THE EFFECT OF PREPLANNED SKID TRAILS AND WINCHING ON A PARTIAL-CUT

by

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A PAPER

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Forestry

Completed March 14, 1979

Commencement June 1979

APPROVED:

Associate Professor of Forest Engineering
in charge of major

Head of Department of Forest Engineering

Date paper is presented March 14, 1979

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AN ABSTRACT OF THE PAPER OF

George Richard Bradshaw for the degree of Master of Forestry

in Forest Engineering presented on March 14, 1979

Title: The Effect of Preplanned Skid Trails and Winching on a Partial-Cut

Abstract approved: Penn A. Peters

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This paper describes the results of a study conducted in the Sierra Nevadas located in California to determine the production rates, skidding costs and the extent of soil disturbance and compaction on two partial cut units harvested with a Caterpillar D-7F. A harvest unit with preplanned skid trails and winching was compared to a conventional harvest unit.

Production for the unit with preplanned skid trails and winching was 11 percent less than the unit with conventional tractor logging. Skidding costs per unit volume were increased by 29 percent. The unit with preplanned skid trails resulted in four percent of the area in skid trails whereas the other unit had 22 percent of the area covered by skid trails.

Regression equations were developed for individual subcycles and the total cycle time. Results indicate that total cycle time with winching is a function of skidding distance, skid trail slope, number of logs per turn, volume per turn, number of winching cycles and the average winching distance.

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INTRODUCTION

Increasing demand for timber products dictates the importance of maintaining or improving the productivity of timber producing land. Logging practices can adversely affect the productivity by excessive soil disturbance, compaction and damage to the residual stand. Many past harvesting practices, in the Corral Timber Compartment, have taken well stocked stands and converted them into poorly stocked stands (Corral Timber Sale Environmental Analysis Report, 1977). The potential for a decrease in productivity is greatest on the higher quality sites. This is a result of the intensive management of such areas.

In a study by Froehlich (1976), conventional tractor harvesting methods resulted in damage to 39 percent of the residual stand and soil disturbance of 18-28 percent of the area. In the same report, Froehlich presented data showing an increase in soil densities of 21 percent on major skid trails.

Presently, the long term effects on timber production are not fully known. Youngberg (1959) showed that tractor roads are not conducive to the growth of Douglas-fir seedlings. Height growth showed a decrease up to 45 percent in the study. Perry (1964) compared height and volume growth of loblolly pine planted on compacted "woods roads" to those planted in adjacent fields. After 26 years, he found a 13 percent reduction in height growth, and a 53 percent reduction in volume for trees planted on the compacted areas. Froehlich (1979) reported that trees planted on heavily used skid trails averaged approximately one-third the volume of those growing on non to lightly compacted soils for 17-year old ponderosa pine. Therefore an effort should be made to minimize the damage to timber producing land until the long term effects are fully understood. Conventional tractor harvesting methods can be modified such that the amount of damage is minimized. The extensive use of winching and preplanned skid trails will reduce the area disturbed and compacted. Consequently, the damage to the residual stand will also be minimized.

Objectives

A study was conducted to observe the environmental benefits and costs of the extensive use of winching and preplanned skid trails. This paper presents the results obtained from a study completed in the summer of 1978 on the Stanislaus National Forest, Tuolumne County, California in cooperation with the Cal Sierra Logging Company.

The four objectives of this study were as follows:

1) Determine the significant factors affecting the skidding cycle, and develop regression equations to predict cycle times.
2) Determine the additional costs incurred with preplanned skid trails and winching compared to conventional tractor methods.

3) Determine the area disturbed with preplanned skid trails with winching and conventional tractor methods.

4) Determine the increase in soil densities on major skid trails for the two harvest methods.

LITERATURE REVIEW

Earlier studies by Adams (1967), Aulerich et al. (1974), McCraw (1964), and McDonald (1972) were conducted to determine the factors which significantly influence cycle time, subcycle time and skidding costs. Schillings (1969) developed a method of estimating skidding costs as function of average distance, terrain class, operator efficiency and size of crawler tractor. These studies dealt with the factors which influenced the skidding cycle but didn't consider winching as an individual subcycle. Although a study was conducted by Aulerich et al. (1974) which considered winching as a subcycle and presented a regression equation that indicated winching distance was a significant variable. However the study by Aulerich was conducted during a thinning operation on 35-year old Douglas-fir whereas this author's study was on a thinning operation in an old growth ponderosa pine stand.

At the U.S. Forest Service Silvicultural Development Unit, Clabaugh (1975) conducted a study on the use of preplanned skid trails in conjunction with winching. Results of the study were never published. Although the study showed that the extensive use of winching increased costs by 26 percent. Another study using preplanned skid trails and winching was conducted by Oregon State University (O.S.U.) in 1977, but the results have not been published to date.

Several studies on soil compaction and disturbance have shown significant effects from logging methods. Dyrness (1963) showed tractor logging (clearcut units) created greater areas of disturbance and compacted more soils than high lead logging. Dyrness separated soil disturbance into four (4) classes. The percent of total unit area of undisturbed, slightly disturbed, deeply disturbed and compacted is 35.6, 26.4, 8.9, and 26.8 percent, respectively. Compacted areas from tractor logging represent almost 27 percent of the area, with average bulk density values increasing 0.657 g/cc before logging to 0.975 g/cc after logging. In this study, the crawler tractors used were comparable in size to an older Caterpillar D-7 or D-8.

In 1976, Froehlich presented results comparing tractor thinning to small skyline. Results from the paper indicate that tractors disturb 18-28 percent of the unit area and increased soil densities from 1.04 g/cc (undisturbed) to 1.26 g/cc (after logging on major skid trails). The crawler tractor used in this study was a John Deere 450. This crawler tractor is smaller than the Caterpillar D-7F used in this author's study.

The type and size of tractor used has a definite bearing on the amount of soil compacted. Crawler type tractors exert average pressure of 5.9 (0.41 kg/cm^2) to 9.9 pounds per square inch (0.70 kg/cm^2) at the soil surface. The pressure depends upon the vehicle and the width of track.

