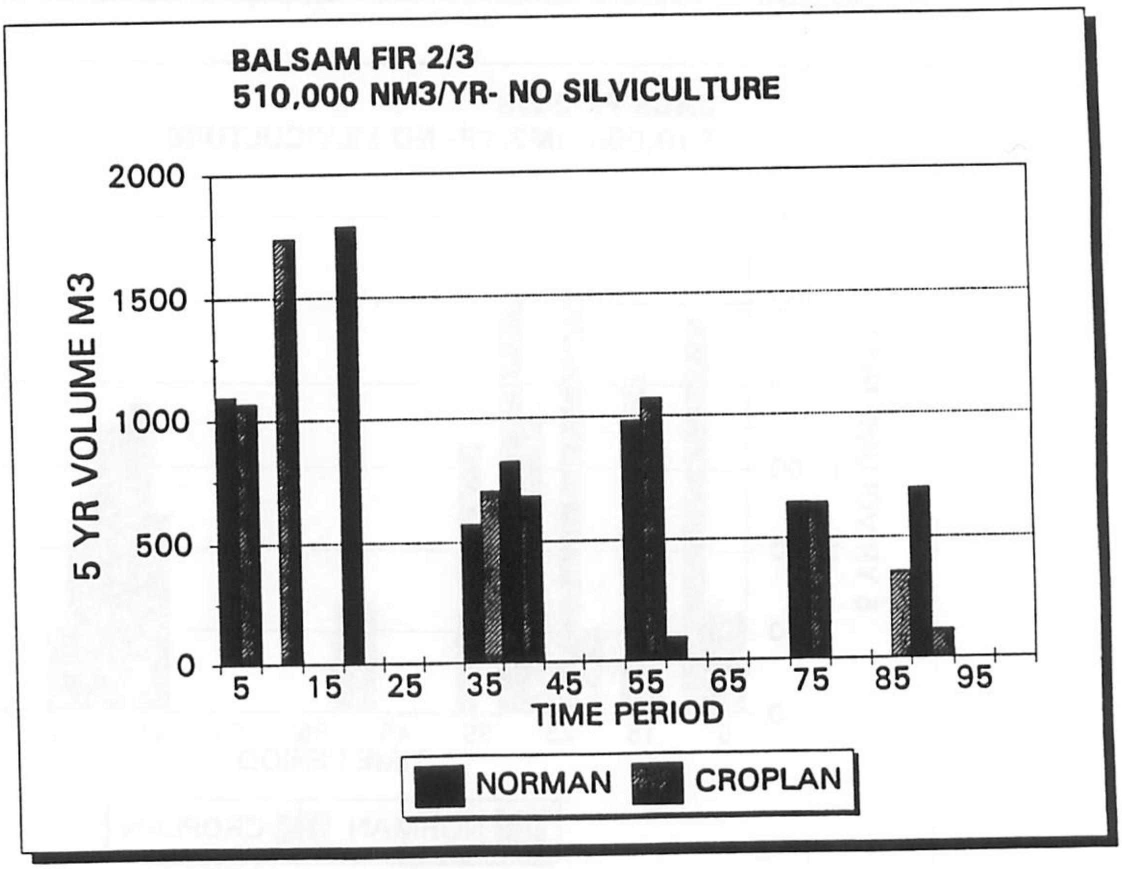
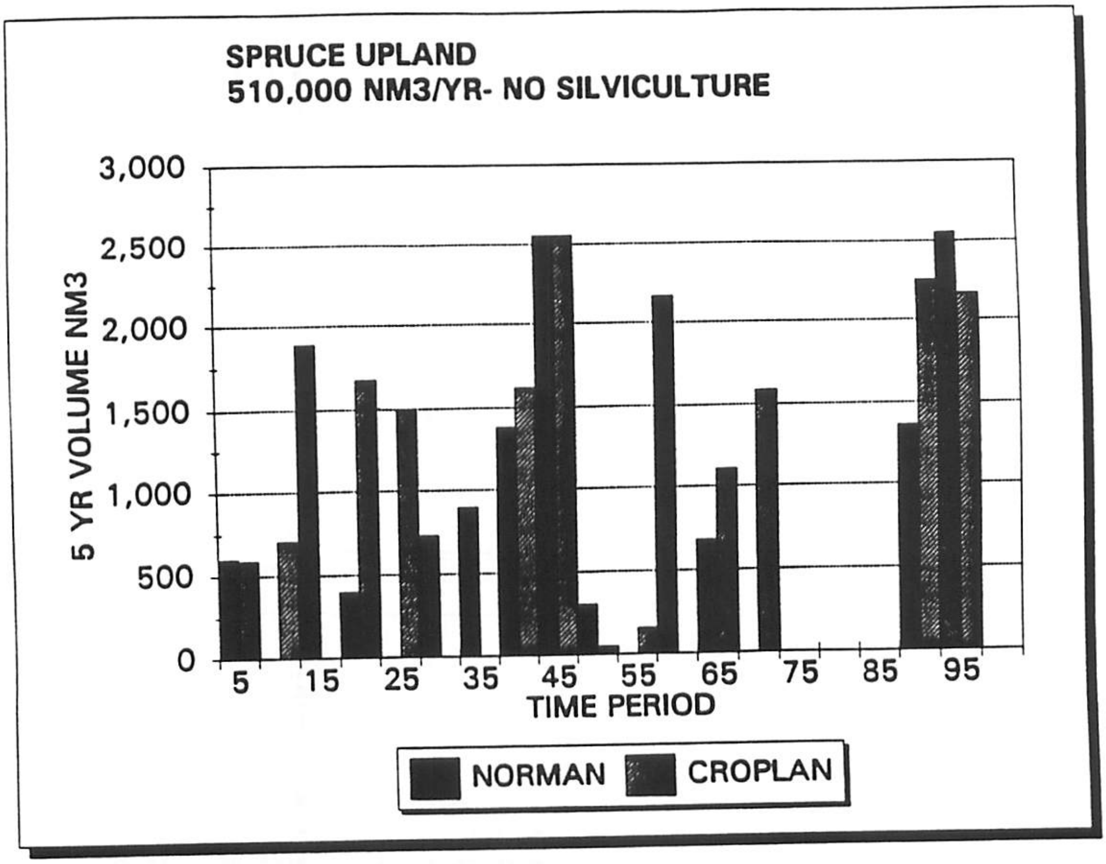


FIGURE #35 HARVEST BY FMU'S DETAILED



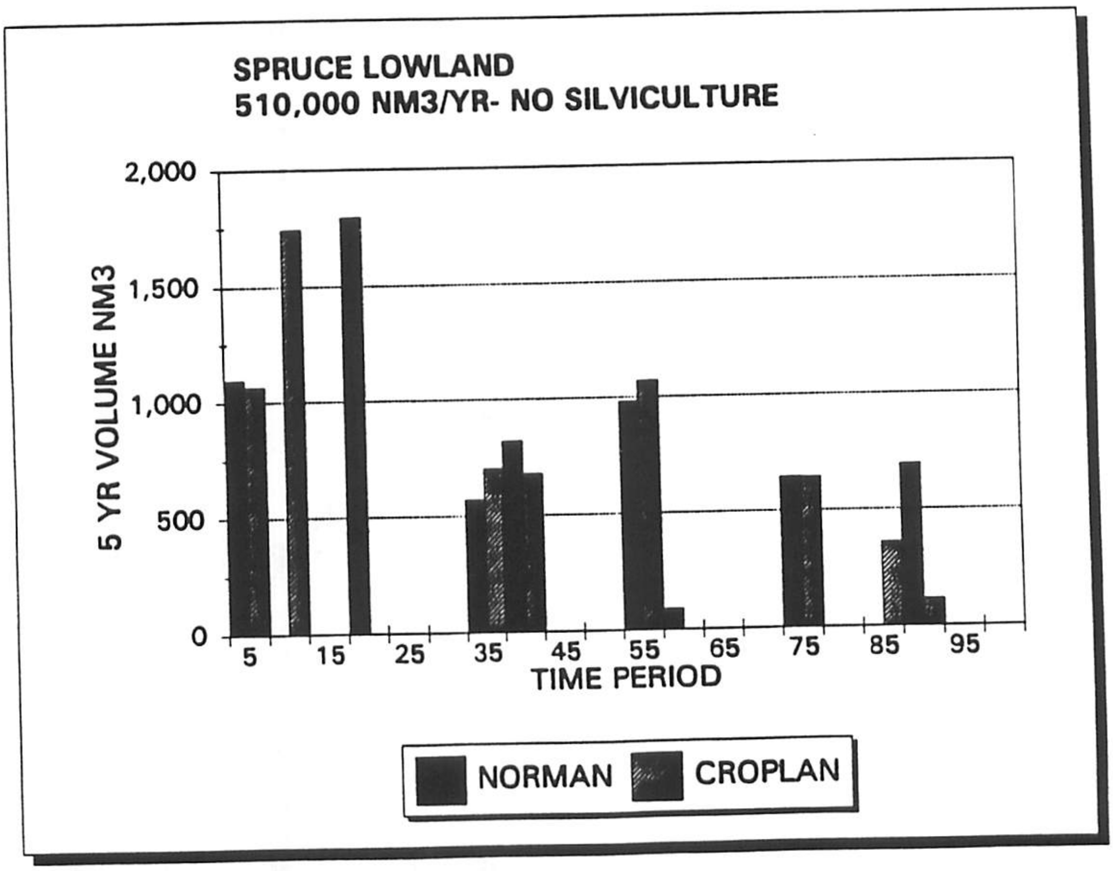
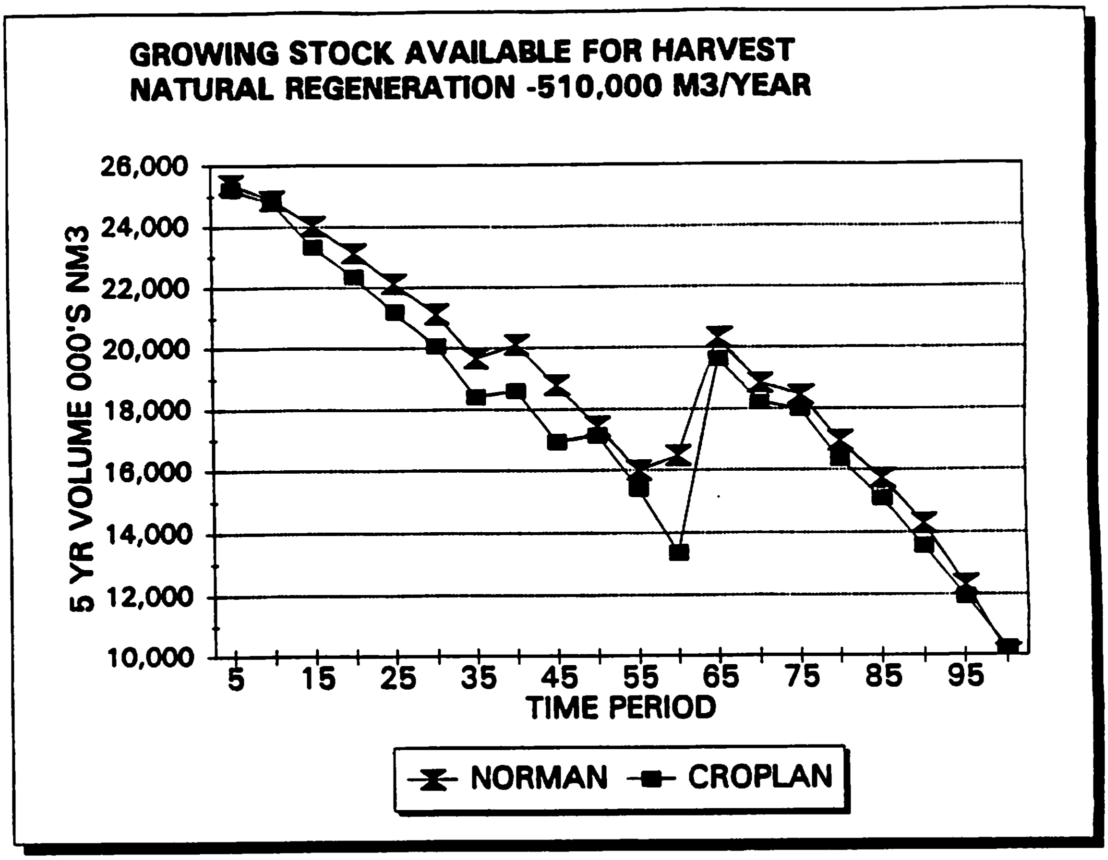


