

AN ABSTRACT OF THE THESIS OF

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Title: SOME FINANCIAL ASPECTS OF THE LEVEL OF GROWING
STOCK PROBLEM IN MANAGED DOUGLAS-FIR

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The problem of determining the proper level of growing stock volume for even-aged forests has long been a problem for forest managers. Under present forms of management the normal yield tables are not valid, therefore some form of gross yield table must be used. One method for determining the proper level of stocking is to analyze the stand under a series of different thinning regimes and determine the economically best stocking point.

Douglas-fir will produce full gross growth under a wide range of stocking densities. Within this range of stocking densities is a point at which the economically best stocking can be determined. The construction of a model forest is used to show the characteristics of stand development. Standard appraisal procedures are applied to the physical characteristics, and a value yield table is constructed for economic analysis.

Soil expectation values and mean compound rate of return

calculations are then used to determine the best stocking point. In this example the best stocking point was determined to be 50% of normal stocking when expressed in square feet of basal area.

Some Financial Aspects of the Level
of Growing Stock Problem in
Managed Douglas-fir

by

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SOME FINANCIAL ASPECTS OF THE LEVEL OF GROWING STOCK PROBLEM IN MANAGED DOUGLAS-FIR FORESTS

INTRODUCTION

Growing stock has always been a problem to the Forester. Both in research and in the field he has been confronted time and time again with the complexities of the multitude of growing stock problems. Some of the questions most often asked by the manager of an even-aged forest are:

1. What is growing stock?
2. How does one measure growing stock?
3. What is full growing stock?
4. What is normal growing stock?
5. What is adequate stocking?
6. What growing stock should be carried on the land?

Statement of the Problem

This thesis is concerned with only one of the many questions surrounding the growing stock problem. Stated simply, the problem is--At what level should the land manager stock his land to receive the greatest benefit from his investment dollar? This question is paramount as the forest lands of the West become more intensively managed. Therefore we will explore this question from the economic

viewpoint.

The study will be concerned with the methodology of determining the best stocking point economically. The method of determining this point will be shown by the use of case studies which will be subjected to economic analysis.

RELATED LITERATURE

Past work in this area has been lacking for the even-aged forest. Some work has been done, by way of example, by Duerr (9, p. 120-128) for a selection forest, and for one approach to the determination of the best stocking point for an even-aged forest (9, p. 128-138).

Additional work has been done by Grah (11). In this work, he ran economic analyses of four stands starting out at different levels of stocking, and carried through the rotation with no cultural work except pruning. Analysis was run on the assumption of both pruning and no pruning. In this analysis, it was stated that the most favorable level of density is full stocking (p. 666).

Staebler (22) has stated that the best stocking point is at that point where the additional input of growing stock does not increase the growth percent.

Walker (26) stated that the best stocking is that which absorbs the full productive capacity of the site without waste of any site factors.

Past related literature on the subject of desirable growing stock has been primarily in the area of theory, with actual field studies lacking. Davis (6, p. 51) stated that this problem of desirable growing stock could not be solved by mathematics. It must be

firmly rooted in the knowledge of the physiology of tree growth and the economics of forest management. Meyer (19, p. 85-92) stated that the desired growing stock levels are best determined by the use of gross yield tables. Desirable growing stock is particularly determined by the objective of the forest manager. If he is interested in maximum wood volume regardless of quality, then growing stock should be maintained to assure a uniform rate of growth. Staebler (23) attacks the problem from a mensurational aspect. His main approach was along the lines of investigating the basal area growth in terms of radial increment.

Davis (8) further advanced the theory of desirable growing stock. The biological and physical limits of desirable growing stock for a specific site are that only so much growth can be produced. The forest manager must be able to concentrate this maximum growth on a specific number of stems. Maximum growth can exist upon a rather wide range of stocking. The desirable growing stock must be defined in mensurational, silvicultural, and financial terms, and these must be translated into basal area, cubic foot, board foot, cords, or piece measurements. Complete and specific solutions meeting all situations cannot be developed. There are endless possibilities of what constitutes desirable growing stock in specific situations, and it is not possible to compile sufficient information of a "what" nature to answer all questions. The final answer is to

define growing stock in this wide range and leave the specific judgment to the man on the ground.

Wilson (27) advanced the theory that growing stock should be expressed in terms of bole area, instead of total basal area or cubic volume. Bole area would give a measure of the total amount of living cambium per area.

Baker (1) stated that growth in a biological sense is not greatly affected by variation in common densities, but in an economic sense is profoundly so. The degree of this economic effect is a matter of current economic conditions.

Behre (3) approached the problem by expressing the relationship of growing stock and yield as a ratio, growing stock being defined as the minimum that will sustain its potential yield. The ratio of the growing stock to the yield is a function of the growing stock. The growing stock ratio is the reciprocal of the growth percent.

Gross (12) advanced the idea that desirable growing stock should be expressed as a percent of normal growing stock. This percentage should be determined by analysis of Continuous Forest Inventory plots and comparing the stocking of such plots with normal yield tables to develop the reduction factor. National forest stocking levels should range from 80% to 50%. Davis (7) in making comments on Gross (12) showed that this approach does not show the maximum yields that can be obtained from a managed forest. The arbitrary use of a

stocking percent of normal is a shifty figure when used to compare cut and uncut stands.

Current work in this area is beginning to make inroads into many of the unanswered questions about what is desirable growing stock. The current work is primarily in the area of long-term field studies and related information. As management becomes more intensive, especially in the Northwest, more and more problems that have been expressed in theory are being investigated on the ground. Studies in growing stock levels are becoming more numerous. One such study is the Hoskins Level of Growing Stock Study by Oregon State University Forest Research Laboratory. This study is designed to study the response and growth obtained from different degrees of thinning, resulting in varying amounts of growing stock. This study is just beginning, and no published data has been released. The Black Rock thinning studies of the Forest Research Laboratory at Corvallis, Oregon is another example of studies in the density ranges and thinning yields of Douglas-fir. Brinkman, Rodgers and Gingrich (5) are studying the effects of thinning density upon the growth and yield of shortleaf pine (Pinus echinata Mill.). The published ten-year results showed that the total wood produced is about the same regardless of stocking. Thirty-year-old pine stand to achieve the best growth and yield should be thinned to 70 square feet of basal area per acre.

As has been shown, the question of desirable growing stock level is a rather complex problem and still goes unanswered for the majority of the cases. The specific answers to the growing stock problem will, of necessity be a long time in coming. The life of man is too short, and the life of a tree too long for rapid answers to today's questions. As research progresses and more is learned, the many complex parts of the puzzle will begin to fall into place and slowly reveal the answers. Until that time it will be the job of the forest manager to use the best knowledge available with the skill and art of experience to judge the complete answer of desirable growing stock.

METHODS AND PROCEDURE

The general method of preparation of this study will be the economic analysis of a constructed forest model. The basic premise of this study is that within a rather wide range of stocking, gross cubic-foot increment can be maintained (13). Somewhere within this range of stocking there is an economic point of best stocking.

The procedure for determining this economically best stocking point is the objective of this study. Basically the procedure is to establish a model of the projected stand. This model should cover the entire rotation, and indicate all products derived from the model. The net value of this model is then established by normal economic methods. With the net values established, the values can then be analyzed by any or all of several basic economic methods. This study will outline the step-by-step procedure by way of analyzing a case study model developed by the investigator for this purpose.

Density Level Determination

The first step in the analysis of this procedure is the establishment of a range of densities which will produce full gross increment as stated previously. Specific studies of the hypothesis that gross cubic foot growth is produced over a wide range of densities for native species in this country are lacking. In general, tests of this

hypothesis by European workers have indicated it to be sound (4, 15). Several studies are now underway in this country to determine the complete soundness of this proposition. Some of the preliminary results indicate that it is equally true for American species (5). The newly initiated Hoskins Levels of Growing Stock Study of Oregon State University Forest Research Laboratory for Douglas-fir is testing this hypothesis. In order to establish a range of densities for use in this case study, analysis of completed and partially complete data was conducted by the investigator. This analysis was for the determination of ranges of stocking, in terms of square feet basal area per acre, which will produce at least full gross cubic foot growth according to Staebler (21).

Analysis was run on some of the Black Rock thinning data. This is unpublished data supplied the investigator by Mr. David Elfers of the Forest Research Laboratory, Corvallis, Oregon. Number of trees, basal area, and average diameter were supplied for four plots of different thinning intensity:

Plot #11 - Light thinning

Plot #12 - No thinning

Plot #13 - Moderate thinning

Plot #31 - Heavy thinning

These plots were summarized and compared with Staebler's gross yield tables (21).

The first step in the analysis of the Black Rock data is the establishment of equal grounds for comparison. Black Rock data are in terms of King's site index (17) and Staebler's gross yield tables (21) in terms of McArdle's site index (18). The plots were converted from King's site index (17) to conventional site index by use of Table 9, p. 32 of "Site Index Curves for Douglas-fir in the Pacific Northwest" (17). Site indexes are interpolated to the nearest age and full site index.

Table 1. Conversion of King's S.I. to McArdle's S.I.

Plot #	King's S.I.	Age at B. H. (1963)	McArdle's S.I.
11	122	48	150
12	118	47	150
13	157	47	200
31	131	47	160

Cubic foot volume was calculated on the basis of average diameter and total tree height from Bulletin 201 (18). The plot data and data from Staebler's gross yield tables (21) were then compared.

An inspection of the table below shows that both plots #11 and #12 exceed Staebler's (21) full gross growth. Plot #11 exceeded full gross growth by 497 cubic feet per acre, and plot #12 exceeded full gross growth by 694 cubic feet per acre.

Table 2. Comparison of Black Rock data (Douglas-fir component only) and Staebler's gross yield tables.

Plot #	Year	Age (total) years	Plot cu. vol. (cu.ft.)	Plot growth (cu. ft.)	Gross growth (cu.ft.)	Plot B.A. (sq. ft.)	Normal B.A. (sq. ft.)	% B.A. normality (%)
11	1955	48	8037			184	204	90
	1960	53	9256	1219	1150			
Light thinning	1960	53	8710			206		
				1988	1590	191	217	87
				3207	2740			
	1967	60	10698			221	232	95
12	1955	47	9547			204	202	101
No thinning				3439	2745			
	1967	59	11640			249	230	108
13	1955	45	7392			133	210	63
				749	1380			
Moderate thinning	1959	49	8141			146		
	1959	49	7068			128	221	58
				2991	2648			
				3740	4028			
	1967	57	10059			167	236	71
31	1957	48	3300			75	208	36
Heavy Thinning	1967	58	5356	2056	2812	115	232	50

Plot #13 fell short of obtaining full gross growth (21) by 288 cubic feet per acre. The addition of the Douglas-fir mortality for this period added 148 cubic feet per acre. This left the growth 140 cubic feet per acre short of full growth (21). The plot also contained a hardwood component whose volume was not determined. However this hardwood component went from 22 trees per acre, 7.0" D.B.H. in 1955 to 19 trees per acre, 8.7" D.B.H. in 1967, and it seems reasonable to assume that this would have added the necessary 140 cubic feet per acre to bring this stand up to full gross growth.