Although crawler tractor pressures are low, their compactive effect may be proportionately greater by reason of the larger area of soil subjected to mechanical vibration. Huberty (1944) pointed out, irregardless of equipment weight, that vibration of the soil plays an important role in soil compaction. This is especially true when the water content of the soil is such that it acts as a lubricant.

Runoff and erosion will increase in proportion to the percentage of an area disturbed. Generally, skid roads take up 20 percent of an area, but the total area compacted, considering landing sites, and trails over which logs are moved, may be as high as 40 percent (Lull, 1959).

SITE DESCRIPTION

The study area is part of the Corral Timber Sale, which is located in Tuolumne County on the Groveland Ranger District, Stanislaus National Forest, approximately 35 miles northwest of Groveland, California (Figure 1). Topography consists of a flat north-south ridge between the Jawbone and Skunk Creek drainages. Slopes range from flat on the ridge top to 60 percent adjacent to Jawbone Creek. The elevations in the study area range from 3000 to 4000 feet.

The predominant timber species within the area is ponderosa pine (Pinus ponderosa Laws.). The next most abundant species was incense-cedar (Libocedrus Decurrens Torr.), followed by sugar pine (Pinus Lambertiana Dougl.), white fir (Abies concolor [Gord. & Glend.] Lendl.) and Douglas-fir (Pseudotsuga menziesii [Mirb.] Franco). The stand had four canopy levels, which consisted of trees from seedlings to saw timber. These were represented both as individuals and small groups scattered throughout the area. The ponderosa pine seedlings in the stand were in poor condition (poor height, crown ratio, and diameter) due to shading provided by the overstory and the remainder of the stand. Old skid trails had heavy stocking of ponderosa pine seedlings and saplings.

This area was previously logged in the late 1930's and early 1940's leaving most areas understocked with merchantable trees. The majority of fully stocked stands prior to the logging in 1978 were located adjacent to the drainages.

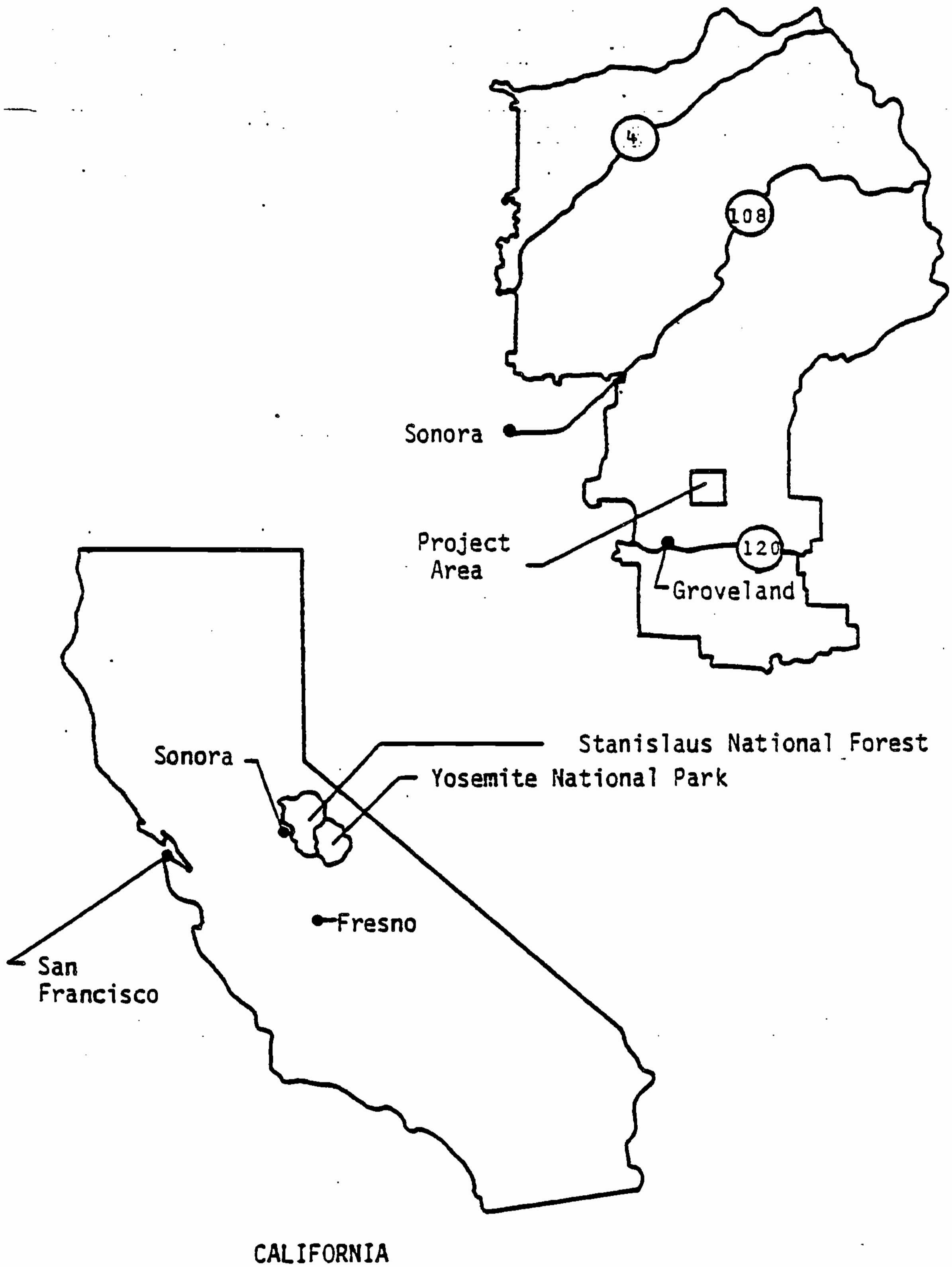

FIGURE 1. LOCATION OF THE STANISLAUS NATIONAL FOREST, CALIFORNIA.