FIGURE #3G GROWING STOCK AVAILABLE-NATURAL REGENERATION



GROWING STOCK AVAILABLE-INTENSIVE REGENERATION

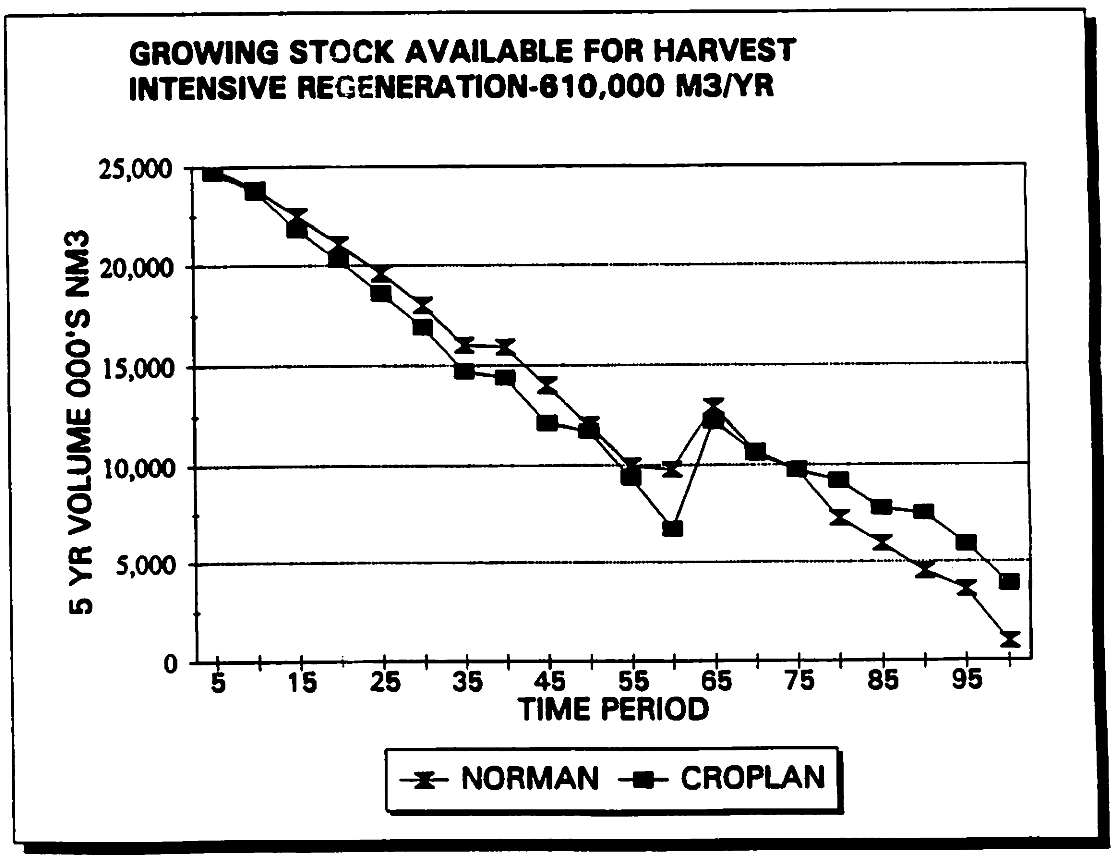
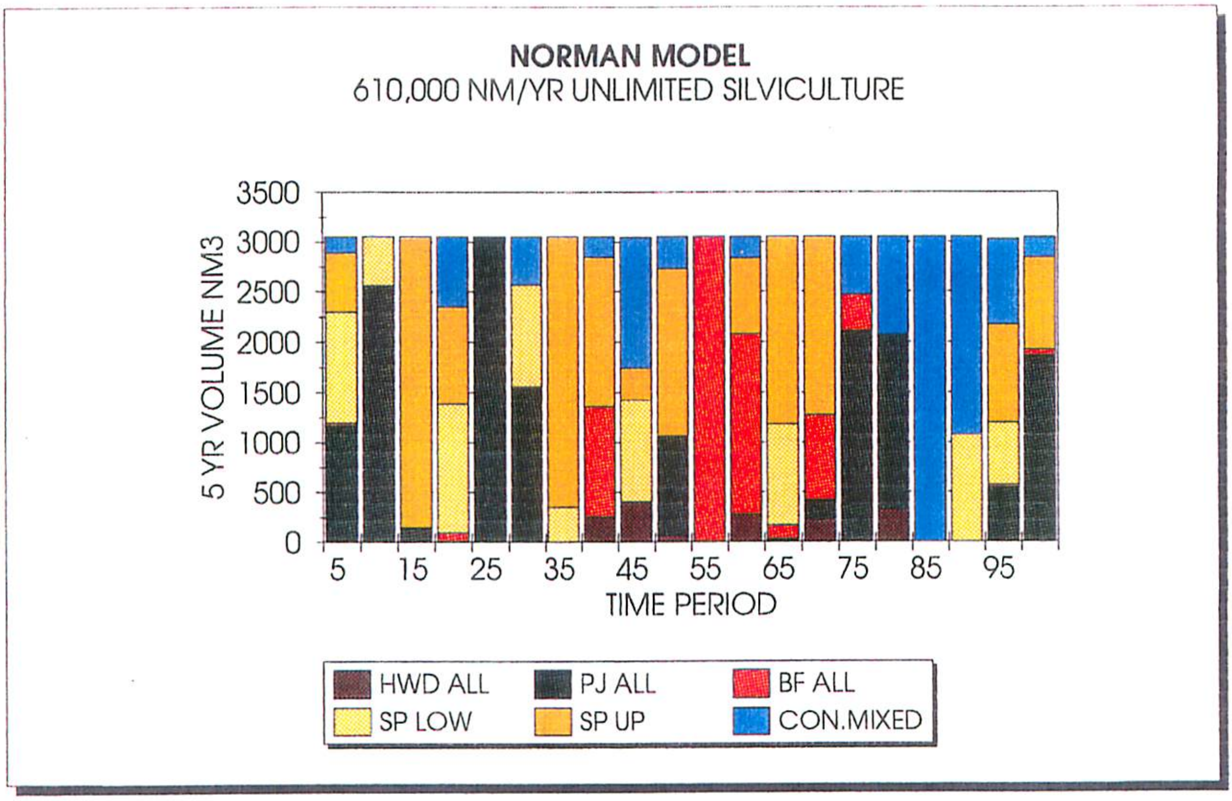