Plot #31, the heavy thinning plot, was initially thinned in 1957. This thinning left 36% of normal Bulletin 201 (18) basal area. No additional work was performed on the plot. The measurements taken in 1967 showed that the plot failed to achieve full gross growth (21) over the ten-year period by 756 cubic feet per acre. However, it is interesting to note that the normality percentage expressed in basal area per acre of this stand increased from 36% of normal to 50% of normal in only a ten-year period. This increase of 14% normality is much faster than the 7% increase shown in Bulletin 201 (21), table 28.

On the basis of the analysis of the Black Rock data it appears that full gross growth may be obtained from density ranges of 58% to 101% when expressed in terms of percent of normal basal area per acre.

Raw data from the Hoskins study, a new level-of-growing-stock study, were supplied by John Bell, Oregon State University, School of Forestry. The data supplied consisted of:

1. Volume per acre, all trees
2. Volume per acre, crop trees
3. Number of trees, basal area per acre, average D. B. H., all trees
4. Number of trees, basal area per acre, average D. B. H., crop trees.

These stands are 14 years old at B. H. on site index 160. The data from the last measurements, September 1967 were compared with full gross growth (21) for the same period.

Analysis of the growth data of the Hoskins study when compared with full gross growth as defined by Staebler (21) shows that greater than gross growth can be obtained from 49% of normal basal area to 138% of normal basal area (control plot).

Data from unpublished yield tables for Douglas-fir plantations in Denmark supplied by Mr. David Elfers of the Forest Research Laboratory, Corvallis, Oregon, were also analyzed for the determination of growth rates. Comparable site index is 130. As Staebler's gross yield tables (21) are in site classes, site Class III was used for comparison. As can be seen in Table 4 full gross growth (21) was exceeded in all cases. The densities in terms of basal area per acre are also shown in Table 4. These densities ranged from 68% of normal basal area

Table 3. Comparisons of Hoskins study data and Staebler's gross yield tables.

Treat- ment	Cu. vol. 1963 cu. ft.	Cu. vol. 1966 before thinning cu. ft.	Cu. vol. 1966 after thinning cu. ft.	Cu. vol. 1967 cu. ft.	Total cu. ft. growth (Staebler's) cu. ft.	Gross growth (Staebler's) cu. ft.	%Nor. B.A. 1963 %	%Nor. B.A. 1966 after %
T-1	880.2	1711.2	1106.9	1302.8	1026.9	825	49	49
T-2	894.3	1701.2	1094.4	1337.8	1050.3	825	50	49
T-3	881.8	1671.2	1259.4	1501.1	1031.1	825	50	57
T-4	920.2	1721.2	1307.8	1557.8	1051.0	825	51	58
T-5	873.5	1703.7	1477.8	1732.8	1085.2	825	49	67
T-6	901.8	1741.2	1482.8	1782.8	1139.4	825	50	66
T-7	935.2	1702.0	1681.2	2022.1	1107.7	825	50	75
T-8	881.0	1730.3	1692.0	1975.9	1133.2	825	51	76
Control	1876.2	2978.1	2978.1	3399.8	1523.6	825	138	163

1/ These treatments represent thinning intensities.

Table 4. Comparison of Denmark Douglas-fir plantation yields with Staebler's gross yield tables.

Age	Denmark		Denmark		Growth		Gross		B.A.		Normal	
	cu. vol. after thinning (cu. ft.)	cu. vol. before thinning (cu. ft.)	Denmark before thinning (cu. ft.)	Denmark after thinning (sq. ft.)	Growth Denmark (cu. ft.)	Growth (Staebler) (cu. ft.)	Denmark after thinning (sq. ft.)	Normal B.A. (sq. ft.)	Normal (%)			
24	3658.6	4487.5	828.9	140.1	681	106	132					
28	3844.4	4644.6	800.2	136.8	466	126	108					
30	3887.2	4987.7	1100.5	131.6	705	135	97					
33	4130.2	5716.6	1586.4	129.1	948	148	87					
37	4487.5	5645.0	1157.5	131.4	948	161	82					
41	4716.1	5673.0	957.6	131.7	708	173	76					
44	4701.8	5673.7	971.9	126.7	705	181	70					
47	4973.4	5816.6	843.2	131.2	696	188	69					
50	5102.0	6888.4	1786.4	133.0	1416	196	68					
56	5187.7			130.8		209	62					
Total			14,630		9,582							

area to 132% of basal area.

The problem of direct comparison of British thinning yield tables (14) is the determination of a comparable production class. The British tables (14) are in terms of yield classes, which are defined as the maximum mean annual increment at any age. Staebler's gross yield tables (21) are in terms of site class. For a valid comparison an equivalent production level must be found. The most equitable method would be to determine the site index from the information contained in the British tables (14) by the procedure outlined by McArdle in Bulletin 201 (18). From the site index tables in Bulletin 201 (18), the closest yield class to SI-140 is yield class 280. The comparison of the British yield tables (14) and Staebler's gross tables (21) are therefore made on this basis.

In this comparison the growth shown by the British thinning yield tables (14) exceeded full gross growth as shown by Staebler (21) up to 70 years of age. Between 70 and 80 years of age the British tables (14) fell short of full gross growth (21) by 19 cubic feet per acre. In Table 5, the basal area after thinning from the British thinning yield tables (14) was compared with normal basal area from Bulletin 201 (18). The stocking percentage was 96% of normal basal area at age 20, at age 30 it dropped to 73% of normal basal area, and thereafter remained at a constant 79% normal basal area. From this comparison it can be stated that at least full gross

Table 5. Comparison of British thinning yield table (14) for Douglas-fir and Staebler's gross yield.

Age	Vol. before thinning (cu. ft.)	Vol. after thinning (cu. ft.)	Growth British (cu. ft.)	Vol. Cu. gross Staebler (cu. ft.)	Growth British (decade) (cu. ft.)	B.A. after thinning (sq. ft.)	B.A. Nor. Nor.
15	1573	1127	1591			81	
20	2718	1738	1890	1250		88	96
25	3628	2648	1979		2250	99	
30	4627	3647	1935	3500		102	73
35	5582	4602	1807		2370	127	
40	6409	5429	1674	5870		140	79
45	7103	6123	1540		3214	151	
50	7663	6836	1413	8220		162	79
55	8249	7536	1298		2270	170	
60	8834	8198	1178	10490		179	79
65	9376	8790	1069		2090	187	
70	9859	9318	955	12580		193	79
75	10273	9764	846		1820	200	
80	10610	10120		14400		204	79

Table 6. Comparison of "Wind River" plots with Staebler's gross yield tables.

Spacing (ft.)	Age (yrs.)	Cu. ft. vol. Wind River (cu. ft.)	Cu. ft. vol. gross (cu. ft.)	Growth Wind River (cu. ft.)	Growth gross Staebler (sq. ft.)	B. A. Wind River (sq. ft.)	B. A. Normal (sq. ft.)	% Normal
4 x 4	27	2320	1976			132	110	132
	32	3147	2772	827	796	160	128	
5 x 5	27	1890	1976			113	110	103
	32	2559	2772	669	796	137	128	
6 x 6	27	1870	1976			104	110	94
	32	2761	2772	891	796	132	128	
8 x 8	27	1470	1976			79	110	72
	32	2418	2772	948	796	106	128	
10 x 10	27	1950	1976			91	110	83
	32	3207	2772	1257	796	125	128	
12 x 12	27	1740	1976			80	110	73
	32	2892	2772	1152	796	110	128	

growth (21) can be obtained from 73% to 96% of normal basal area as defined by Bulletin 201 (18).

Data from the Wind River Experimental Forest (10,20) were compared with Staebler's gross yield tables (21). These data are the reported results of spacing tests on Douglas-fir planted in 1925. Results of the spacing test were reported in 1955 (10) and 1959 (20). For the purpose of comparison, site index 110 feet is used.

The Wind River spacing tests were on a planted mechanical basis. The spacing varied from 4' x 4' to 12' x 12' and were maintained at that level until established. Measurements were taken at five-year intervals. Data were published at 27 years (10) and 32 years (20). Full gross growth (21) or greater was obtained in all spacings except the 5' x 5' which was consistently low in all cases. This may be explained by a difference in site quality. Stand densities, in terms of square feet of basal area, ranged from 132% to 72%. Based upon the data presented above full gross growth (21) can be obtained with densities ranging from 72% to 132% of normal (18) basal area.

The conversion of one British yield table to American units by Barnes (2) was for Douglas-fir plantations found in Great Britain converted to American units. The results, when compared to Staebler's gross yield tables (21) show that at least Staebler's level of gross growth may be obtained from 96% to 132% of normal when expressed in square feet of basal area. The growth between 45 and

Table 7. Comparison of British plantation yields (2) and Staebler's gross yields (21).

Age	Cu. vol. before thinning (cu. ft.)	Cu. vol. after thinning (cu. ft.)	Growth British (cu. ft.)	Staebler's gross vol. (cu. ft.)	Staebler's gross growth (cu. ft.)	British B.A. after (sq. ft.)	Normal B.A. (sq. ft.)	Normal (%)
13	850	680		375		79	60	132
16	1600	1320	920	750	375	103	72	143
19	2350	2000	1030	1125	375	118	85	139
22	3000	2600	1000	1700	575	129	102	126
25	3600	3170	1000	2375	675	139	166	120
28	4170	3720	1000	3050	675	148	130	114
32	4950	4470	1230	3974	924	158	147	107
36	5650	5150	1180	4922	948	168	162	104
40	6300	5785	1150	5870	948	176	177	100
45	7000	6470	1215	7045	1175	187	192	97
50	7600	7055	1130	8220	1175	196	204	96

50 years of age failed to reach full gross growth by 45 cubic feet per acre. This difference, which is 3.5% of gross growth for that period, is very small, and possibly attributed to differences in site quality as suggested by Barnes (2).

In a study by Rudolf F. Grah (11, p. 627), the following statement is found:

While a difference in total volume exists between stocking levels, the matter of primary interest is the virtual equality of yield between the stands of full initial stocking and those of low initial stocking. This situation indicates that low initial stocking within the limits considered here has very little, if any, effect on board-foot volume yields beyond the fortieth and sixty-fifth years, depending on site, and agrees with preliminary findings of Barker (1953) in ponderosa pine as well as with statements of others, such as Hawley and Smith (1954), that stand density, within reasonable limits, does not affect total net yield.

This study was an economic study of the effects of different initial stockings upon the economic value of the stand. The stands under study were four density levels of 100%, 75%, 50%, and 25% of normal, based on number of stems per acre from a normal stand of site index 200 (18).

Floyd A. Johnson (16) tested seven methods of predicting the future volumes of Douglas-fir stands. The 17 plots tested ranged in stocking from 35 to 338 percent of normal, when expressed in terms of Scribner volume.

The results of the tests as stated by Johnson (16) were:

Among methods which give no indication of bias, the normal growth method is apparently superior because variation among individual differences was least by this method.

This would seem to reinforce the calculations and comparisons previously made in this study.