Two units were selected from within one large partial-cut unit, Figure 2. The first unit (1A, 20.95 acres) had preplanned skid trails and required the extensive use of winching. The tractor was not allowed to leave the skid trail. The second unit (1B, 2.45 acres) was harvested with conventional methods; that is, the tractor was allowed to leave the skid trail. The timber stocking for the two units is shown in Tables G-I through G-VI, which are located in Appendix G. The tables present the pre-harvest stocking in 1975 and the post-harvest stocking in 1978. The data presented in the tables illustrates that the planned cutting prescription which called for a sanitation cut and partial overstory removal was accomplished. Figures 3 and 4 present the number of stems per acre pre- and post-harvest in Units 1A and 1B, respectively. The stocking information was obtained from the compartment inventory analysis data provided by the Groveland Ranger District. In the study units, the amount of cull (dead and down) timber and brush was non-existent. Most open areas were occupied with ponderosa pine seedlings or other conifer seedlings.

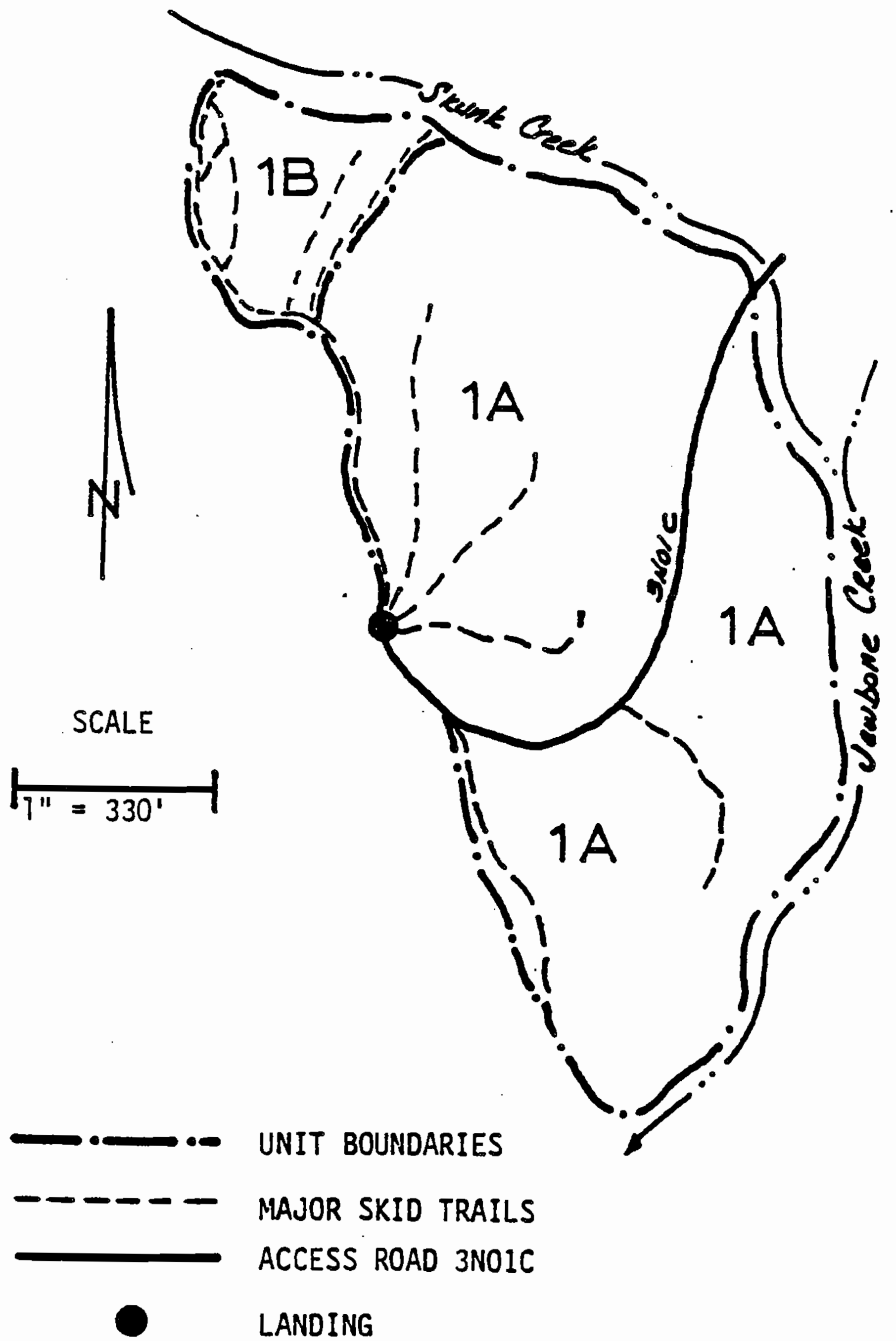

FIGURE 2. UNIT 1A (PREPLANNED SKID TRAILS) AND 1B (CONVENTIONAL).