FIGURE #3H HARVEST BY FMU'S -UNLIMITED SILVICULTURE



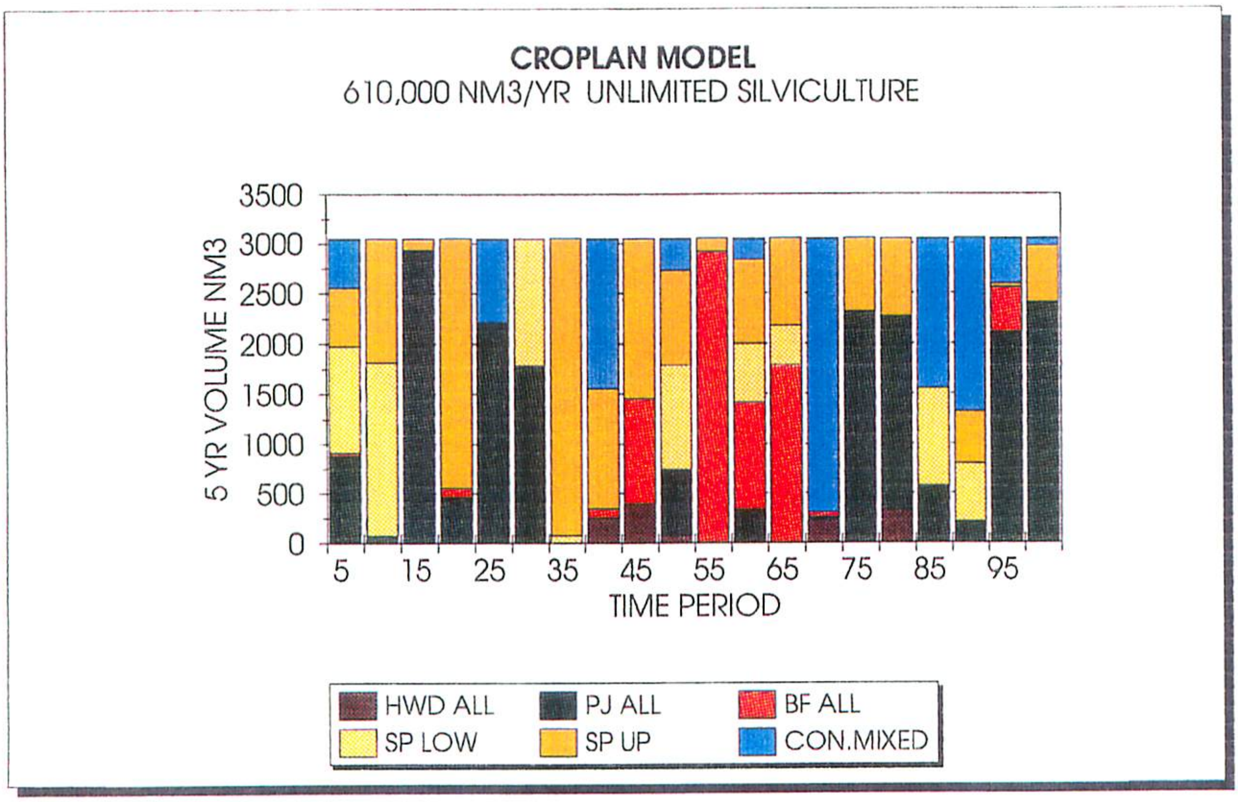
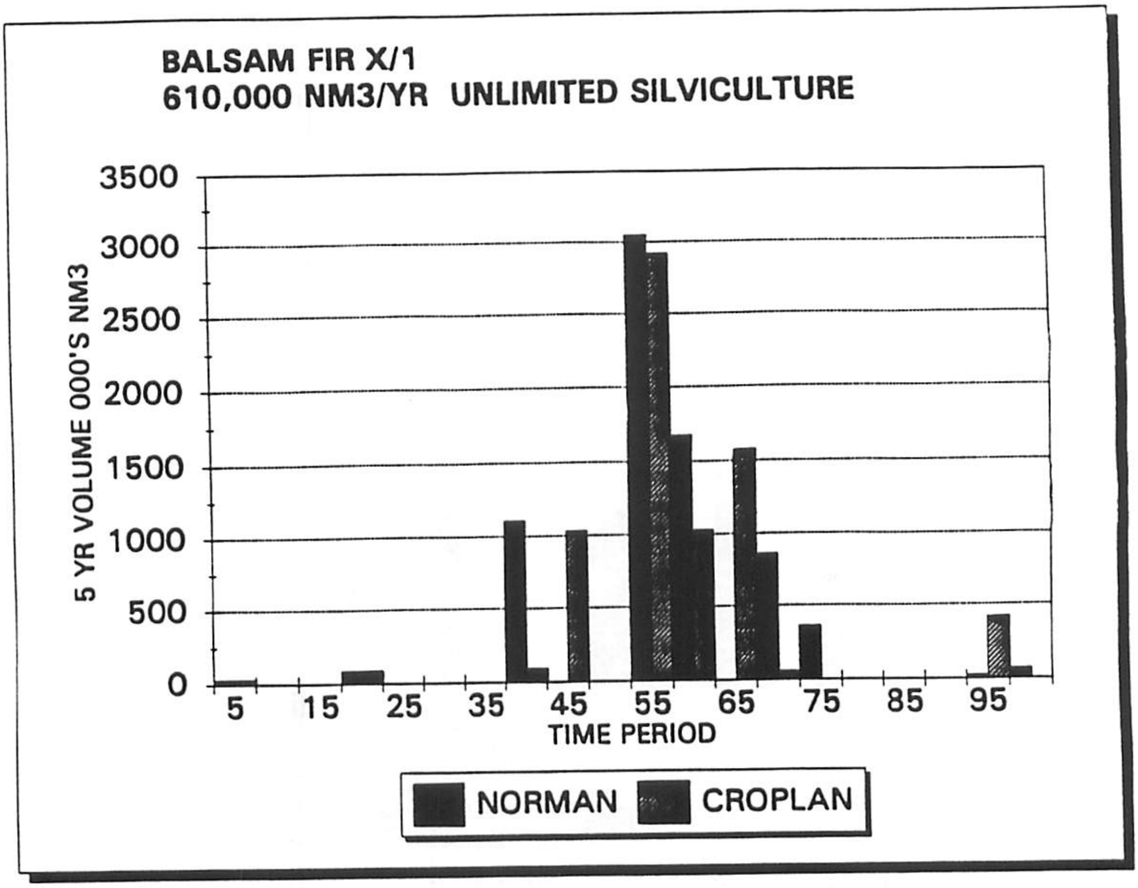
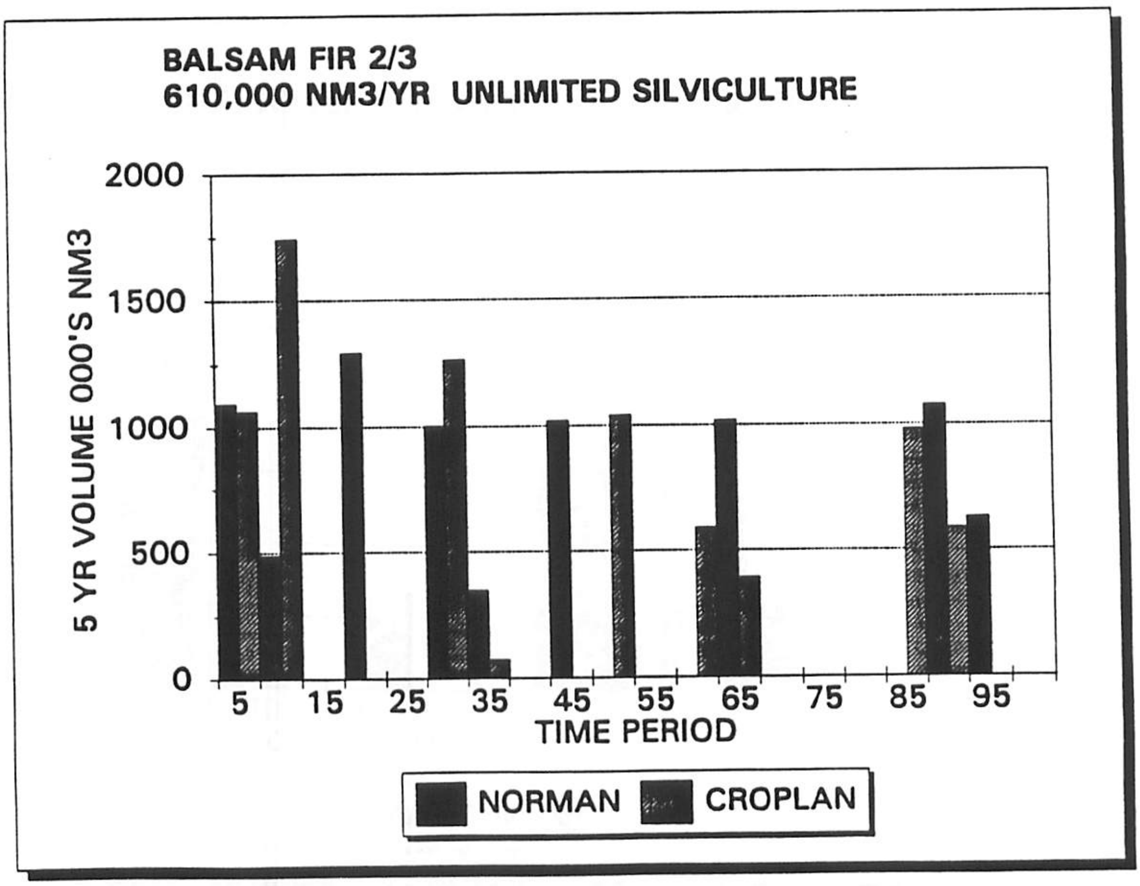
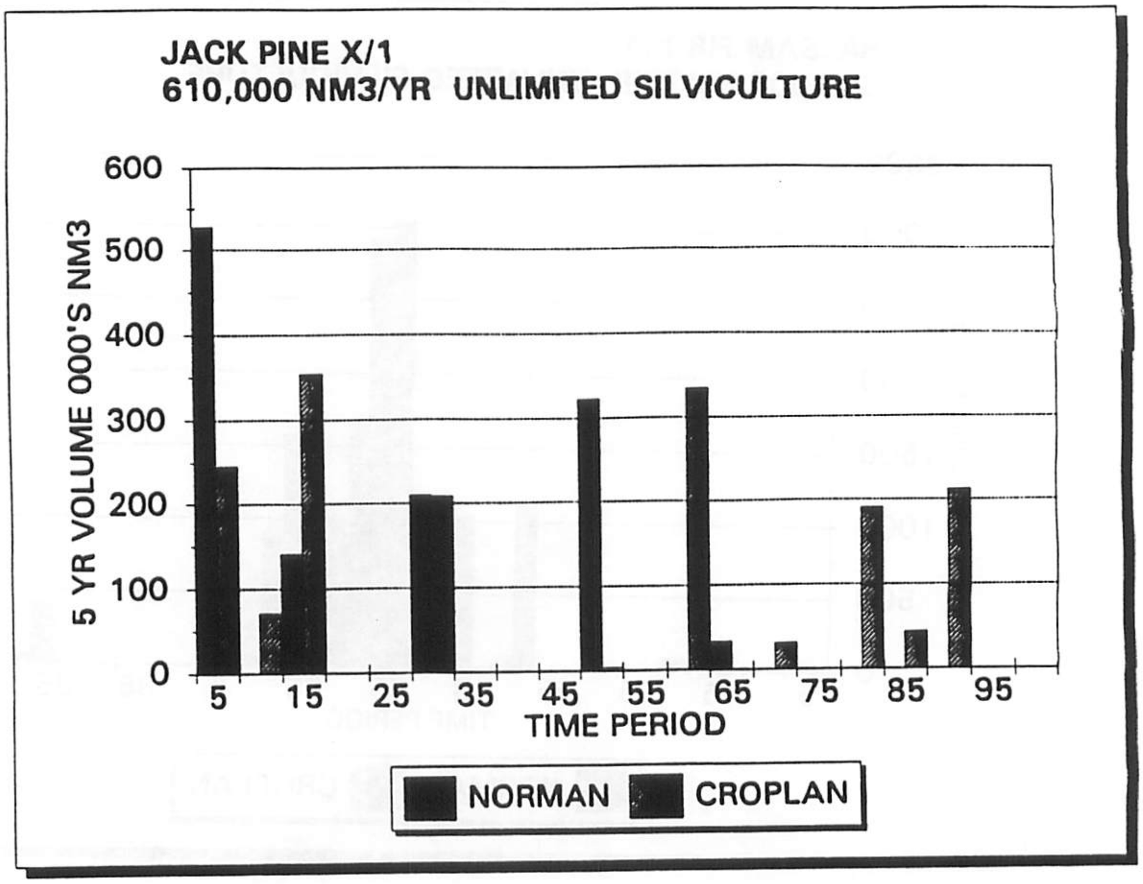