More information may be found in studies now in process, and by more completed work. A study by Brinkman et al. (5) on the shortleaf pine observed the growth and yield in young stands thinned to five different levels of density. The plots were thinned to constant basal area of 50, 70, 90, 110 and check (138) square feet per acre. These density levels, when using the check plot as normal, are 36%, 51%, 65% and 80% of the check. The yearly results are reported. The results showed all plots producing greater growth than the check plot. In summary, the authors stated: "Total volume of wood produced during the 10 years was about the same regardless of stocking" (5). Therefore, it appears that this stand of shortleaf pine (Pinus echinata Mill.) will produce equal growth over a rather wide range of stocking densities.

After review of the comparisons of the data made, it can be seen that Staebler's gross growth (21) can be obtained over a rather wide range of stocking densities. From the results of the analysis of data provided here, and the review of other work, an assumption on the range of stocking density from which full gross growth (21)

can be obtained is made. The basic assumption that full gross growth (20) can be obtained over a wide range of stocking densities is paramount to the full development of this study.

CONSTRUCTION AND ANALYSIS OF MODEL

Study Density Levels

On the basis of the foregoing analyses the following density levels are chosen for the development of this study:

50%	80%
60%	90%
70%	100%

These percentages are in terms of basal area of normal stands as shown in Bulletin 201, Table 2 (18, p. 14). The ranges stated here appear reasonable from the results of analysis of data provided. In some instances it appears that Staebler's gross growth (21) may be conservative to what can be achieved.

This study is primarily the development of an economic method for determining the best stocking point of a managed Douglas-fir forest. For a given rotation, this stocking point lies somewhere within the range of stocking that produces full gross growth (21). In order to test this hypothesis, stands of the exact stocking density over the rotation would have to be analyzed. Stands that meet this criterion would be extremely difficult if not impossible to find. Therefore it is necessary to use a reasonable model. This model should be built on a mathematical base with a sound silvicultural backing. The case studies used in this approach will be primarily

mathematical. Because of the tremendous number of variables in the development and management of any stand, a certain number of assumptions will be made to clarify the model and not cloud the issue with so many variables that the basic theme of the study is lost.

This case study will be assumed to represent the holdings of a comparatively small owner. The owner is interested in managing his average site class III land on a sawlog production basis. The owner wants to know at what density he should manage his land to return the greatest economic return. It has already been determined that a 70-year rotation is best for his needs. The economic analysis will be on six different levels of stocking. Stocking control will be by periodic thinning of a planted stand. The stand was planted to a surviving density at 20-years of age of 540 stems per acre. The thinning interval will be ten years, at which time the stand will be thinned to the specified density levels. The stand is analyzed on each of the six density levels mentioned. Each stand model will be based upon the reduction in stems per acre required to achieve the desired basal area at the end of each ten-year period. The growth achieved during the thinning interval will be the full gross growth as defined by Staebler (21) as measured in cubic feet per acre. The mathematical procedure for determining the number of stems per acre, average D.B.H., and cubic foot volumes will be similar to those outlined by Staebler in Theoretical Derivations of Numerical

Thinning Schedules for Douglas-fir (24), and modified to fit this case over the entire range of stocking densities. Total tree height will be consistent with site Class III and will be reflected as such.

In these models, the basic assumption is the establishment of pre-determined basal area levels. As previously stated, the cases under study will be density levels of 50% to 100% of normal basal area per acre. At each age, the stand after thinning will contain the appropriate percentage of normal basal area as defined by Bulletin 201 (18). Table 25 of Bulletin 201 (18, p. 68) will be used as the base for all calculations in the development of the models through the cubic foot volume stages. The models of the forest under the six forms of management are shown in Tables 8 through 13.

A column by column explanation of the mathematical derivation is as follows:

Age. Age, as stated here, is the total age of the stand at the time of thinning carried to final harvest.

Basal Area After Thinning. This column is the basal area that the stand is thinned to at the end of each ten-year period. The basal area figure is the percentage of normal basal area as defined by Bulletin 201, Table 2 (18, p. 14). For example: density class 60, age 20, the basal area is 60% of normal, 92 square feet, or 55 square feet of basal area. This figure establishes the density level for the case model.

Table 10. Density class 70

Age	B. A. after thin sq. ft.	Stem/ac. after thin #	Ave. D. B. H. inches	Cu. vol. /tree cu. ft.	Cu. vol. after thin cu. ft.	Cu. vol. before thin cu. ft.	Vol. removed cu. ft.
0							
10		540					
20	64	327	6.0	5.1	1668	2754	1086
30	98	261	8.3	12.0	3132	3918	796
40	124	214	10.3	21.1	4515	5502	987
50	143	179	12.1	32.1	5746	6865	1119
60	158	152	13.8	44.8	6810	8016	1206
70	161		15.4	58.6		8900	8900
							14,084

Table 11. Density class 80.

Age	B. A. after thin. sq. ft.	Stem/ac. after thin. #	Ave. D. B. H. inches	Cu. vol. /tree cu. ft.	Cu. vol. after thin cu. ft.	Cu. vol. before thin cu. ft.	Vol. removed cu. ft.
0							
10		540					
20	74	378	6.0	5.1	1928	2754	826
30	112	321	8.0	11.1	3563	4178	615
40	142	271	9.8	18.5	5014	5933	919
50	163	234	11.3	27.2	6365	7364	999
60	181	202	12.8	36.9	7454	8635	1181
70	195		14.1	47.2		9544	9544
							14,084

Table 12. Density class 90.

Age	B. A. after thin. sq. ft.	Stem/ac. after thin. #	Ave. D. B. H. inches	Cu. vol. tree cu. ft.	Cu. vol. after thin. cu. ft.	Cu. vol. before thin. cu. ft.	Vol. removed cu. ft.
0							
10		540					
20	83	423	6.0	5.1	2157	2754	597
30	126	380	7.8	10.4	3952	4407	455
40	159	330	9.4	16.6	5478	6322	844
50	184	294	10.7	23.7	6968	7828	860
60	203	259	12.0	31.4	8133	9238	1105
70	220		13.1	39.5		10,223	10,223
							14,084

Table 13. Density class 100.

Age	B. A. after thin. sq. ft.	Stem/ac. after thin. #	Ave. D. B. H. inches	Cu. vol. /tree cu. ft.	Cu. vol. after thin. cu. ft.	Cu. vol. before thin. cu. ft.	Vol. removed cu. ft.
0							
10		540					
20	92	469	6.0	5.1	2392	2754	362
30	140	433	7.7	9.9	4287	4642	355
40	177	392	9.1	15.4	6037	6657	620
50	204	352	10.3	21.4	7533	8387	854
60	226	319	11.4	27.8	8868	9803	935
70	244		12.4	34.4		10,958	10,958
							14,084

Stems Per Acre After Thinning. This column shows the result of the systematic reduction of the stand through thinning. The amount of this reduction is determined by the percent basal area level to which the stand is being managed. The numbers of stems to be left after thinning is determined by dividing the basal area after thinning by the basal area of the tree of average diameter breast high. The 540 stems per acre before thinning at age 20 is the assumed stocking of a planted stand. This figure is the stocking rate of a 9' \times 9' planting density, and is a common spacing used in planting today.

Average D. B. H. The average diameter is determined by a curve of the cubic foot volume per tree column of Table 25 of Bulletin 201 (18, p. 68), (Figure 1). The D. B. H. at age 20 is 6" D. B. H. and is an assumed value.

Cubic Volume Per Tree. The cubic volume per tree is determined by dividing the cubic foot volume before thinning by the number of trees per acre before thinning. The cubic volume per tree for the 20-year age class, is taken directly from Table 25 of Bulletin 201 (18, p. 68) for trees 6" D. B. H.

Cubic-Foot Volume After Thinning. The cubic-foot volume after thinning is determined by the product of the number of stems per acre after thinning and the cubic foot volume per tree.

Cubic-Foot Volume Before Thinning. The cubic foot volume

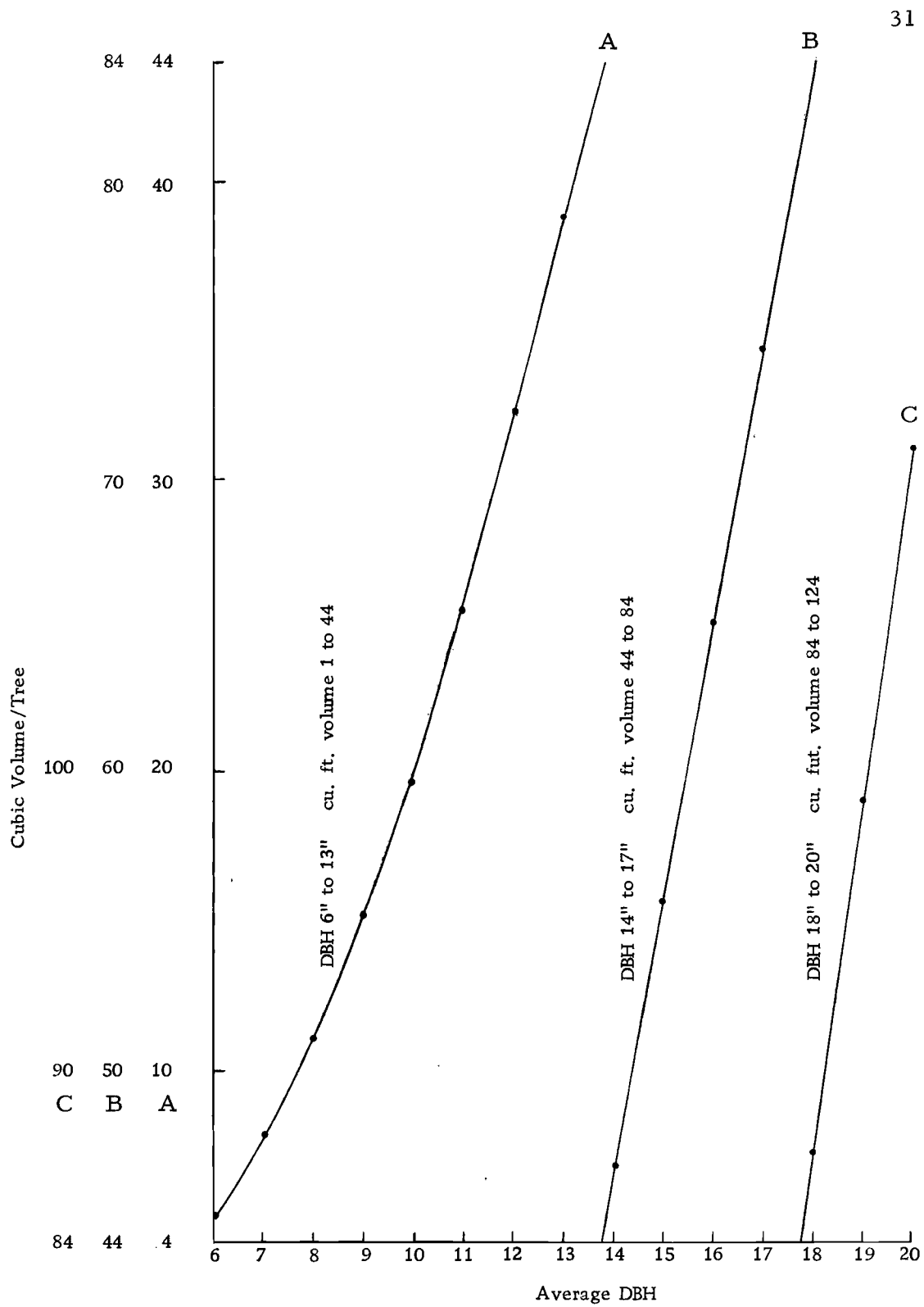


Figure 1. Cubic foot volume per tree of average DBH.

before thinning is the sum of the cubic foot volume after thinning for the previous ten-year period and the ten year full gross growth, according to Staebler (21), for that period. The cubic volume for the 20-year age class is the product of the cubic volume per tree and the number of trees before the 20-year thinning.