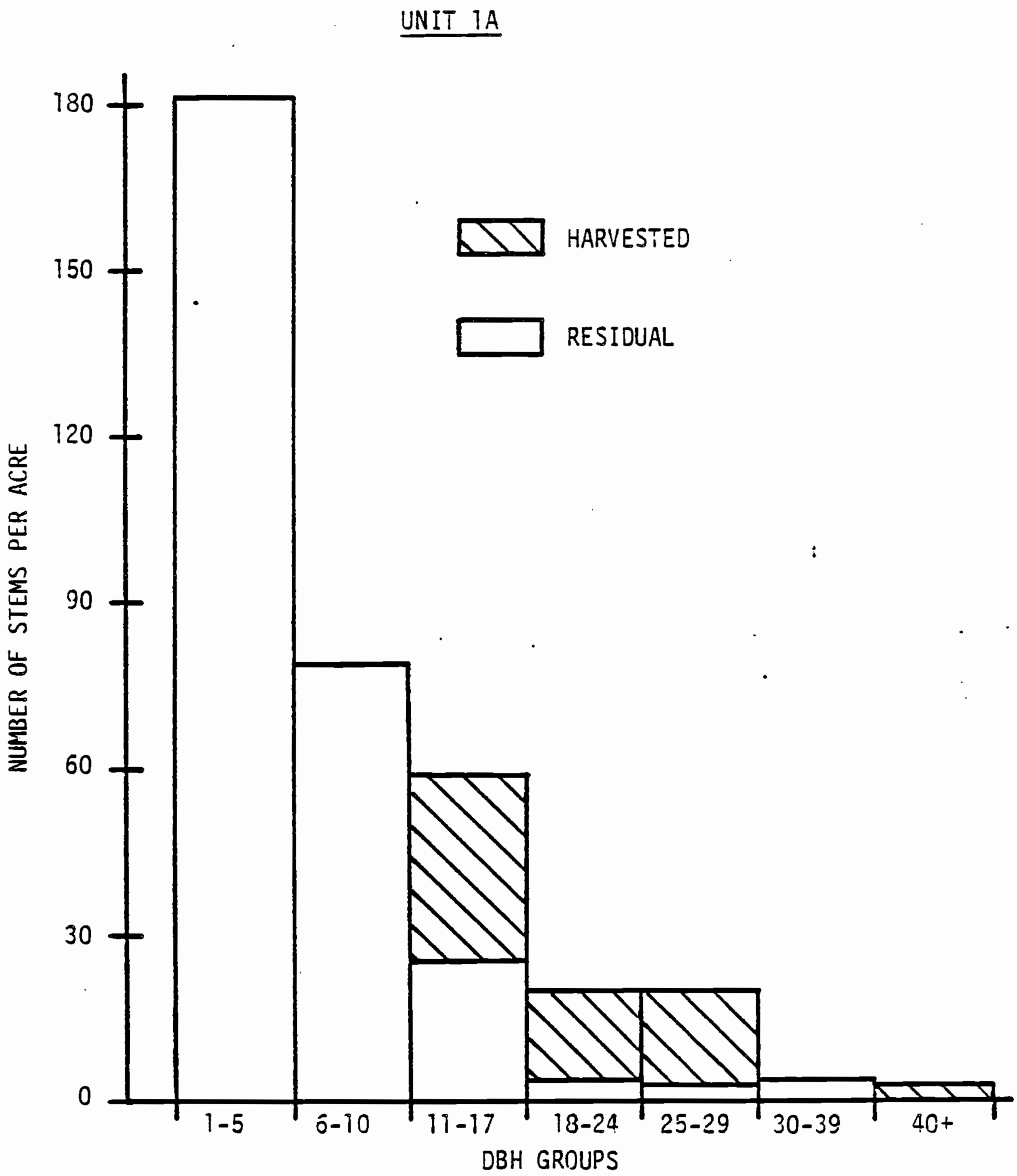

FIGURE 3. NUMBER OF STEMS PER ACRE; PRE- AND POST-HARVESTING FOR UNIT 1A.

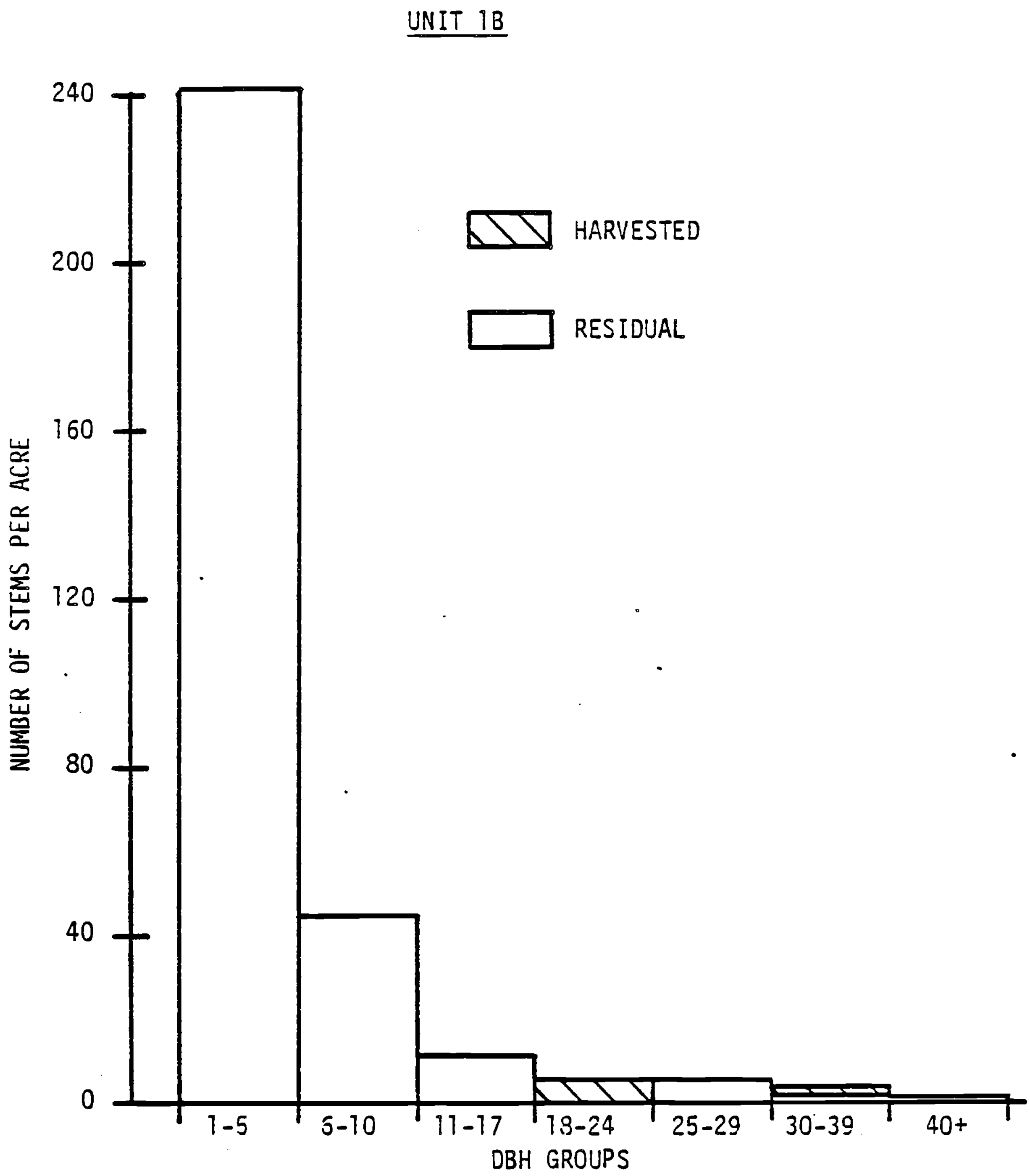

FIGURE 4. NUMBER OF STEMS PER ACRE; PRE- AND POST-HARVESTING FOR UNIT 1B.