FIGURE #3I HARVEST BY FMU'S DETAILED






JACK PINE X/1
610,000 NM3/YR UNLIMITED SILVICULTURE
600
500
400
300
200
100
0
5 YR VOLUME 000'S NM3
5 15 25 35 45 55 65 75 85 95
TIME PERIOD
NORMAN
CROPLAN

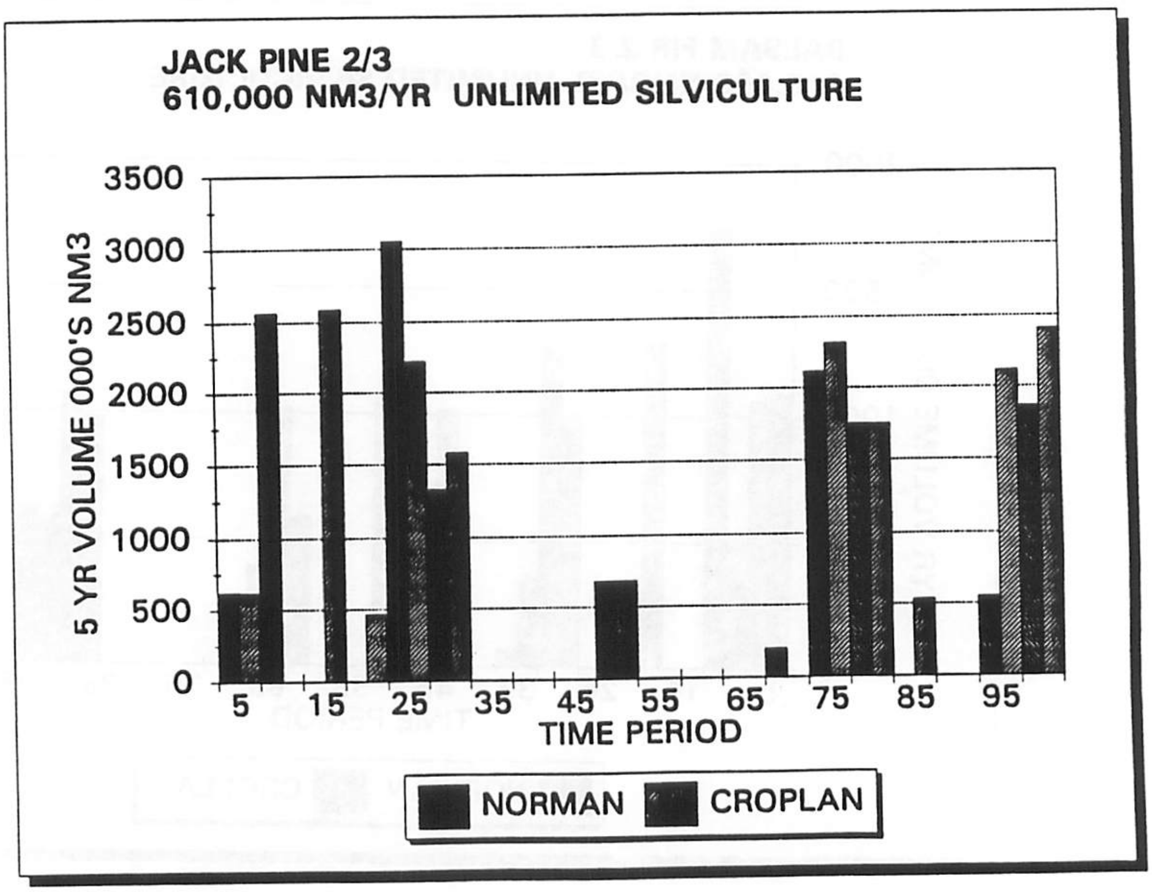
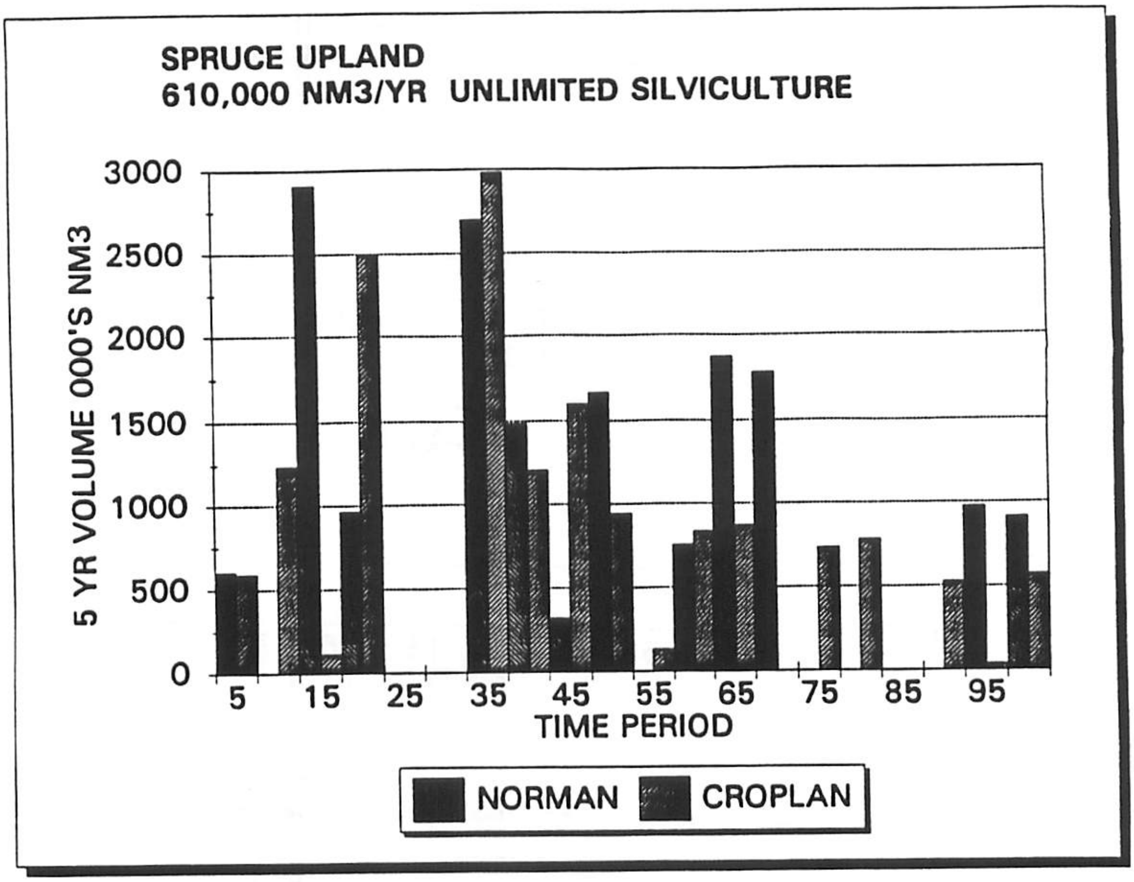

JACK PINE 2/3
610,000 NM3/YR UNLIMITED SILVICULTURE
3500
3000
2500
2000
1500
1000
500
0
5 YR VOLUME 000'S NM3
5 15 25 35 45 55 65 75 85 95
TIME PERIOD
NORMAN
CROPLAN