Volume Removed. The volume removed is the cubic-foot volume removed in each thinning, and the total stand at age 70, the final harvest. The value is found by subtracting the cubic-foot volume after thinning from the cubic-foot volume before thinning.

In this manner the model is constructed. This model is a simplification of a rather complex problem. The model is purposely made simple not to cloud the basic theme of the study with a large number of variables involved in the determination of a more complex model. A word of explanation is necessary to help clarify the calculations made.

The ten-year thinning interval may, at first, seem too long under the recommendations of some of today's studies (24). In actual practice a ten-year thinning interval seems to be more practical.

The basal area after thinning is the stocking density, and is the base of the models: the stand being thinned to the appropriate basal area. This thinning intensity has previously been explored for validity in this study. The use of basal area as a measure of stocking density is in widely accepted practice. There are other

methods of measuring stocking density that are more accurate, such as bole area (27), but basal area is more easily understood, and applied in the field.

The stems per acre are in direct mathematical relationship between average D. B. H. and basal area. The beginning density of 540 stems per acre seems entirely reasonable for a managed stand at 20 years of age. From some studies of initial planting density, a spacing density of $10' \times 10'$ is recommended (10, 20). The U.S. Forest Service uses $9' \times 9'$ in many of their planting projects.

The average diameter for this model plays an important role in its development. The assumed 6.0" D. B. H. at 20 years of age for 540 stems per acre appears entirely reasonable, if not conservative. Several of the studies reviewed showed this type of stand development for 20-year-old stands on site III land. The "Wind River" (10) experiments show 6.4" D. B. H. for a 27-year-old stand on site index 110. Some British yield tables (14, 2) show 6.0" D. B. H. average at 20 years of age. On the basis of these samples, it seems entirely reasonable to assume a stand of 6.0" D. B. H. at 20 years of age with 549 stems per acre.

It should be noted that as the density level increases the corresponding average diameter decreases. This is to be expected, as with natural stands, the diameter decreases with increasing density (10, 20, 11). The Density Class 100 final average diameter falls very

closely to that of a normal stand (18, p. 14). The range of diameters, as determined in the model appears reasonable for the case in point.

It should also be noted, that the average diameter is the same before and after thinning. There are three primary methods of thinning: thinning from below, thinning from above, and mechanical thinning. For the purposes of this study, it is assumed that the thinning in this example will be a mechanical thinning in which trees of all diameters are removed. This would leave the average diameter the same after thinning as before. This does not seem unreasonable under a little close examination. Under an intensive management regime, the individual trees in a stand would tend to be much more the same size than would be found in a natural stand. This same method, that is trees of the same average diameter before thinning as after, is used by Staebler (24).

Cubic volume per tree is simply the mathematical relationship between the total number of trees per acre before thinning and the cubic foot volume before thinning. It is assumed that the thinning in each case will remove the mortality that normally would occur. Therefore, the number of trees after thinning for the previous ten-year period is divided into the present cubic volume before thinning to determine the present cubic volume per tree.

As has been previously explained, the average diameter is the same before and after thinning, therefore the cubic volume per

tree is the same, and the cubic volume after thinning is determined by the product of the number of stems per acre after thinning and the cubic volume per tree.

The assumption that full gross growth according to Staebler (21) is obtained for each ten-year period has been explored previously in this study. This assumption, that Staebler's full gross growth (21) can be obtained over a wide range of stocking densities, is paramount to this study. Cubic foot volumes are used in the development of this model because it "is the only commonly employed unit of measure that has biological significance" (24).

It should be noted that the cubic foot volume for the 20-year-old stand is considerably more than Staebler's gross yield. As stated by Staebler (21) the yield tables actually show net yield, because there are no estimates of mortality below age 20. The net yields as shown by McArdle (18, p. 14) are based upon 1460 trees per acre 3.4 inches D.B.H. Our forest manager's model is based on 540 stems per acre 6.0 inches D.B.H. Therefore it seems reasonable to assume that the managed model stand would contain much more cubic volume than an unmanaged natural stand.

Board Foot Volumes

The next step for the forest manager is to convert the cubic-foot volumes in the model to board foot volumes. The present market

structure is based on the board-foot; therefore in order to obtain a realistic value the model must be in final terms of Scribner board feet. Board foot/cubic foot ratios for Douglas-fir trees in terms of D.B.H. and total tree height can be found in Commercial Thinning of Douglas-fir in the Pacific Northwest, Table 31 (28, p. 115). The values for the model are interpolated from Table 31 (28) for the height and diameter from the model, and are presented here.

Table 14. Average board-foot/cubic-foot ratios by density class and age class.

Age	50	60	70	80	90	100
0						
10						
20	1.5	1.5	1.5	1.5	1.5	1.5
30	2.6	2.5	2.4	2.2	1.9	1.6
40	4.5	4.1	3.8	3.4	3.1	2.8
50	5.1	5.1	5.0	4.6	4.1	3.8
60	5.2	5.2	5.2	5.2	5.2	5.2
70	5.3	5.3	5.3	5.3	5.3	5.3

The board foot/cubic foot ratios from Table 14 are then applied directly to the cubic foot volumes for each density class. The resulting Scribner board-foot volumes for the volume removed in each thinning and final harvest are shown in Table 15.

Table 15. Average board-foot volumes per acre by density class and age.

Age	Type of volume	50	60	70	80	90	100
20	after	1798	2150	2502	2892	3236	3588
	removed	2333	1981	1629	1239	895	543
	before (total)	4131	4131	4131	4131	4131	4131
30	after	6190	6812	7517	7839	7509	6859
	removed	2777	2395	1886	1353	864	568
	before (total)	8967	9207	9403	9192	8373	7427
40	after	15952	16474	17157	17048	16982	16904
	removed	5427	4416	3751	3124	2616	1736
	before (total)	21379	20890	20908	20172	19598	18640
50	after	23098	26122	28730	29279	28569	28625
	removed	6967	6355	5595	4595	3526	3245
	before (total)	30065	32477	34325	33874	32095	31870
60	after	28506	31741	35412	38761	42292	46114
	removed	6849	6697	6271	6141	5746	4862
	before (total)	35355	38438	41683	44902	48038	50976
70	after						
	removed	40132	43428	47170	50583	54182	58077
	before (total)						

The forest manager now has his model constructed, and knows the volumes and tree sizes he can expect from each of six forms of management. He now must determine the value of the timber produced and the growing stock to complete the rest of his analysis. Forestry is a unique industry for many reasons. One of the prime reasons is the fact that the factory (growing stock) and the product (growth) are essentially the same. Being the same, when the value per unit of one is determined, the value of the other is also determined. For simplicity, the accepted procedure is to determine the stumpage value of the product by means of conversion surplus (9, p. 122). Conversion surplus is the market value of the product minus all variable costs. This leaves the owner with a margin for profit and risk, and revenue to pay the fixed costs of conversion and management. In this way the realization value to the land owner can be determined.

Any appraisal of timber values must be performed under a set of conditions, such as distance to market, type of roads, type of logging, type of terrain, and size of timber. The model presented here is an example of six methods of management for the same piece of ground. Therefore one set of conditions will suffice for all density classes. The area under consideration will be owned by a small land owner, who contracts the logging operation to a small logging operator. The logs will be sold to a local sawmill for current delivered pond value, and pulpwood will be sold to a pulp mill at the same

location. The study will be located 20 miles from the mills in Benton County, Oregon. The haul distance will be ten miles on hard surface road, five miles on gravel surface, and five miles on dirt surface. All roads will be considered as in place and no construction or reconstruction needed. The products will all be sold by the land owner to the same mills. The products will consist of pulpwood and sawlogs, with sawlogs being the primary product. The log prices will be taken from the March 5, 1968 Farm Forest Products Market Report for area 4, central west side Oregon. The log prices are as follows:

Table 16. Log prices for Douglas-fir area #4.

Log grade	\$/M. B. F. Scribner
1P	110-130
2P	100-120
3P	90-100
SP	85
CP	28-30
2S	65-70
3S	40-50
Pulpwood	25

Log Grade Determination

The first step in an appraisal is the establishment of weighted pond values based on log grade percentages. With the weighted pond values a more direct appraisal can be made. The establishment of

log grades for stands of different stocking is a very important part of this appraisal. Grah (11) has done work in this area. The breakdown of log grade percentages will be based upon his study. Although Grah's study was for unmanaged stands starting at different levels of stocking, it can be applied to the model in this case. The model is assumed to be thinned on a mechanical basis. Therefore the average diameter and stand development will be much the same as the natural stands in Grah's study (11). With this assumption, the grade percentages may be applied to the model volumes. The log volume percentages in each grade were plotted on the basis of percentages of log volume and stand density for that age class. The log volume percentages were taken from Table 8 of Grah's study (11, p. 640) and projected here in Figures 2, 3, and 4. The percentage of volume for each log grade and age are read from the curves and incorporated in tabular form. Grah's study was based upon the standard log grades. Only three grades appear in a 70-year rotation, #2 sawlogs, #3 sawlogs, and fast growth. Fast growth logs are essentially the same as #3 sawlogs with the exception of growth rate. Fast growth logs are those logs that grow at a rate greater than six rings per inch.