DESCRIPTION OF THE STUDY METHODS AND PROCEDURES

The sale prescription called for a sanitation cut and overstory removal within Units 1A and 1B. Marking guidelines in the area specified for the removal of "must cut" trees (trees expected to die in 10 years, trees with a net growth loss, or fully suppressed trees) and portions of the overstory to open up the stand. The planned harvest called for an average of 10-12 Mbf per acre to be removed.

The skid trails in Unit 1A were laid out by the logger and the Forest Service prior to the felling operation. The faller tried to fall the trees to lead in the direction of skid and minimize the damage to the residual stand. In addition, the faller utilized stage felling where more than one tree could be felled in the same bed. Although measurements of the damage to the residual stand are not available, observed results indicated that 50-60 percent of the residual stand damage was a direct result of the felling operation.

Skid trails in Unit 1A were planned to minimize the area disturbed, damage to the residual stand, and provide both favorable and adverse skids for the time study. Prior to the skidding operation in Unit 1A, all planned skid trails were stationed such that the skid distance could be easily determined within ± 10 feet. Unit 1B was laid out at the loggers discretion. No control was exercised over the felling or skidding operation in Unit 1B.

The study methods and procedures were separated into the following three sections:

1) Skidding cycle times
2) Production and cost data
3) Soil disturbance and compaction

Skidding Cycle Time

Total cycle time was segregated into four basic subcycles to facilitate the analysis and interpretation of the data. Subcycle times, that directly influenced the output, were classified as productive time. Interruptions occurring during the cycle time were classified as delays or non-productive time.

The four basic subcycles used in the study are described in the following paragraphs.

Outhaul. This is the time required to move the unloaded tractor from the landing to the hooking area. Outhaul time begins as the tractor moves away from the landing following the unhooking of the previous turn. Outhaul time ends when the tractor arrives at the hooking area and the chokers are removed.

Hook. This is the time required to set the chokers on a turn of logs and attach them to the tractor. The time required for winching has been included in this subcycle. Hook time starts when the chokers are removed from the tractor and ends when the tractor begins inhaul.

Inhaul. This is the time required to move the turn of logs from the hooking area to the landing. Inhaul time starts when a full turn of logs is hooked and the tractor starts toward the landing. Inhaul time ends when the tractor reaches the unhooking area.

Unhook. This is the time required to release the chokers from the turn of logs. Unhook time begins when the logs reach the unhooking area and ends when all the chokers are released.

Times for equipment, landing and experimental delays were recorded and totaled over the entire study period. Personal and unexplained delays were calculated by subtracting the measured delays and yarding time from the total study time. Delays never occurred regularly, but were scattered throughout all the components.

The time data was collected using a continuous timing technique. The end of one subcycle generally was the start of the next subcycle unless there was some type of delay. Times were recorded to the nearest second with the use of two stopwatches.

In addition to measuring the dependent variable, time, the following variables were measured to determine the significance of their influence on the variable time.

SKID DISTANCE (SKDIST) is the slope distance, in feet, measured along the skid trail from the landing to the hook area.

SKID TRAIL SLOPE (SKTRSL) is the average slope, in percent, of the skid trail from the hook area to the landing.

AVERAGE WINCHING DISTANCE (AWD) is the average distance, in feet, the winch line is pulled per turn.

NUMBER OF WINCHING CYCLES (NWC) is the number of times the winch line is pulled per turn.

GROUNDSLOPE (GRDSL) is the slope, in percent, of the ground on which a log is laying during the winching cycle.

NUMBER LOGS PER TURN (NLGTN) is the number of logs that were brought into the landing per turn.

VOLUME PER TURN (VOLTN) is the gross volume per turn (Scribner) that was brought into the landing per turn.

Skid distance, winching distance, number of winching cycles, groundslope, number of logs, and volume were recorded for each turn. Winching distance was determined by marking the winch line every ten (10) feet with fluorescent paint.

Production and Cost Data

A daily cost of the tractor operation was provided by the Cal Sierra Logging Company. The daily production in thousand board feet (MBF) was recorded for the operation.

The crew in Unit 1A consisted of a tractor operator, two chokersetters, a chaser and a loader operator. Two chokersetters were necessary to pull the one inch line to the required distance. The crew in Unit 1B was the same, with the exception of the deletion of a chokersetter.

A Caterpillar D-7F equipped with a Model 57 winch was used in this study. The winch had a capacity of 200 feet of one inch cable with a maximum line pull of 80,000 pounds. The line pull exceeds the safe working load for the one inch cable. A maximum of five 7/8 inch chokers were used. The loader was a Caterpillar 966c rubber-tired front end loader.

Soil Disturbance and Compaction

After the harvesting operation was complete, all major skid trails, access roads and landings were measured to determine the amount of area disturbed. Each unit was traversed to determine the total unit area.

Soil densities were collected for all major skid trails and adjacent undisturbed areas. Densities were measured with a single probe nuclear densometer at depths of 2, 4, 6, and 8 inches. The density data provided by the densometer is an average value of the soil from the ground surface to the depth of the probe. This value must not be used synonymously with that of the point density for a given layer. Moisture contents were taken at each of the four depths to obtain the moisture at each of the soil layers.