FIGURE #3K HARVEST BY FMU'S DETAILED



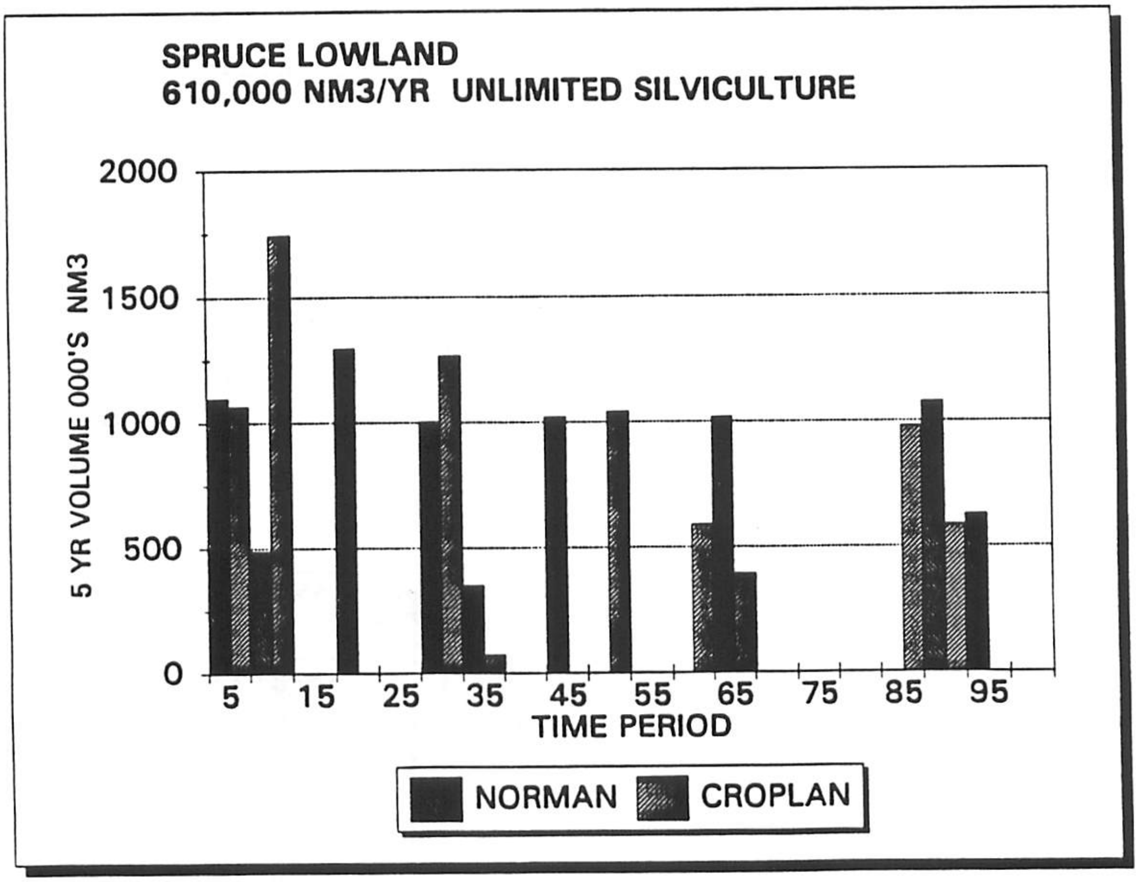
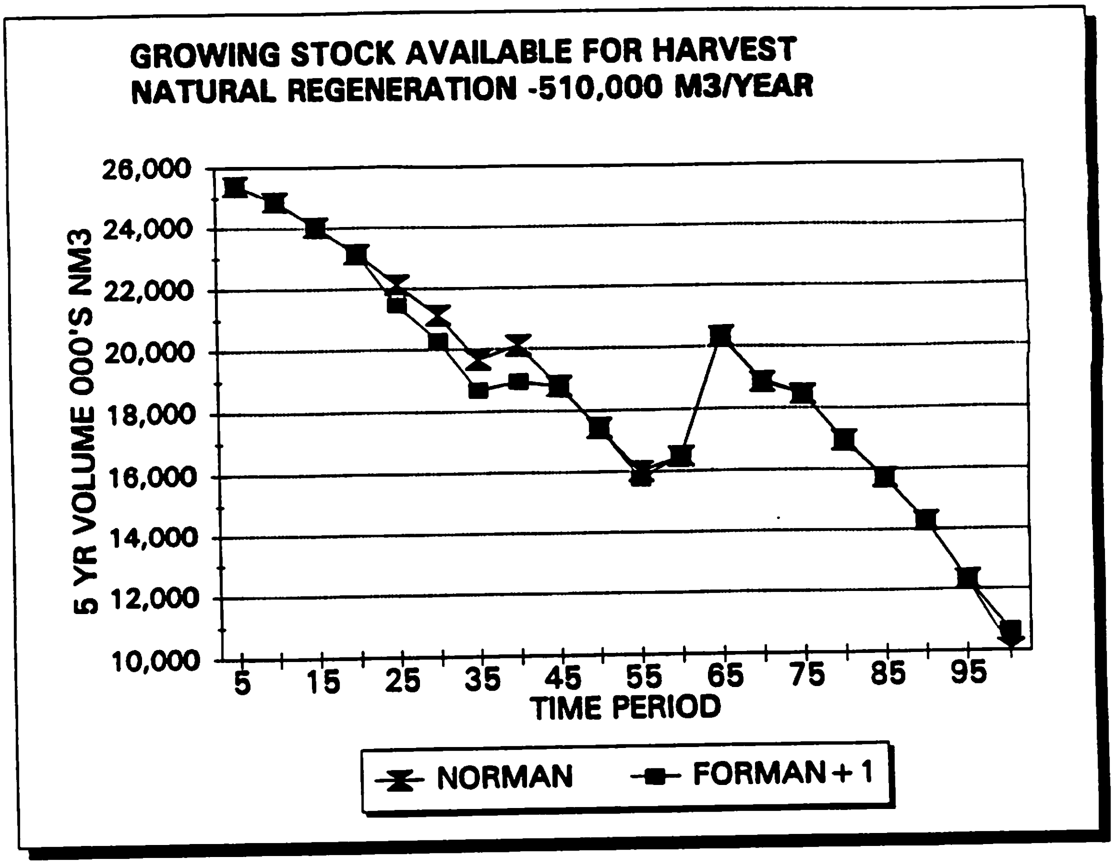


FIGURE #3L GROWING STOCK



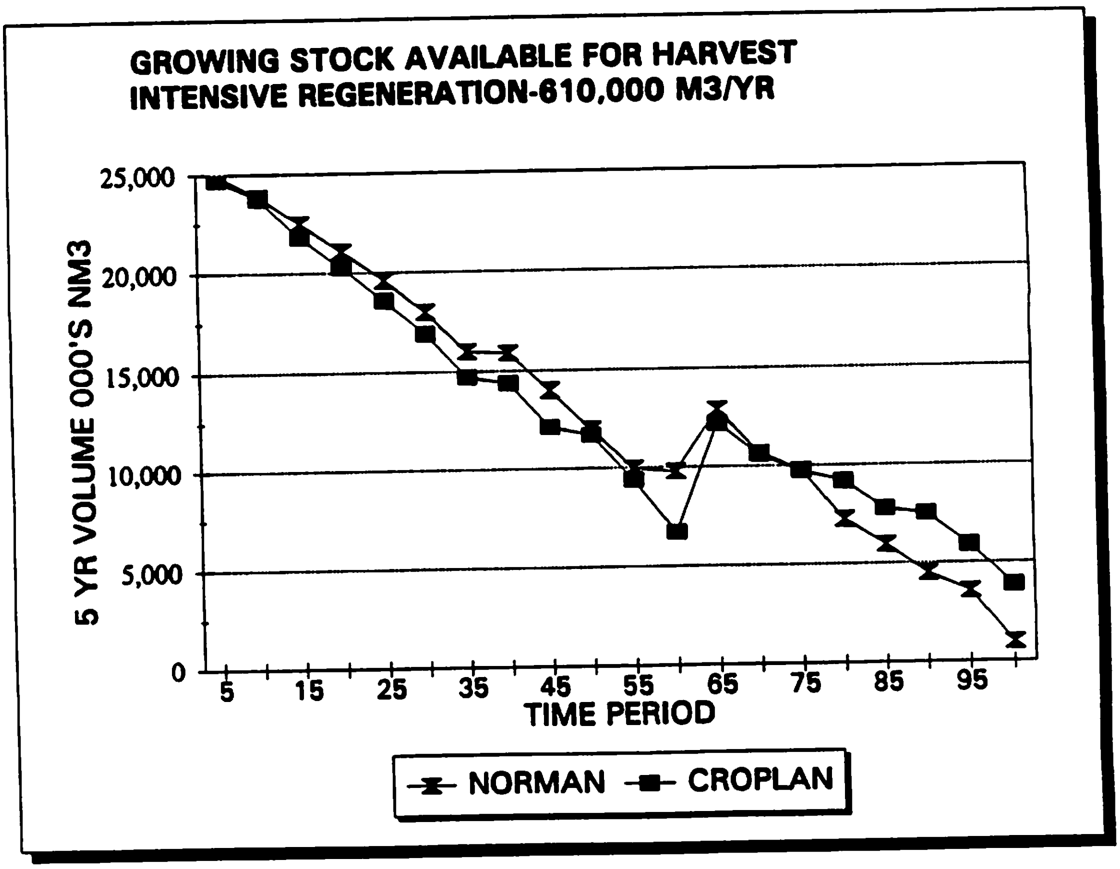
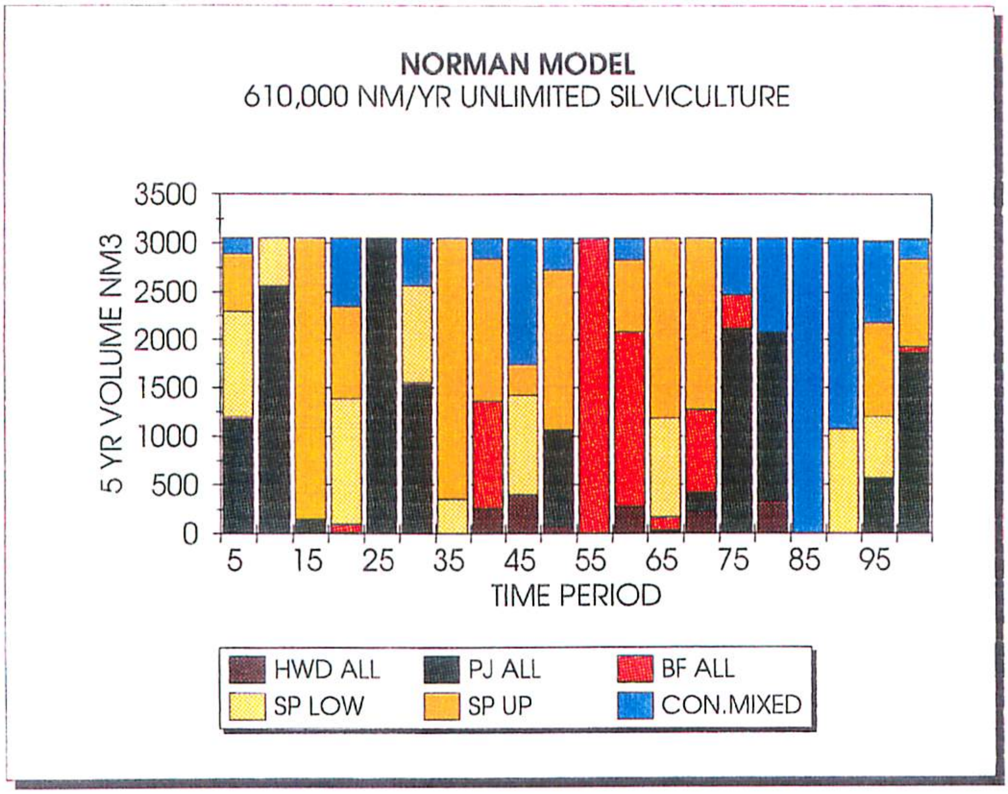