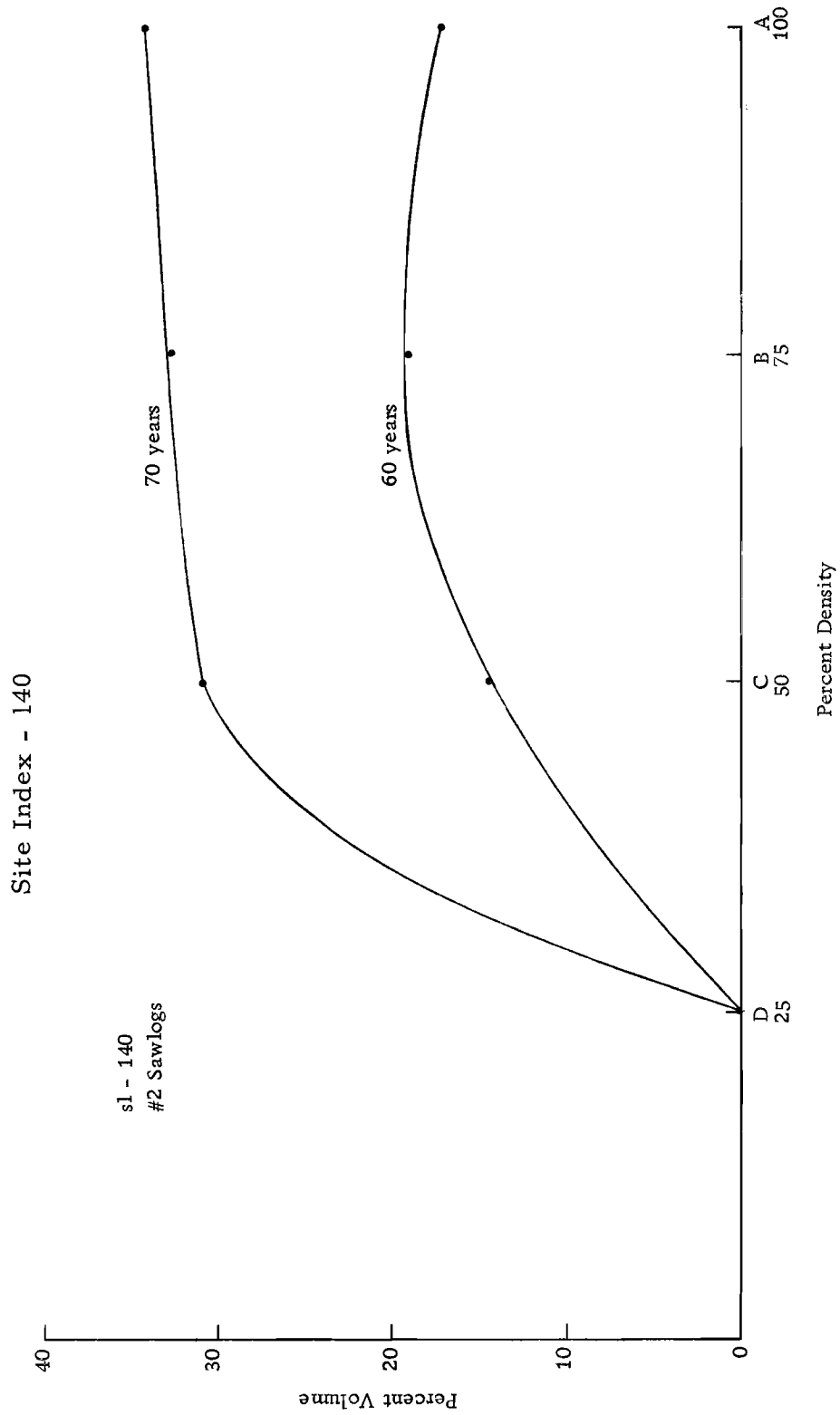


Figure 2 Percent volume of #2 sawlogs for different age classes by stocking density.

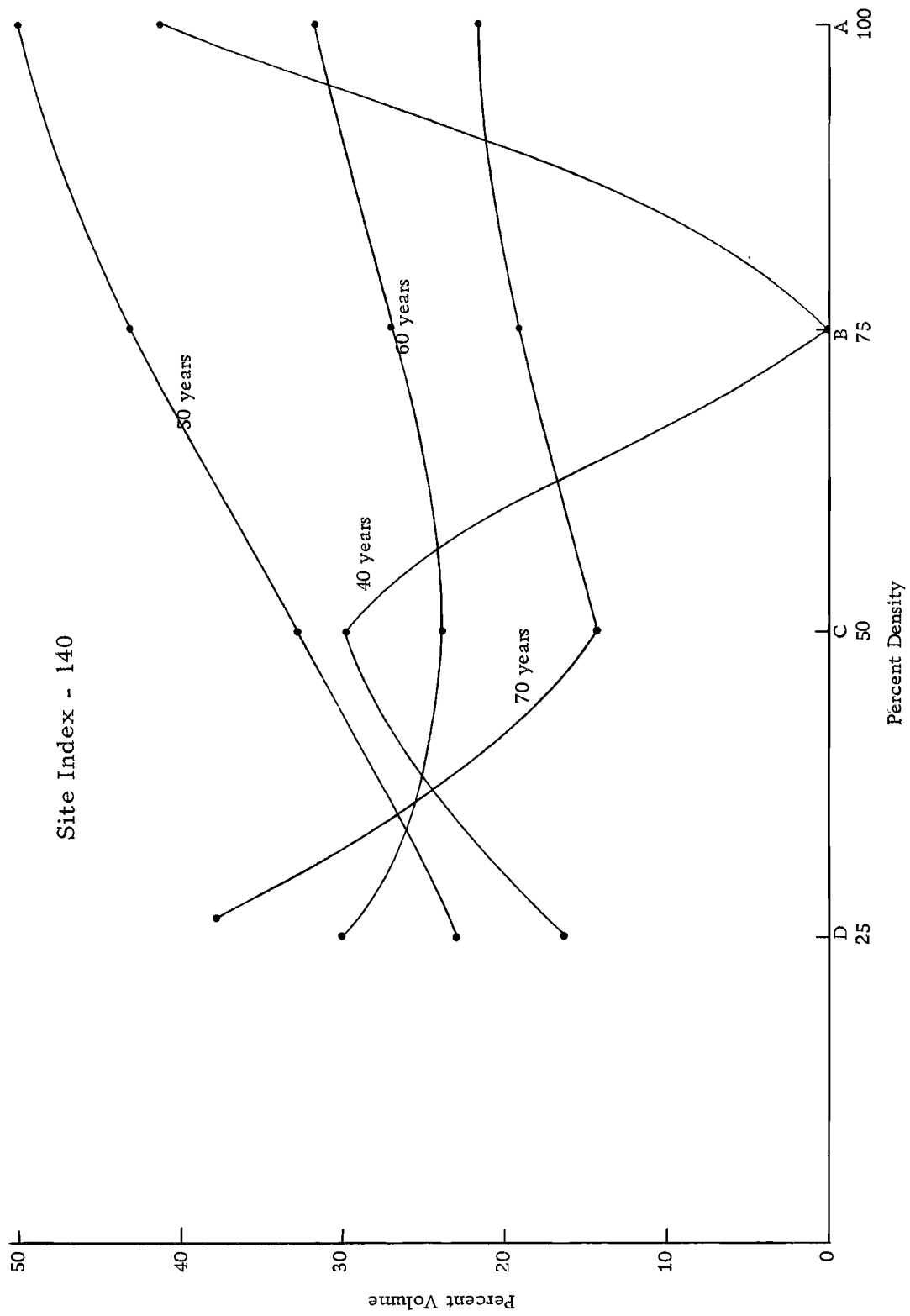


Figure 3 Percent volume of #3 sawlogs for different age classes by stocking density.

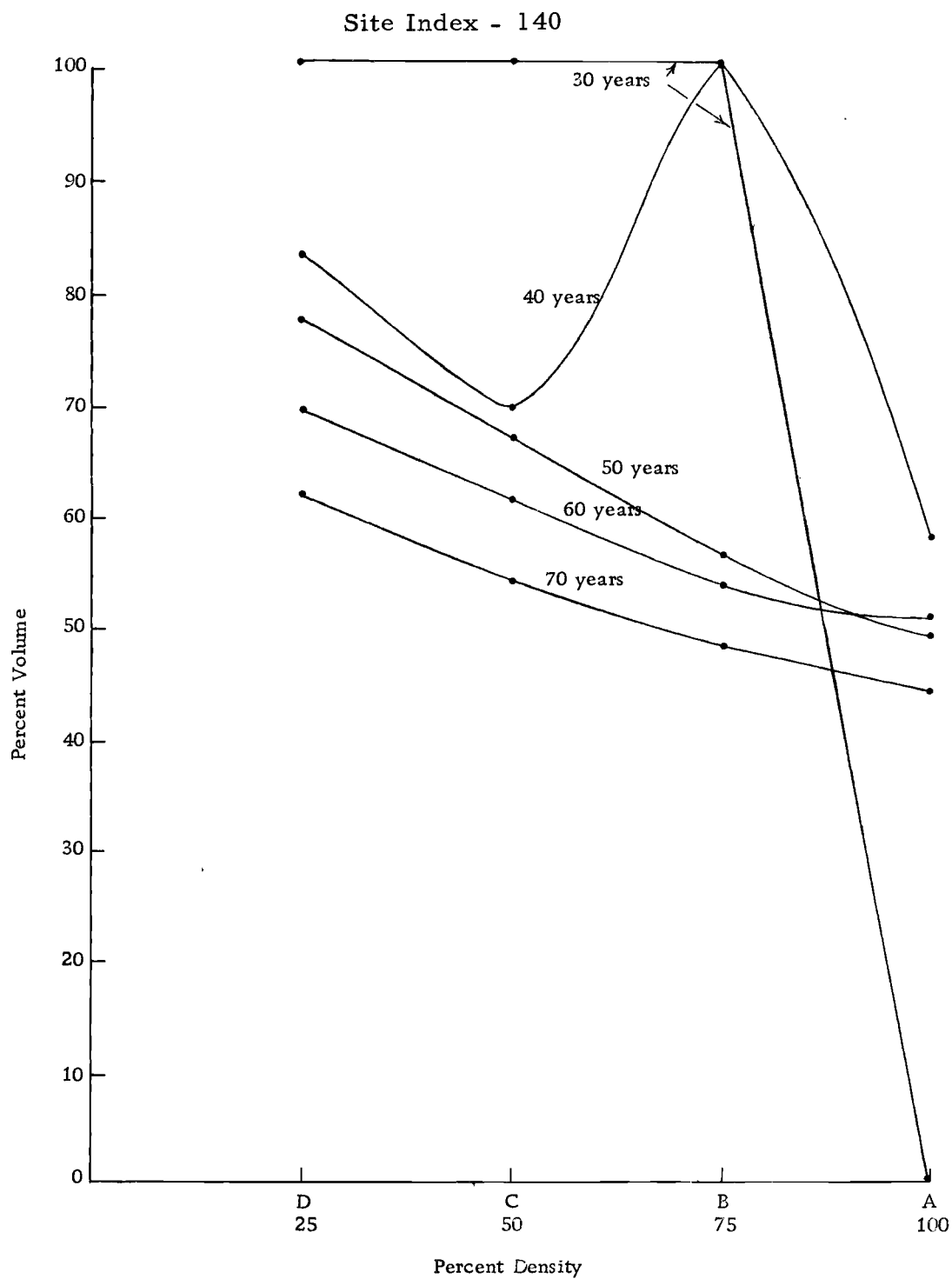


Figure 4. Percent volume of fastgrowth sawlogs for different age classes by stocking density.

Table 17. Log grade volume percentages for density classes and ages.

Density class log grade Age	50				60				70			
	#2 sawlogs %	#3 sawlogs %	fast growth %	total %	#2 sawlogs %	#3 sawlogs %	fast growth %	total %	#2 sawlogs %	#3 sawlogs %	fast growth %	total %
20				0				0				0
30			100	100			100	100			100	100
40		30.0	70.0	100			17.5	82.5		5.2	94.8	100
50		32.7	67.3	100			37.0	63.0		41.3	58.7	100
60	14.3	24.2	61.5	100	17.5	24.4	58.1	100	19.4	25.3	55.3	100
70	30.8	14.7	54.5	100	32.1	16.1	51.8	100	32.4	18.1	49.5	100

Density class log grade age	80				90				100			
	#2 sawlogs %	#3 sawlogs %	fast growth %	total %	#2 sawlogs %	#3 sawlogs %	fast growth %	total %	#2 sawlogs %	#3 sawlogs %	fast growth %	total %
20				0				0				0
30			100	100				0				0
40		4.4	95.6	100			20.6	79.4		41.9	58.1	100
50		45.3	54.7	100			48.2	51.8		50.3	49.7	100
60	19.0	28.0	53.0	100	18.5	29.7	51.8	100	17.0	31.8	51.2	100
70	33.0	20.0	47.0	100	33.0	21.0	46.0	100	34.3	21.7	44.0	100

Model Appraisal

Table 17 shows the volume percentages for each age class and density class for the three log grades used and defined by Grah (11, p. 630). Fast growth log grades, as defined by Grah (11, p. 630), are primarily the same as the other grades except growth rate. The rapid growth rate reduces the quality of these logs. Current marketing practices do not specify the fast growth log grade. The volume percent in the fast growth category must, therefore, be included in another grade. Because the fast growth is generally of poorer quality, it will be combined with the #3 sawmill grade and be assigned the same value. In this way, the reduction in quality due to growth rate will be reflected in log prices.