Soil samples were taken from the two study units. These samples were analyzed to determine the soil classification.

DATA ANALYSIS

Skidding Cycle

Qualitative Analysis

The minimum, average, and maximum subcycle times and delay times are presented in Table I. The average cycle time was 24.40 minutes which includes both productive and nonproductive time. Hook time was the largest subcycle time which represented 40.4 percent of the average total cycle time. Delay time accounted for 36.4 percent of the average total cycle time.

TABLE I. UNIT 1A
SUMMARY OF SUBCYCLE TIMES
(Minutes)

TIME ELEMENT	TOTAL	MEAN	STANDARD DEVIATION	RANGE	% TOTAL TURN TIME
Delay	1242.00	8.87	--	--	36.4
Outhaul	178.55	1.67	0.95	0.13- 5.35	6.8
Hook	1055.17	9.86	5.45	1.38-27.5	40.4
Inhaul	364.12	3.40	2.47	0.32-14.05	13.9
Unhook	78.28	0.60	0.25	0.17- 1.35	2.5
		24.40			100.0%

Table II presents the minimum, average, and maximum values recorded for the independent variables which were measured to test their influence on the cycle and subcycle times. Forty-nine percent of the turns required adverse skidding with an average skid trail slope of an adverse 2.95 percent. The method for determining skid trail slope is presented in Appendix F. In Unit 1A 56 percent of the turns involved at least one or more winching cycles.

TABLE II. SUMMARY OF INDEPENDENT VARIABLES.

	AVERAGE	MINIMUM	MAXIMUM
Skid distance	515 feet	50 feet	2550 feet
Skid trail slope	2.95% (adverse)	-2.0% (favorable)	25.0% (adverse)
Logs per turn	3.8	1	6
Volume per turn	2280 B.F.	340 B.F.	5250 B.F.
No. winching cycles	1.0	0	5
Ave. winching distance	57 feet	12 feet	163 feet
Groundslope	25.69%	1%	65%

Regression Analysis

Regression equations were generated which relate subcycle and cycle time to one or more of the measured variables. The equations are used for predicting productive time. The stepwise regression procedure was used with the SIPS statistical package program for the Control Data Corporation 3300 computer (Cyber operating system) to determine the regression coefficients and coefficients of multiple determination (R^2).

The acceptance or rejection of variables in each regression was determined by comparing the marginal increase in the R^2 value to the current R^2 value. If the addition of a new variable did not improve the R^2 by more than one percent, the variable was rejected. This procedure was followed even if the variable was significant at the 0.05 level. In the regression equations that follow:

SKDIST = Skid distance, in feet

SKTRSL = Skid trail slope, in percent

AWD = Average winching distance, in feet

NWC = Number of winching cycles

GRDSL = Groundslope, in percent

NLGTN = Number of logs per turn

VOLTN = Volume per turn (gross)

n = Number of sample observations

* = Indicates the regression coefficient associated with an independent variable is significantly different from zero at the 0.005 probability level;

** = Indicates the regression coefficient is significant at the 0.01 probability level but not at the 0.005 level;

*** = Indicates the regression coefficient is significant at the 0.025 probability level but not at the 0.01 level.

1) Outhaul time (minutes)

H_o: Outhaul = f(SKDIST, SKTRSL)

Outhaul = 0.421955 + 0.00225195 (SKDIST)* + 0.0298443 (SKTRSL)*

$n = 107$

$R^2 = 0.8749$

2) Hook time (minutes)

H_o: Hook = f (NLGTN, VOLTN, NWC, AWD, GRDSL)

Hook = 1.21252 $n = 107$

+ 1.84241 (NWC)* $R^2 = 0.5721$

+ 0.805609 (NLGTN)**

+ 0.000832452 (VOLTN)**

+ 0.0347324 (AWD)**

+ 0.0597453 (GRDSL)***

2a) Hook time (minutes)

H_o: Hook = f (NLGTN, VOLTN, NWC, AWD, GRDSL).

Hook = 1.80498 $n = 107$

+ 2.36303 (NWC)* $R^2 = 0.5486$

+ 0.0377977 (AWD)*

+ 0.000852033 (VOLTN)**

+ 0.706996 (NLGTN)***

This equation predicts hook time without the variable groundslope included in the regression.

3) Inhaul time (minutes)

H_o: Inhaul = f (SKDIST, SKTRSL, NLGTN, VOLTN)

Inhaul = -0.660835 $n = 107$

+ 0.00431039 (SKDIST)* $R^2 = = 0.7251$

+ 0.121844 (SKTRSL)*

+ 0.000651756 (VOLTN)*

The addition of the remaining variable, NLGTN, added less than 0.01 to the R^2 value and was rejected.

4) Unhook time (minutes)

H_o: Unhook = f (NLGTN, VOLTN)

Unhook = 0.170924 n = 107

+ 0.0965520 (NLGTN)* R^2 = 0.2356

+ 0.0000430498 (VOLTN)**

The relatively low R^2 value obtained indicates that the unhook time is better explained by some other variable or combination of variables than were measured in this study. This equation leaves 76 percent of the variation in unhook time unexplained.

5) Total cycle time (minutes)

H_o: Total cycle time = f (SKDIST, SKTRSL, NLGTN, VOLTN, NWC, AWD, GRDSL)

Total cycle time = 0.416927 n = 107

+ 0.00787697 (SKDIST)* R^2 = .7178

+ 0.324505 (SKTRSL)*

+ 0.884865 (NLGTN)*

+ 0.00149291 (VOLTN)*

+ 2.45244 (NWC)*

+ 0.0333951 (AWD)**

The addition of groundslope added less than 0.01 to the R^2 value and was rejected.

6) Delay time (minutes)

Delay time was obtained by summing all the delays and dividing them equally over the total number of turns. The occurrence of delays was erratic and didn't appear to happen in any one subcycle more often than another. The average value for delay time was determined to be 8.87 minutes per turn.

The delay time was separated into four categories.