FIGURE #3M HARVEST BY FMU



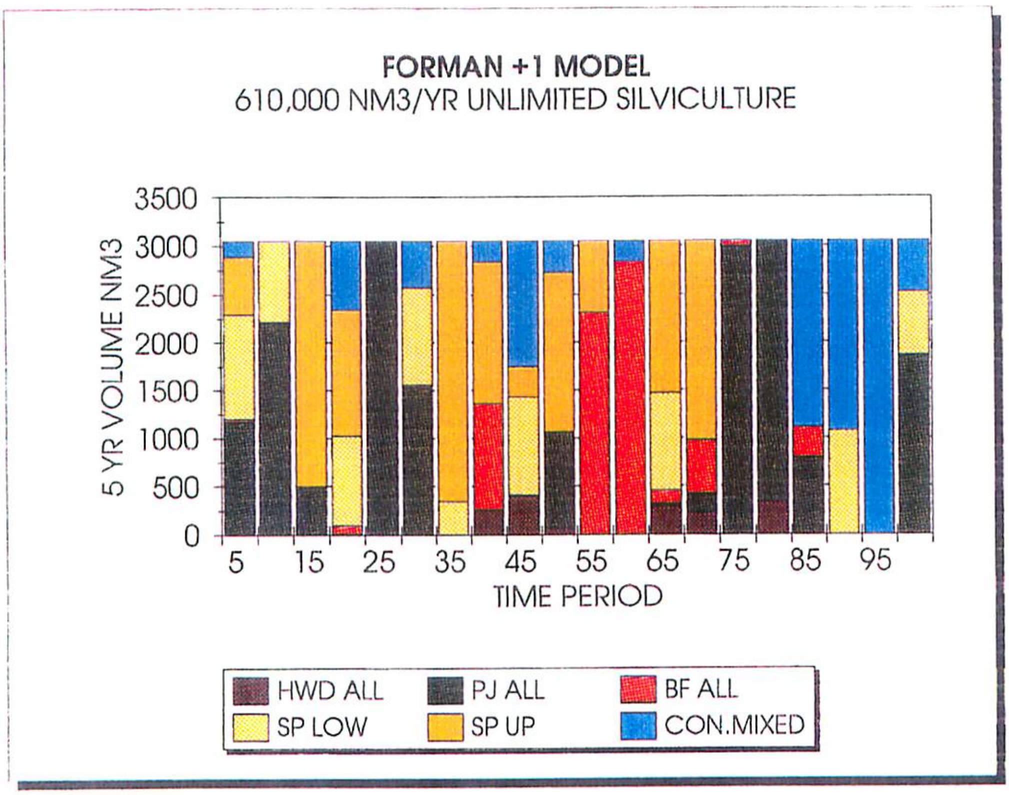
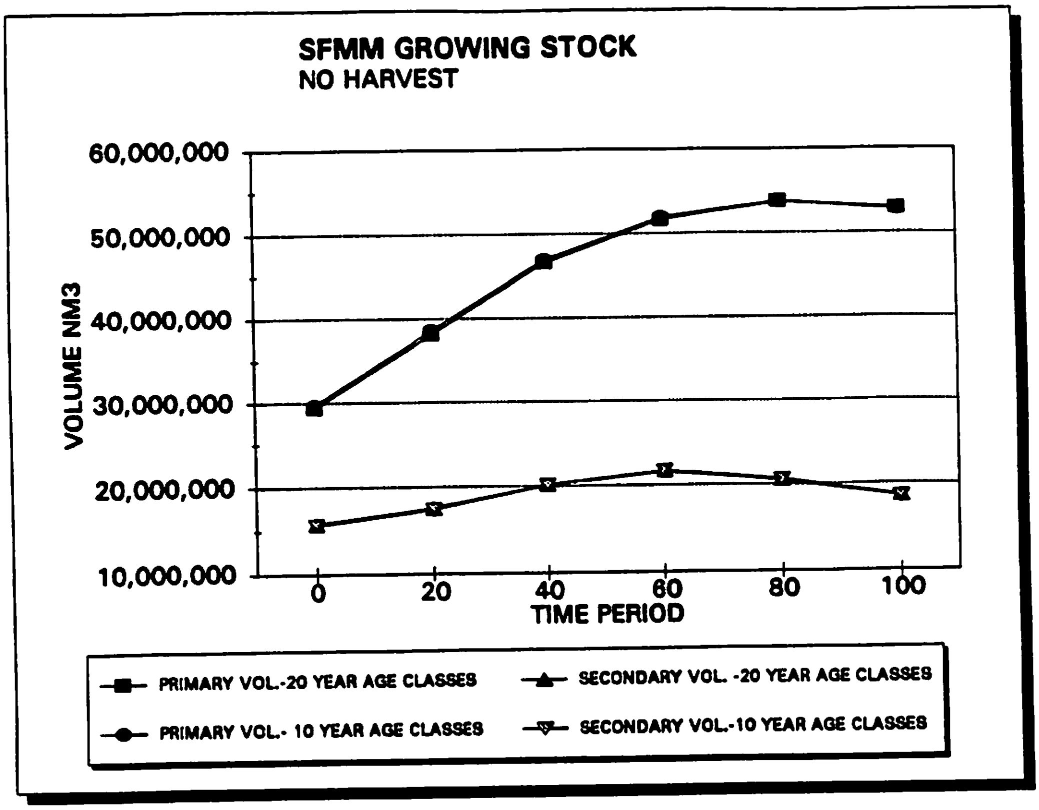
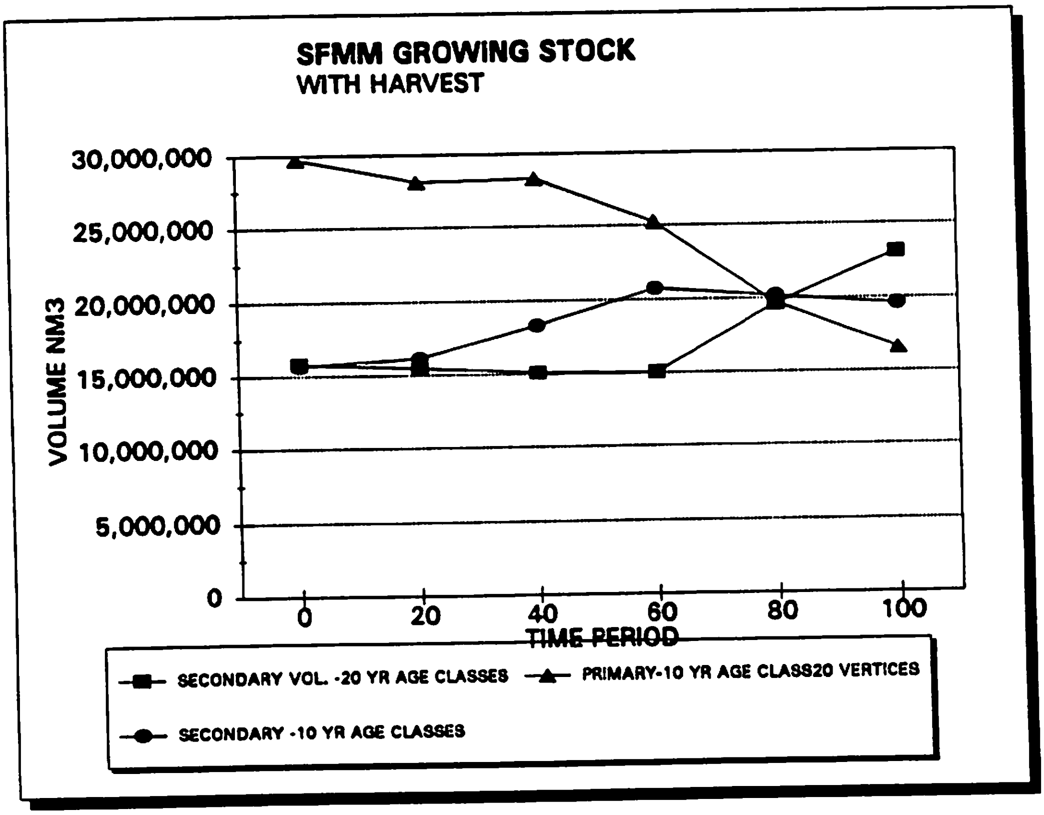


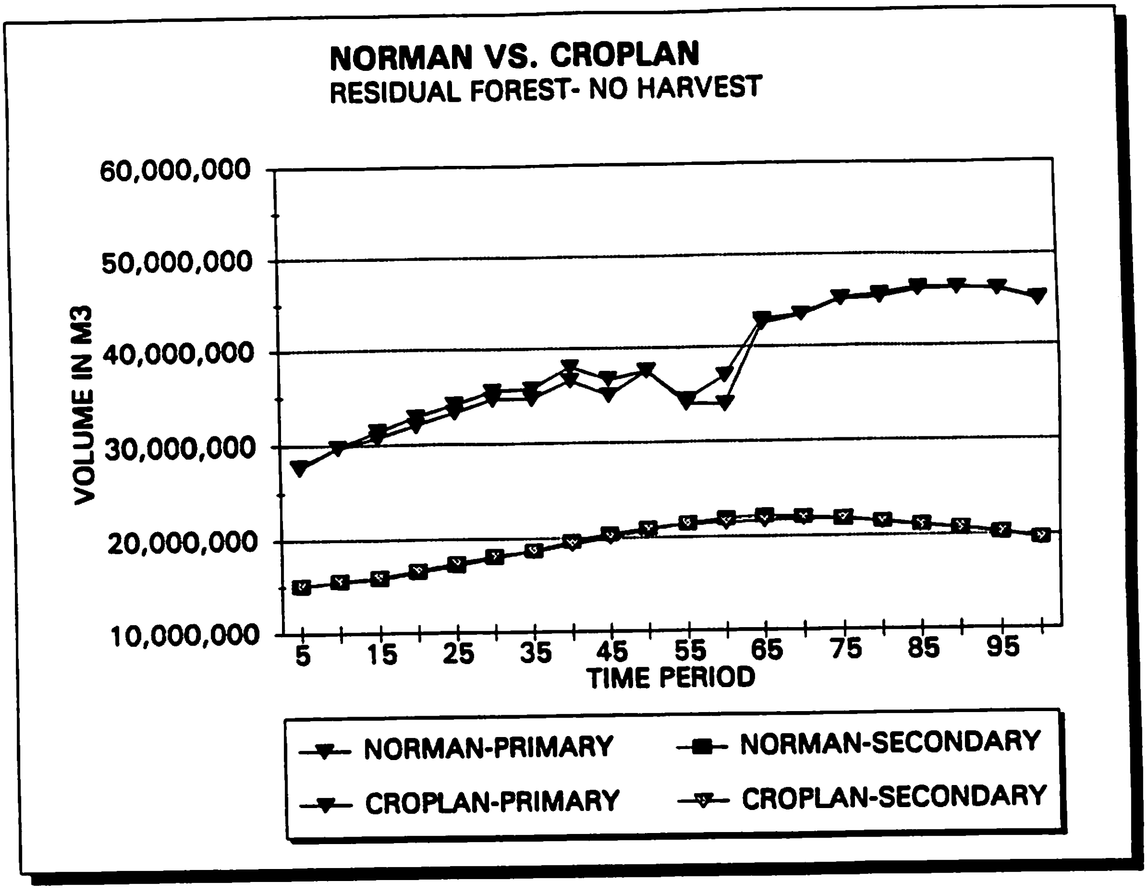
FIGURE #3N SFMM GROWING STOCK





INITIAL TARGET FOR -20 YR. AGE CLASSES WAS SET AT 610,000 NM3/YR. RUN WITH -10 YR. AGE CLASSES MATCHED TO HARVEST WITH TEN YEAR AGE CLASSES AS BEST AS POSSIBLE.