The grade percentages for each age and stocking density are then multiplied by the grade values found in Table 16 to obtain the weighted average value per thousand board foot pond value. These values are used for the appraisal, and are the base for all economic calculations.

The average board feet per tree is determined by dividing the board feet (Scribner) per acre by the number of trees per acre from the model. These volumes are then interpolated in Table 13 of Bulletin 201 (18, p. 52). The merchantable height for the smaller diameters are estimated.

Table 18. Combined log grade percentage by density classes and age.

Age	50				60				70			
	#2		#3		#2		#3		#2		#3	
	sawlog %	total %	sawlog %	total %	sawlog %	total %	sawlog %	total %	sawlog %	total %	sawlog %	total %
20		0		0		0		0		0		0
30		100	100	100		100	100	100		100	100	100
40		100	100	100		100	100	100		100	100	100
50		100	100	100		100	100	100		100	100	100
60	14.3	85.7	100	100	17.5	82.5	100	100	19.4	80.6	100	100
70	30.8	69.2	100	100	32.1	67.8	100	100	32.4	67.6	100	100
80												
				80				90				100
Age	#2		#3		#2		#3		#2		#3	
	sawlog %	total %	sawlog %	total %	sawlog %	total %	sawlog %	total %	sawlog %	total %	sawlog %	total %
20		0		0		0		0		0		0
30		100	100	100		0		0		0		0
40		100	100	100		100	100	100		100	100	100
50		100	100	100		100	100	100		100	100	100
60	19.0	81.0	100	100	18.5	81.5	100	100	17.0	83.0	100	100
70	33.0	67.0	100	100	33.0	67.0	100	100	34.3	65.7	100	100

Table 19. Weighted average pond log prices by age and density class.

Age	50	60	70	80	90	100
20	\$25.00	\$25.00	\$25.00	\$25.00	\$25.00	\$25.00
30	45.00	45.00	45.00	45.00	25.00	25.00
40	45.00	45.00	45.00	45.00	45.00	45.00
50	45.00	45.00	45.00	45.00	45.00	45.00
60	48.21	48.93	49.37	49.28	49.16	48.83
70	51.93	52.23	52.29	52.43	52.43	52.71

Table 20. Average board-feet per tree (Scribner) and corresponding average merchantable height
(in 16 foot logs) by density class and age.

Age	50			60			70			80			90			100		
	Bd.ft. /tree	Mer. ht.		Bd.ft. /tree	Mer. ht.		Bd.ft. /tree	Mer. ht.		Bd.ft. /tree	Mer. ht.		Bd.ft. /tree	Mer. ht.		Bd.ft. /tree	Mer. ht.	
0																		
10																		
20	8	1		8	1		8	1		8	1		8	1		8	1	
30	38	2		33	2		29	2		24	2		20	2		16	2	
40	132	3		100	3		80	3		63	3		52	2		43	2	
50	248	5		198	4		160	4		125	3		97	3		81	3	
60	380	6		291	5		233	4		192	4		163	4		145	4	
70	535	6		398	6		310	5		250	5		209	4		182	4	

Using Table 20 as a base, the felling and bucking costs for the models are determined from Table 1 of Schedule 15 of Logging Costs published by the Bureau of Land Management (25, 9331.22a). An assumed average top loss of five percent is used throughout. Percent top loss is the estimated average volume loss in the upper stem from breakage and rot expressed as a percentage of gross volume. The base costs are then reduced by \$.05 per 12 trees per acre cut in accordance with the instructions in Schedule 15 (25, 9331.22a). The felling and bucking costs are summarized in Table 21.

As stated in the case description, this model represents a small operation by a small operator. For this reason the skidding and loading costs will be based on the light yarder-loader costs as found in Schedule 15 Table 24 (25, 9331.23G2b). The yarding costs are based on a 200 foot yarding distance, and the average Scribner Decimal C. volume per log. A fixed cost of \$1.30 per M.B.F. is added for loading, from Table 35 of schedule 15 (25, 9331.23G2b). An additional cost of rigging and move-in are added to complete the yarding and loading costs. The rigging and move-in costs are based on one setting per operation of ten acres of logging. The total rigging and move-in costs from Schedule 15 Table 36 and 6 respectively (25, 93331.23G, 93331.23cl) is \$62. This is prorated on a M.B.F. basis for the volume removed and added to the yarding and loading costs. The total yarding and loading costs are shown in Table 22.

Table 21. Total felling and bucking costs per M. B. F. by density class and age.
(in dollars)

Age	50	60	70	80	90	100
0						
10						
20						
30	4.65	4.65	4.65	4.70		
40	3.85	3.80	3.80	3.80	4.75	4.80
50	2.40	3.00	3.00	3.85	3.85	3.85
60	1.90	2.40	3.05	3.00	3.00	3.00
70	1.65	1.50	1.85	1.65	2.05	1.80

Table 22. Total yarding and loading costs (light yarder loader) per M.B.F. by density class and age.
(in dollars)

Age	50	60	70	80	90	100
0						
10						
20						
30	17.33	17.79	18.49	19.88		
40	15.64	16.20	16.55	17.08	17.27	18.67
50	15.19	15.28	15.71	15.95	16.56	16.81
60	14.80	15.03	15.09	15.31	15.68	15.98
70	13.35	13.94	14.13	14.42	14.31	14.51

The base yarding costs are read from a curve of yarding costs over log volume in order that the cost of yarding the smaller diameter logs may be determined. The yarding costs are shown in Figure 5.

Transportation costs in Schedule 15 (25) are based upon the travel time for various road surfaces and the average weight per board-foot. The round trip time is based on the description of haul distance previously stated, on an average percent of rise of 30-40 percent, and on a rate of rise and fall of 5.0 percent drop. The round trip times in minutes per mile are found in Tables 1, 2, and 3 of Schedule 15 (25, 9331.25). The total round trip time is determined as follows:

<u>Road Surface</u>	<u>Minutes per mile</u>	<u>Miles</u>	<u>Time</u>
hard surface	5.7	10	57.0
gravel surface	8.9	5	44.5
dirt surface	10.5	5	<u>52.5</u>
Total			154.0

The costs per M. B. F. are then determined by the average weight per board-foot plus the cost for delay time. The average log scale recovery is assumed to be 95 percent. The average weight per board foot is assumed to be 11 pounds per board-foot because of the relative small timber being hauled. Delay time for each round trip is assumed to be 20 minutes. The hauling costs are determined from Tables 4 and 5 of Schedule 15 (25, 933.25), and are calculated as follows:

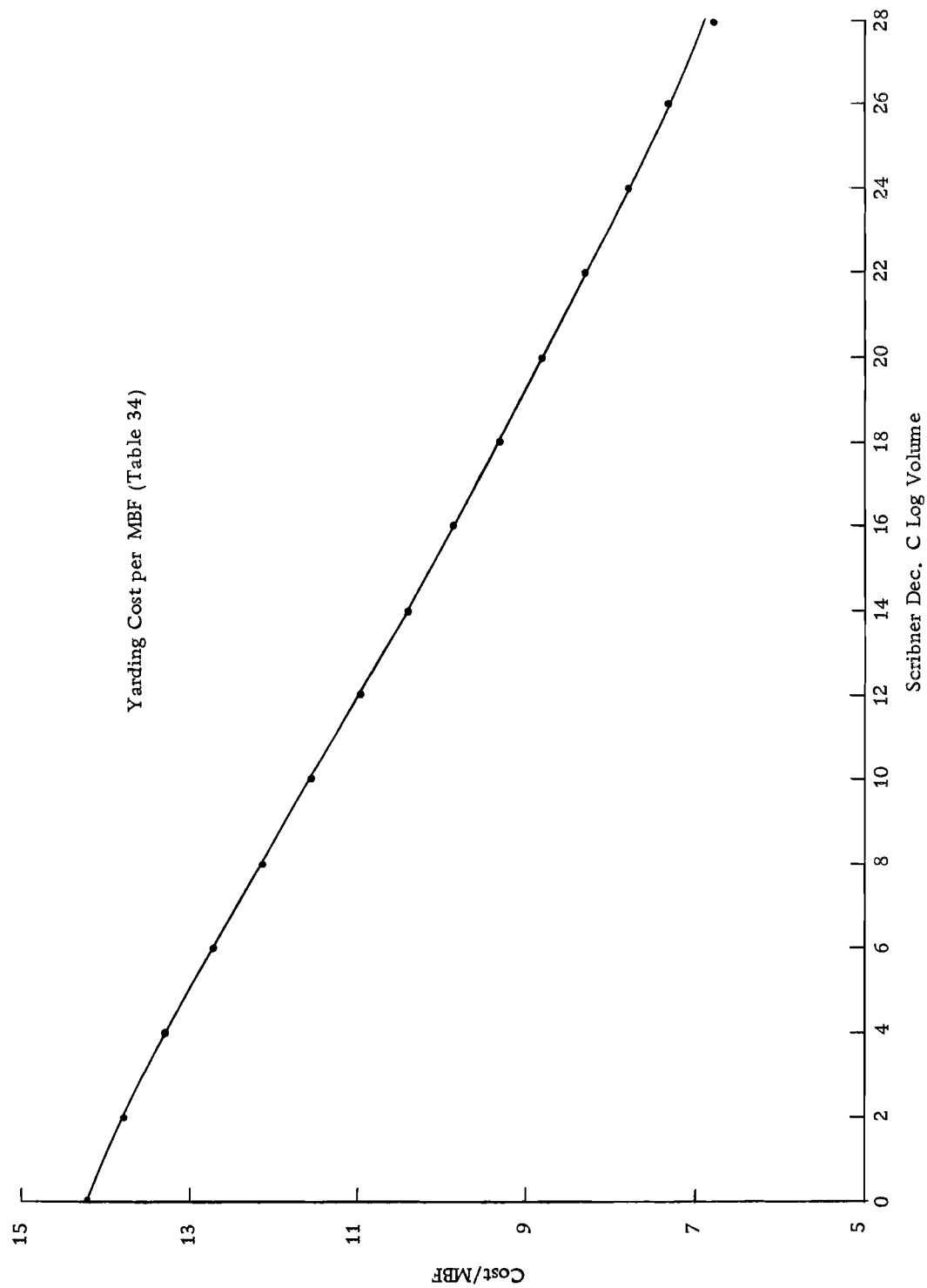


Figure 5 Yarding costs per M. B. F. by Scribner Dec. C volume of average log.