1) Equipment delays
2) Landing delays
3) Personal and unexplained delays
4) Experimental delays

Table III presents the values measured for each of the delay categories and the skidding time. Personal and unexplained delays represented 17.3 hours (84 percent) of the total delay time of 20.70 hours. Recall these delays were not measured but were determined by subtracting the equipment, landing and experimental delay times and the skidding time from the total study time.

TABLE III. SUMMARY OF SKIDDING AND DELAY TIMES.

	TIME (hours)
Skidding	37.80
Delays	
Equipment	0.90
Landing	1.50
Personal and unexplained	17.30
Experimental	1.00
TOTAL STUDY TIME	58.50

An effective hour of 40 minutes was calculated using the productive and nonproductive times presented in Table III. The effective hour was calculated by dividing the productive time (skidding time) by the total study time.

$$\text{Effective Hour (minutes)} = \frac{37.80}{58.5} \times 60 \text{ min.} = \cancel{38.77} \ \underline{\text{use 40}} \ \text{minutes}$$

Production and Cost

Skidding costs are usually calculated on an hourly rate and by means of production rates are converted to a cost per volume basis for cost appraisals. The costs presented in this report will be cost per unit volume (gross) as the logs were gross scaled.

The costs calculated will include values for the skidding and loading operation. Daily costs were provided by Cal Sierra, Table IV.

TABLE IV. SUMMARY OF DAILY COSTS FOR EQUIPMENT AND LABOR.

UNIT 1A		Cost Per 9 Hour Day
Cat D-7F w/operator		$450
Cat 966c w/operator		$360
Chokersetter - 2 @ $100 each		$200
Chaser - 1 @ $100		$100
	Total with loader	$1110
	Total without loader	$ 750
UNIT 1B		
Cat D7-F w/operator		$450
Cat 966c w/operator		$360
Chokersetter - 1 @ $100		$100
Chaser - 1 @ $100		$100
	Total with loader	$1010
	Total without loader	$ 650

Daily production for Unit 1A averaged 44,020 B.F. over a 6.5 day period at a daily cost of $750. Production in Unit 1B averaged 49,350 B.F. daily at a cost of $650. The difference in production was attributed to 56 percent of the turns in Unit 1A requiring at least one winching cycle.

Unit 1A

$$\text{Skidding Cost} = \frac{\text{Daily Cost}}{\text{Daily Production}} = \frac{\$750}{44.02 \text{ MBF}} = \$17.04 \text{ per MBF}$$

$$\text{Loading Cost} = \frac{\$360}{44.02 \text{ MBF}} = \$8.18 \text{ per MBF}$$

Unit 1B

$$\text{Skidding Cost} = \frac{\text{Daily Cost}}{\text{Daily Production}} = \frac{\$650}{49.35 \text{ MBF}} = \$13.17 \text{ per MBF}$$

$$\text{Loading Cost} = \frac{\$360}{49.35 \text{ MBF}} = \$7.29 \text{ per MBF}$$

The skidding cost for Unit 1A is $3.87 per MBF greater than that for Unit 1B. This represents an increase of 29 percent in the actual skidding costs over that of conventional tractor harvesting methods with little or no winching required. Costs have been calculated by an alternative method using the regression equation presented on page 24. Details of the calculations are shown in Appendix A. Results from the alternative method ($17.48 per MBF) were $0.44 per MBF higher than the cost ($17.04 per MBF) calculated using actual daily cost and average daily production. Skidding costs for Unit 1A ($17.04 per MBF) were $3.87 per MBF higher than those for Unit 1B ($13.17 per MBF).

A computer program was developed for use on a Hewlett Packard 9830 desk-top computer to calculate the hourly production for a Caterpillar D-7F if used in stands similar to the two studied.

The program calculates the production rates as follows:

(1) accepting input data for the average skid distance, skid trail slope, winching distance, number of winching cycles, number of logs per turn, volume per turn, and effective hour.

(2) calculating the predicted turn time (without delays) using the equation presented on page 24.

(3) calculating the number of turns per hour using a 40 minute effective hour.

(4) calculating the production per hour by multiplying the number of turns per hour by the average volume per turn.

Using the program, production nomographs were developed and are shown in Figures 5 through 9.