FIGURE #3-O GROWING STOCK



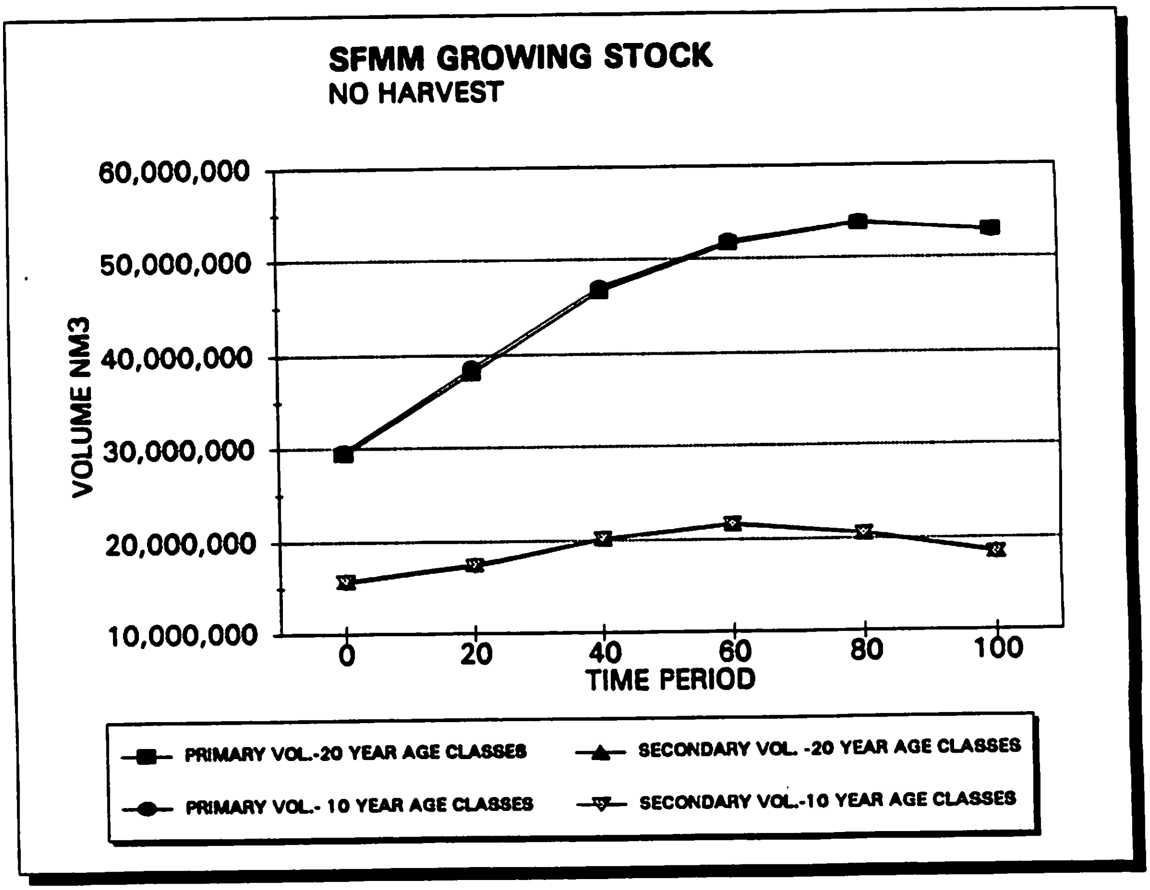
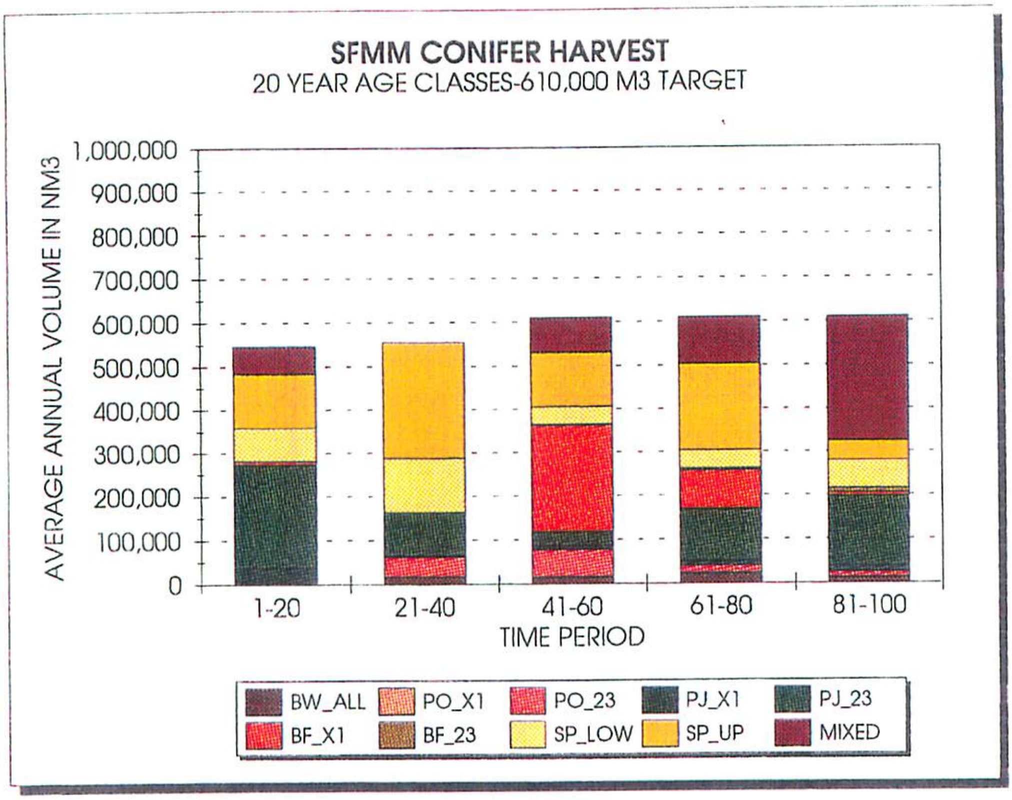
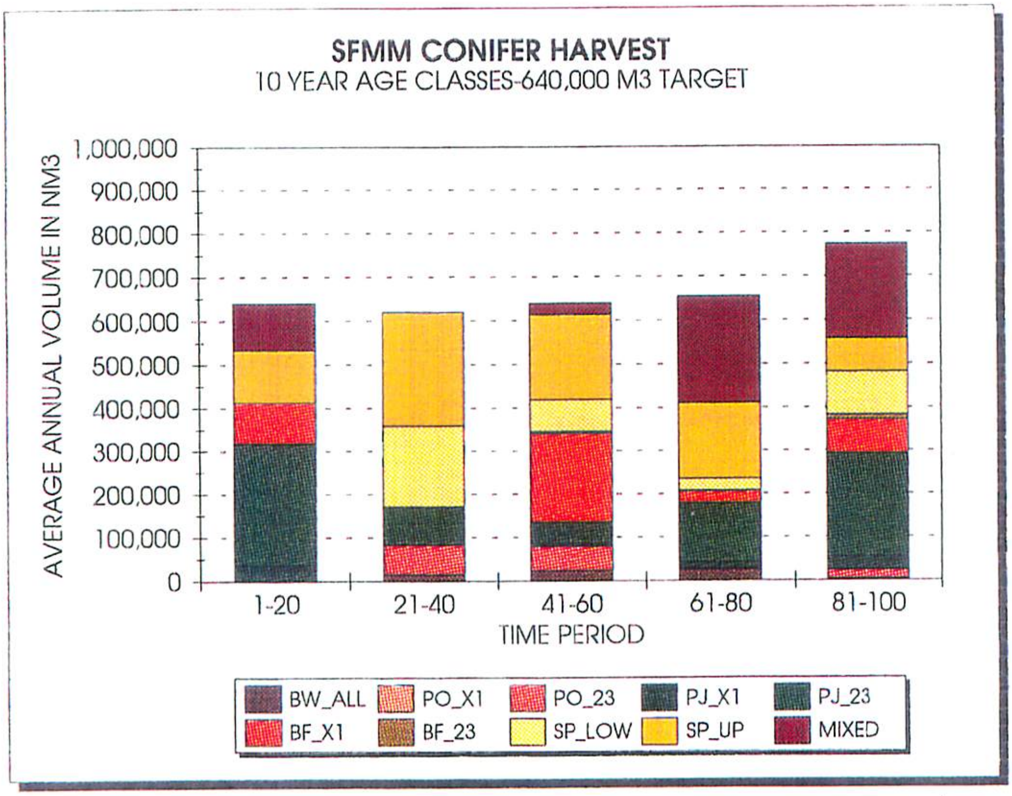