	<u>Cents per minute</u>	<u>minutes</u>	<u>costs per M. B. F.</u>
hauling	4.40	154	6.78
delay	3.20	20	<u>0.64</u>
Total haul costs			\$7.42

In addition to the basic logging costs, there are other costs that must be covered by the appraisal. These would include the cost of road maintenance, and slash disposal costs for the final harvest. As general logging supervision is included in the individual cost allowances an additional allowance will not be made. Road maintenance will be charged at the rate of \$.10 per M. B. F. (25, 9331.26) per mile of unsurfaced road. On that basis \$1.00 per M. B. F. will be charged for road maintenance. The slash disposal costs for the final harvest are based on Table 3 of Schedule 15 (25, 9331.26D) for a balanced model of ten acres cut each year in final harvest. The slash disposal costs per M. B. F. by density class are:

Age	50	60	70	80	90	100
70	\$.40	\$.36	\$.32	\$.32	\$.32	\$.27

The appraisal for logging costs of pulpwood on the same basis as that for sawlogs is not realistic. Therefore the pulpwood harvest will be appraised separately from the sawlogs. The pulpwood harvest, would of necessity be a very small operation involving one or two men with very little or no equipment. The investigation into the literature on hand failed to reveal any reliable cost estimates based upon M. B. F.

Therefore, the cost of production for pulpwood must be based upon personal knowledge of operations of this type. For the logging of this small volume per acre, the cost for small size material will average \$16.00 per M. B. F. The figure is determined as follows:

1. A two-man operation, each man to receive \$25.00 for a day's wage.
2. One small tractor costing \$4.00 per hour with average operating time of four hours per day.
3. One small truck with self loader charged at \$6.00 per hour operating for five hours per day.
4. Crew would put out an average of two loads per day, each load averaging 3 M. B. F.
5. This brings the total cost for 6 M. B. F. to \$96.00 or \$16.00 per M. B. F.

The cost of production for all pulpwood will be assumed to be \$16.00 per M. B. F.

Another factor in the determination of conversion is the variable forestry cost due to the different forms of management. In this case the variable cost is that of marking the stands for harvest. Since all cuts until the final harvest are forms of commercial thinning, and must be marked on an individual tree basis, the time required to mark each individual tree must be determined and this converted to cost per thousand board feet. In Bulletin 1230,

Table 23. Cost per M. B. F. for marking and preparation by age and density class (in dollars).

Age	50	60	70	80	90	100
0						
10						
20	2.96	2.96	2.96	2.96	2.99	2.95
30	2.05	2.22	2.40	2.69	2.99	3.53
40	1.49	1.65	1.82	2.04	2.24	2.53
50	1.36	1.45	1.56	1.72	1.92	2.11
60	1.29	1.38	1.47	1.57	1.67	1.75
70	1.00	1.00	1.00	1.00	1.00	1.00

Table 5 (28, p. 57) gives the marking time required per tree. These values are plotted and the marking time per tree for each age class is read directly from the curve. These marking times are then multiplied by an assumed rate of five dollars per man hour and the number of trees removed in each thinning. To determine the cost per M. B. F. the cost per acre is divided by the volume removed. An additional cost of one dollar per M. B. F. is added for preparation. The cost per M. B. F. is found in Table 23.

The cost of the preparation of the final harvest is set at one dollar per M. B. F. No trees will be marked at final harvest.

With this the total variable costs for this case timber tract can now be determined. The total variable costs subtracted from the weighted pond log value will give the stumpage value that will be used in the final calculation of this study. The variable costs are summarized in Table 24.

Table 24. Total variable costs and conversion surplus by age and density class.

Age	Type of value	50	60	70	80	90	100
20	Pond value	\$25.00	\$25.00	\$25.00	\$25.00	\$25.00	\$25.00
	Logging costs	16.00	16.00	16.00	16.00	16.00	16.00
	Forestry costs	2.96	2.96	2.96	2.96	2.99	2.95
	Conversion surplus	6.04	6.04	6.04	6.04	6.01	6.05
30	Pond value	45.00	45.00	45.00	45.00	25.00	25.00
	Logging costs	30.40	30.86	31.56	33.00	16.00	16.00
	Forestry costs	2.05	2.22	2.40	2.69	2.99	3.53
	Conversion surplus	12.55	11.92	11.04	9.31	6.01	5.47
40	Pond value	45.00	45.00	45.00	45.00	45.00	45.00
	Logging costs	27.91	28.42	28.77	29.30	30.44	31.89
	Forestry costs	1.49	1.65	1.82	2.04	2.24	2.53
	Conversion surplus	15.60	14.93	14.41	13.66	12.32	10.58
50	Pond value	45.00	45.00	45.00	45.00	45.00	45.00
	Logging costs	26.01	26.70	27.13	28.22	28.83	29.08
	Forestry costs	1.36	1.45	1.56	1.72	1.92	2.11
	Conversion surplus	17.63	16.85	16.31	15.06	14.25	13.81
60	Pond value	48.21	48.93	49.37	49.28	49.16	48.83
	Logging costs	25.12	25.85	26.56	26.73	27.10	27.40
	Forestry costs	1.29	1.38	1.47	1.57	1.67	1.75
	Conversion surplus	21.80	21.70	21.34	20.98	20.39	19.68
70	Pond value	51.93	52.23	52.29	52.43	52.43	52.71
	Logging costs	23.82	24.22	24.72	24.81	25.10	25.00
	Forestry costs	1.00	1.00	1.00	1.00	1.00	1.00
	Conversion surplus	27.11	27.01	26.57	26.62	26.33	26.71

Value Model

The stumpage values are applied to the board foot volume per acre as shown in Table 15. The resultant volume yield per acre of volume harvested and growing stock are shown in Table 25.

For a more realistic result the values in Table 25 must be reduced by county property taxes. It is assumed that this land will be classed under the Oregon forest-fee-and-yield-tax. This tax is assessed at ten cents per acre annual tax plus $12\frac{1}{2}\%$ yield tax on the value of the products harvested. The ten cents per acre annual tax will be handled as an annual expense in the soil expectation value equation. The gross value yield, as shown in Table 25 will be reduced by $12\frac{1}{2}\%$ to obtain the net revenue. This net revenue will be used in the economic analysis. The net revenues are expressed in Table 26.

Table 25. Value yield per acre by density class and age.

Age	Type of yield	50	60	70	80	90	100
20	After thin	\$10.86	\$12.99	\$15.11	\$17.47	\$19.45	\$21.71
	Removed	14.09	11.96	9.84	7.48	5.38	3.28
	Before (Total)	24.95	24.95	24.95	24.95	24.83	24.99
30	After thin	77.68	81.20	82.99	72.98	45.13	37.52
	Removed	34.85	28.55	20.82	12.60	5.19	3.11
	Before (Total)	112.53	109.75	103.81	85.58	50.32	40.63
40	After thin	248.85	245.96	247.23	232.88	209.22	178.84
	Removed	84.66	65.93	54.05	42.67	32.23	18.37
	Before (Total)	333.51	311.89	301.28	275.55	241.45	197.21
50	After thin	407.22	440.16	468.59	440.94	407.11	395.31
	Removed	122.83	107.08	91.25	69.20	50.25	44.81
	Before (Total)	530.05	574.24	559.84	510.14	457.36	440.12
60	After thin	621.43	688.78	755.69	813.21	862.33	907.52
	Removed	149.31	145.32	133.82	128.84	117.16	95.68
	Before (Total)	770.74	834.10	889.51	942.05	979.49	1003.20
70	After thin						
	Removed	1087.98	1172.99	1253.31	1346.52	1426.61	1551.24
	Before (Total)	1087.98	1172.99	1253.31	1346.52	1426.61	1551.24

Table 26. Net revenue per acre by density class and age.

Age		50	60	70	80	90	100
20	Harvest	\$14.09	\$11.96	\$ 9.84	\$ 7.48	\$ 5.38	\$ 3.28
	Yield tax	1.76	1.50	1.23	.94	.67	.41
	Net revenue	12.33	10.46	8.61	6.54	4.71	2.87
30	Harvest	34.85	28.55	20.82	12.60	5.19	3.11
	Yield tax	4.36	3.57	2.60	1.58	.65	.39
	Net revenue	30.49	24.98	18.22	11.02	4.54	2.72
40	Harvest	84.66	65.93	54.05	42.67	32.23	18.37
	Yield tax	10.58	8.24	6.76	5.33	4.03	2.30
	Net revenue	74.08	57.69	47.29	37.34	28.20	16.07
50	Harvest	122.83	107.08	91.25	69.20	50.25	44.81
	Yield tax	15.35	13.38	11.41	8.65	6.28	5.60
	Net revenue	107.48	93.70	79.84	60.55	43.97	39.21
60	Harvest	149.31	145.32	133.82	128.84	117.16	95.68
	Yield tax	18.66	18.17	16.73	16.10	14.65	11.96
	Net revenue	130.65	127.15	117.09	112.74	102.51	83.72
70	Harvest	1087.98	1172.99	1253.31	1346.52	1426.61	1551.24
	Yield tax	136.00	146.62	156.66	168.32	178.33	193.91
	Net revenue	951.98	1026.37	1096.65	1178.28	1248.28	1357.33

Economic Analysis

The economic analysis is run on the basis of the best choice. The analysis is by soil expectation value and mean compound rate of return. The analysis of the soil expectation value will use the standard compound interest formula which is:

$$S.E.V. = \left[\frac{T_1(1+p)^{r-n_1} + T_2(1+p)^{r-n_2} + \dots + T_k(1+p)^{r-n_k} + Y_r - C}{(1+p)^r - 1} \right] - C - \frac{e}{p}$$

Where:

S.E.V. = soil expectation value

Y_r = value yield at harvest

T_1, T_2, \dots, T_k = thinning value yield of 1, 2, ..., k thinning

n_1, n_2, \dots, n_k = age at which thinnings occur

C = stand establishment costs per acre

e = average annual fixed costs per acre

p = interest rate

r = rotation age

For the purposes of comparison, the bare land value, or soil expectation value of each alternate method of management will be determined. The alternate rate of return for this calculation will be $4\frac{1}{2}\%$ for the private owner. This $4\frac{1}{2}\%$ is comparable to the

long-term average rate of return on common-stocks of well established corporations, or other investments of comparable risks. The fixed costs of management, which were not used in the calculation of the stumpage value, are assumed to be the same for all alternatives. The stand establishment costs are fixed at \$30.00 per acre, which includes the cost of planting and the cost of the seedlings. The fixed annual costs are assumed to be \$0.50 per acre for all alternatives. This \$0.50 includes the \$.10 per acre forest-fee tax previously mentioned.

The variables for calculating the soil expectation values are summarized in Table 27.

The variables are incorporated into the formulas and the following soil expectation values are found:

<u>Density class</u>	<u>Soil expectation value</u>
50	\$52.72
60	49.13
70	45.59
80	42.24
90	38.67
100	38.46

The same soil expectation value formula was used to determine the mean compound rate of return for the alternatives. This compound rate of return was found by assuming a bare soil value of

Table 27. Soil Expectation Value variables by density class.