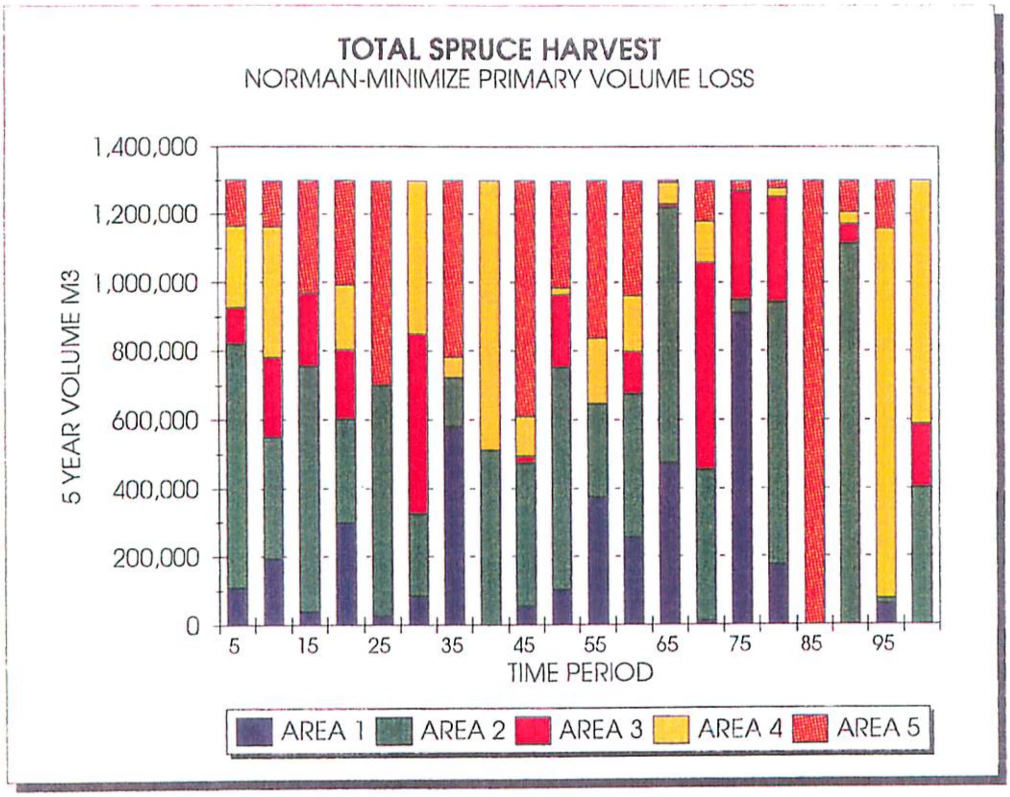
FIGURE #3P HARVEST BY FMU





APPENDIX 4

FIGURE #4A SPRUCE HARVEST BY AREA



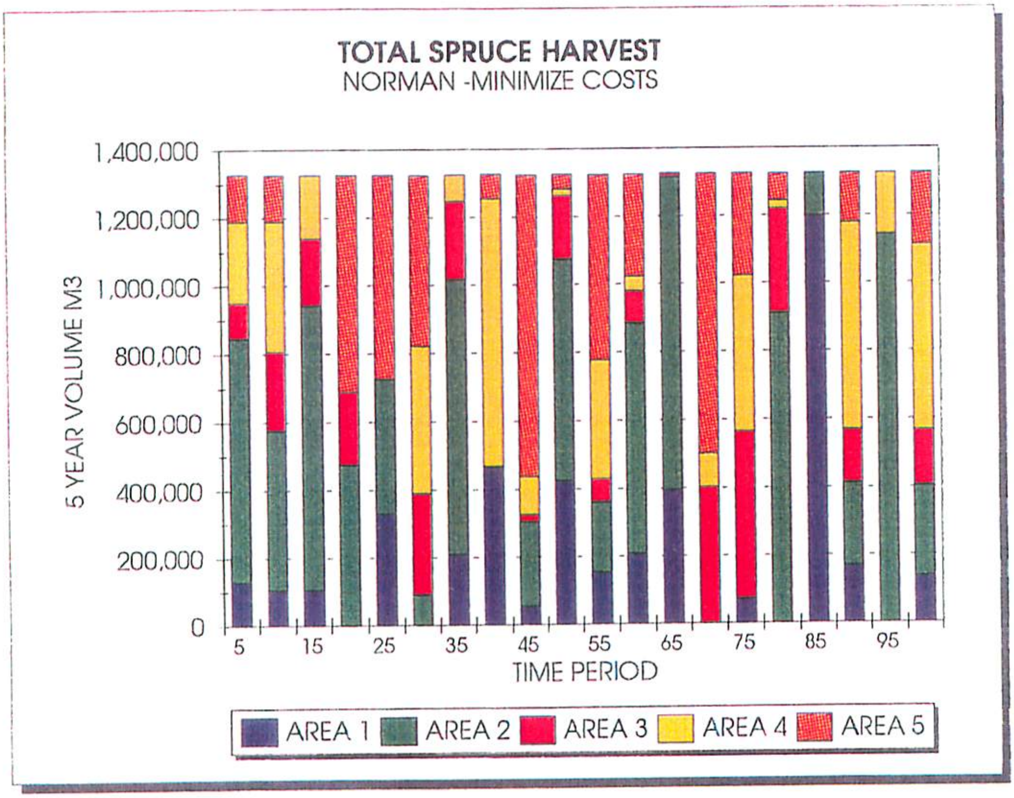
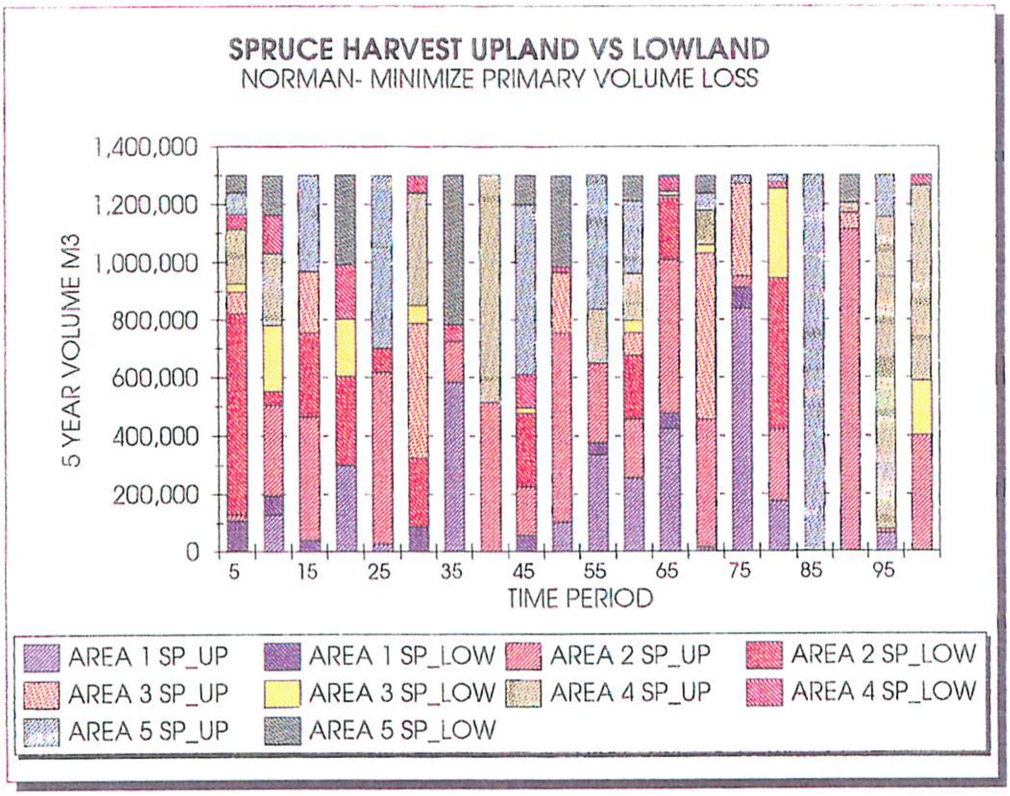


FIGURE #4B SPRUCE HARVEST BY SITE



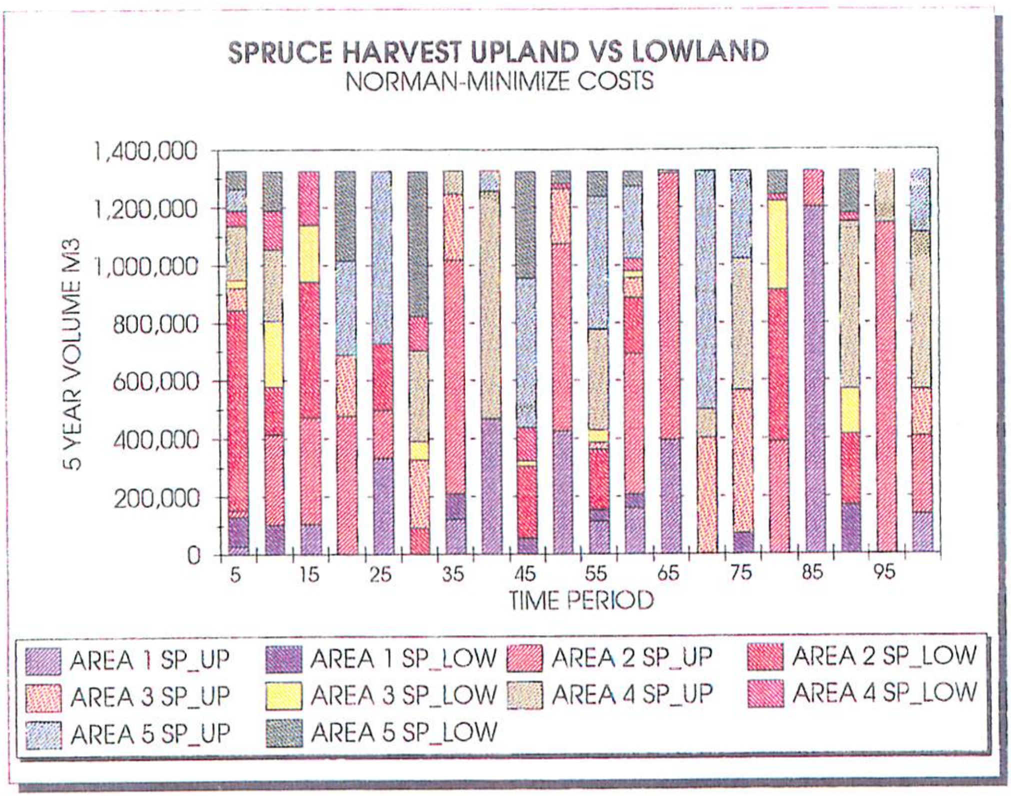


FIG... SPRUCE HARVEST