Variable	50	60	70	80	90	100
T ₁	\$12.33	\$10.46	\$ 8.61	\$ 6.54	\$ 4.71	\$ 2.87
T ₂	30.49	24.98	18.22	11.02	4.54	2.72
T ₃	74.08	57.69	47.29	37.34	28.20	16.07
T ₄	107.48	93.70	79.84	60.55	43.97	39.21
T ₅	130.65	127.15	117.09	112.74	102.51	83.72
Y _r	951.98	1026.37	1096.65	1178.20	1248.28	1357.33
C	30.00	30.00	30.00	30.00	30.00	30.00
e	0.50	0.50	0.50	0.50	0.50	0.50
p	4.5%	4.5%	4.5%	4.5%	4.5%	4.5%

\$24.00 per acre, which is the average for the Benton County area of Oregon, and the same fixed costs. The value of "p" was found by trial and error. The results of these calculations were as follows:

<u>Density class</u>	<u>Mean compound rate of return</u>
50	5.3%
60	5.1%
70	5.0%
80	4.9%
90	4.85%
100	4.80%

From both of these analyses, it would seem that the forest manager working under the assumptions and the characteristics of stand development as shown by the model for this one stand would manage his land on the basis of 50% of normal basal area. It is at this point, density class 50, that the soil expectation value is the highest, and the mean compound rate of return is also the highest. These results would tend to confirm the hypothesis made by Staebler in "Optimum Levels of Growing Stock for Managed Stands" (22). The Density class 50 would represent the dividing line between density class 2 and 3 as stated by Staebler (22), as the point at which growth is at maximum, and growing stock is at the minimum necessary to sustain maximum growth. This proposition should be further tested for concrete proof.

DISCUSSION AND CONCLUSIONS

As stated at the beginning of this study, one objective is the demonstration of a method for determining an economic point of stocking in managed Douglas-fir. The procedure has been shown by way of example. The next step will be to boil down this procedure for easier understanding. The basic steps of the procedure would be:

1. Development of a physical forest model for each alternative.
2. Determine log grade distribution of each alternative and the weighted average selling value.
3. Determine the cash value of the return of each alternative.
4. Choose the best alternative through economic analysis of each projection, by means of soil expectation value and compound rate of return.

The development of the physical model is the most difficult and important part of the procedure. Without an adequate projection of the stand development within the alternatives being tested, the remaining steps will be of little value. The alternatives should encompass the entire range of stocking densities on the extreme ends, as controls or contrasts. The models should be based upon the best information available to the individual land owner. Past growth data from permanent plots should be used as indicators of production

capacity. Stand projections will need to be tailored to the individual's management decisions. To be the most profitable, the model should include as diversified a number of products as possible. In this way a manager may take advantage of as many markets as possible. Each alternative method of management and harvest should be analyzed from the standpoint of the full production capacity of the site and individual needs. The model should also be in terms that can easily be converted to physical stand characteristics, such as stems per acre, basal area per acre, cubic-foot volume per acre, and board-foot volume per acre. The easiest terms, for final application of the alternative, would be stems per acre and basal area per acre. The models under consideration should reflect the conditions that the stand would have under sustained yield, not under the present condition. Because as the stand comes under management the growth characteristics and stand composition of the stand would drastically change, and under final sustained yield management would have no relation to a normal wild stand.

Each alternative model should be programmed by mechanical calculations tempered with the silvicultural capacities of the site. The physical model must reflect the best judgment of the forest manager as to the development of each alternative. The stand projections presented here, as an example, were based on a relationship between basal area per acre of the alternatives and the basal area of

a normal unmanaged stand. Other stand projections have been based upon attainable diameter (25), and number of trees per acre in relation to normal (11). There are many methods of expressing stand density and making stand projections. With the use of a computer, more of the complex variables of stand growth and management can be brought into play, and the resultant stand projection be based on fewer assumptions. Actual field measurements and comparisons with established studies will form the basis for many of the assumptions used here. With the development of a physical model of stand development under each alternative being investigated, the next step may be taken.

The next step, product identification, is also an important one. The proper distribution of products between sawlog grades and additional products will determine the final cash value of the stand. The stand projection of each alternative will result in a different sawlog grade distribution as shown in previous studies (11). The product identification should take all products into account, and the changes in individual tree characteristics as a result of managing under different stocking densities. The distribution of products should also reflect the most profitable products in each alternative. In the lower stocking classes the number of high-grade sawlogs tends to decrease because of the increased limbiness of the more open-grown trees. This decrease in grade is partly offset by the larger board-foot

volume per tree in the lower density classes. Product distribution should be based upon the integration of field studies, stand measurements, and the results of the physical stand projections for each alternative method of management.

The establishment of stand value is in reality two steps. One step is the establishment of stumpage values. For a comparison study, conversion surplus can be used for determining the values per unit of volume. Conversion surplus does not include the fixed costs, which would be the same for all alternatives and would not affect the comparison of alternatives. The stumpage appraised should include the difference in costs of conversion for the different products and stand densities as found in the physical model. The stumpage values are then converted to stand values from the physical models to produce a value model for each alternative.

The final step is the economic analysis of the value model to determine the best stocking point. The most equitable method of comparing the alternatives would be to discount the net returns to the same point for each alternative using the bare soil value for the highest. This is known as the soil expectation value, and gives a direct comparison of the alternative methods of management. Another variation of the soil expectation method is to substitute the market values per acre of bare land and solve the soil expectation value formula for the rate of return by trial and error. In this way, the

alternative with the highest rate of return can also be determined. This will give the forest manager the stocking density he should be managing for to maximize the rate of return.

With the choice of the best stocking density made, the forest manager must proceed to bring his stand under this form of sustained yield management. The forest manager can then begin to bring, by thinning, these young stands to the desired density. The overmature stands can be cut out and reproduced to the desired density and be on the way to sustained yield more quickly. If the density class is determined to be rather low, as shown in the example in this study, the cutting of the immature stands to the desired density will give an increased immediate return over the management of a normal forest. The thinnings of high-density stands to lower-density stands should be done gradually to insure that loss due to shock, and wind-throw will be a minimum. The young stands should be thinned as rapidly as possible to take advantage of the early response and rapid growth that the young stands are capable of. Periodic recalculations of the most desirable stocking density as permanent plot data, and independent studies bring more information to the hands of the manager will keep the forest producing at the most advantageous point.

It must be stated in conclusion that the results of this study seem to confirm the statements of Davis (6, p. 51) that the desirable

level of growing stock cannot be solved for all cases by mathematical deduction. Along with this statement, the desirable level of growing stock for one individual may not necessarily be the same for the next. Each forest manager must solve the problem for his own unique management desire. This will also be a constantly changing determination as more is learned about the growth characteristics of the individual stands. The determination of the best stocking density must be based not only on strong economic principles, but also in light of the physiological limitations of the species and site as demonstrated by past and predicted performance of the individual stand.

This study has shown that the best stocking point can be determined through accepted standard comparison methods of alternatives. In this example, a simplified forest model, the best stocking point is the lowest stocking density considered. The establishment of a value forest model, then the comparison of the alternatives by use of soil expectation value seems to offer the best opportunity to determine this stocking point.

BIBLIOGRAPHY

1. Baker, F. S. Stand density and growth. *Journal of Forestry* 57:95-97. 1953.
2. Barnes, George H. Yield tables for Douglas-fir under intensive thinning regimes. Corvallis, 1955. 3 p. (Oregon State College. Forest Experiment Station. Research Note no. 1)
3. Behre, C. E. Growing stock, cutting age, and sustained yield. *Journal of Forestry* 53:403-408. 1955.
4. Braathe, Peter. Thinnings in even-aged stands. A summary of European literature. Fredericton University of New Brunswick, Faculty of Forestry, 1957. 92 p.
5. Brinkman, K. A., N. F. Rogers and S. F. Gingrich. Shortleaf pine in Missouri--stand density affects yield. Columbus, Ohio, 1955. (Central States Forest Experiment Station. Research Paper CS-#14)
6. Davis, K. P. American forest management. New York, McGraw-Hill, 1954. 482 p.
7. Davis, K. P. Comments of 'Forest growing stock'. *Journal of Forestry* 53:735-739. 1955.
8. Davis, K. P. Determination of desirable growing stock - a central problem of forest management. *Journal of Forestry* 54:811-815. 1956.
9. Duerr, William A. Forestry economics. New York, McGraw-Hill, 1960. 579 p.
10. Eversole, Kenneth R. Spacing tests in a Douglas-fir plantation. *Forest Science* 1:14-18. 1955.
11. Grah, Rudolf F. Effects of initial stocking on financial return from young-growth Douglas-fir. *Hilgardia* 29:613-679. 1960.
12. Gross, L. S. Forest growing stock. *Journal of Forestry* 53:403-408. 1955.

13. Hawley, Ralph C. and David M. Smith. The practice of silviculture. New York, Wiley, 1954. 435 p.
14. Hoyer, Gerald E. British thinning yield tables converted to American units of measure. Olympia, Wash. 1967. 15 p. (Washington, Dept. of Natural Resources. Report no. 9)
15. Homsgaard, Erik. Comments on some German and Swedish thinning experiments in Norway spruce. Forest Science 4: 54-60. 1958.
16. Johnson, Floyd A. Predicting future stand volumes for well-stocked Douglas-fir forests: a comparison of methods. Journal of Forestry 53:253-255. 1955.
17. King, James E. Site index curves for Douglas-fir in the Pacific Northwest. Centralia, Wash., 1966. 49 p. (Weyerhaeuser Forestry Paper no. 8)
18. McArdle, Richard E. and Walter H. Meyer. The yield of Douglas-fir in the Pacific Northwest. Rev. ed. Washington, D.C., 1949. 74 p. (U.S. Dept. of Agriculture. Technical Bulletin no. 201)
19. Meyer, H. A. et al. Forest management. 2d ed. New York, Ronald, 1961. 282 p.
20. Reukema, Donald L. Some recent developments in the Wind River Douglas-fir plantation spacing tests. Portland, 1957. 7 p. (Pacific Northwest Forest and Range Experiment Station. Research Note no. 167)
21. Staebler, George R. Gross yield and mortality tables for fully stocked stands of Douglas-fir. Portland, Ore., 1955. 20 p. (Pacific Northwest Forest and Range Experiment Station. Research Paper no. 14.)
22. Staebler, George R. Optimum levels of growing stock for managed stands. Society of American Foresters, Proceedings, 1959, p. 110-113.
23. Staebler, George R. Some mensurational aspects of the level-of-growing stock problem in even-aged forests. Journal of Forestry 56:112-115. 1958.

25. U. S. Bureau of Land Management. Logging costs, Schedule 15. Portland, Portland Service Center. May 15, 1967. 189p.
26. Walker, N. Growing stock volumes in unmanaged and managed forests. Journal of Forestry 54:378-83. 1956.
27. Wilson, F. G. Control of growing stock in even-aged stands of conifers. Journal of Forestry 49:692-295. 1951.
28. Worthington, N. P. and S. R. Staebler. Commercial thinning of Douglas-fir in the Pacific Northwest. Washington, D.C., 1961. 124 p. U. S. Dept. of Agriculture. Technical Bulletin no. 1230.)