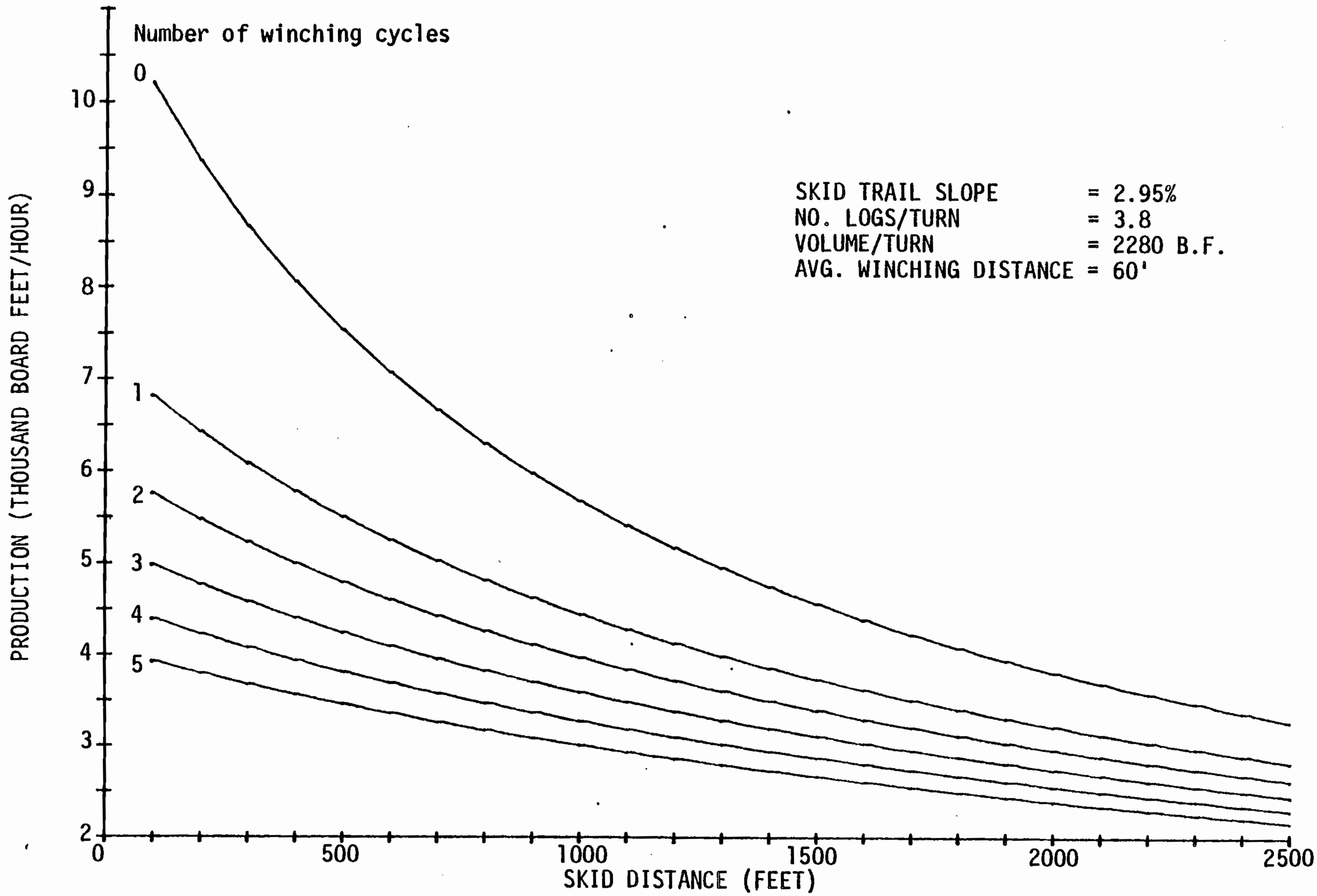

FIGURE 5. PRODUCTION AS A FUNCTION OF SKID DISTANCE AND NUMBER OF WINCHING CYCLES.

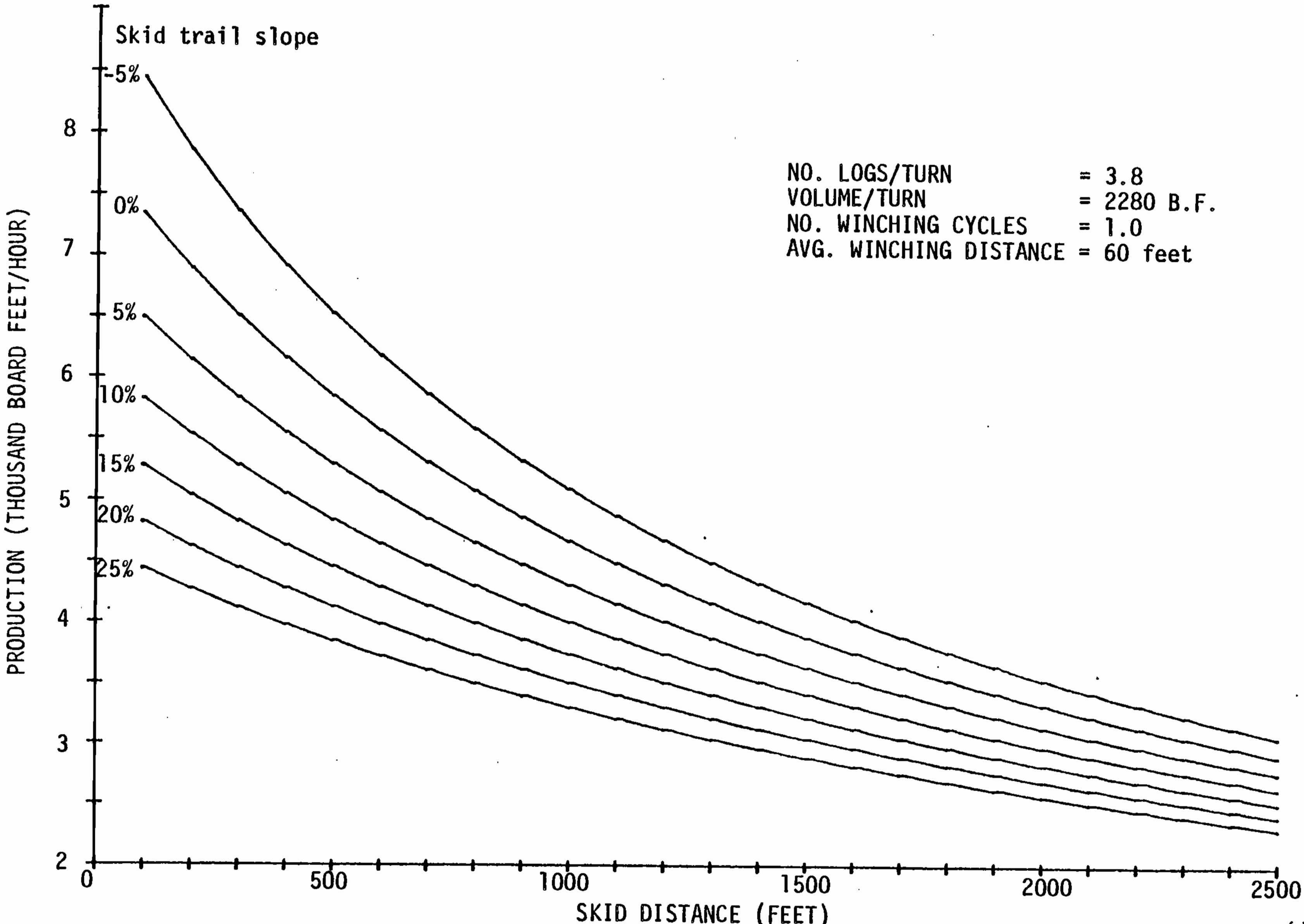

FIGURE 6. PRODUCTION AS A FUNCTION OF SKID DISTANCE AND SKID TRAIL SLOPE.

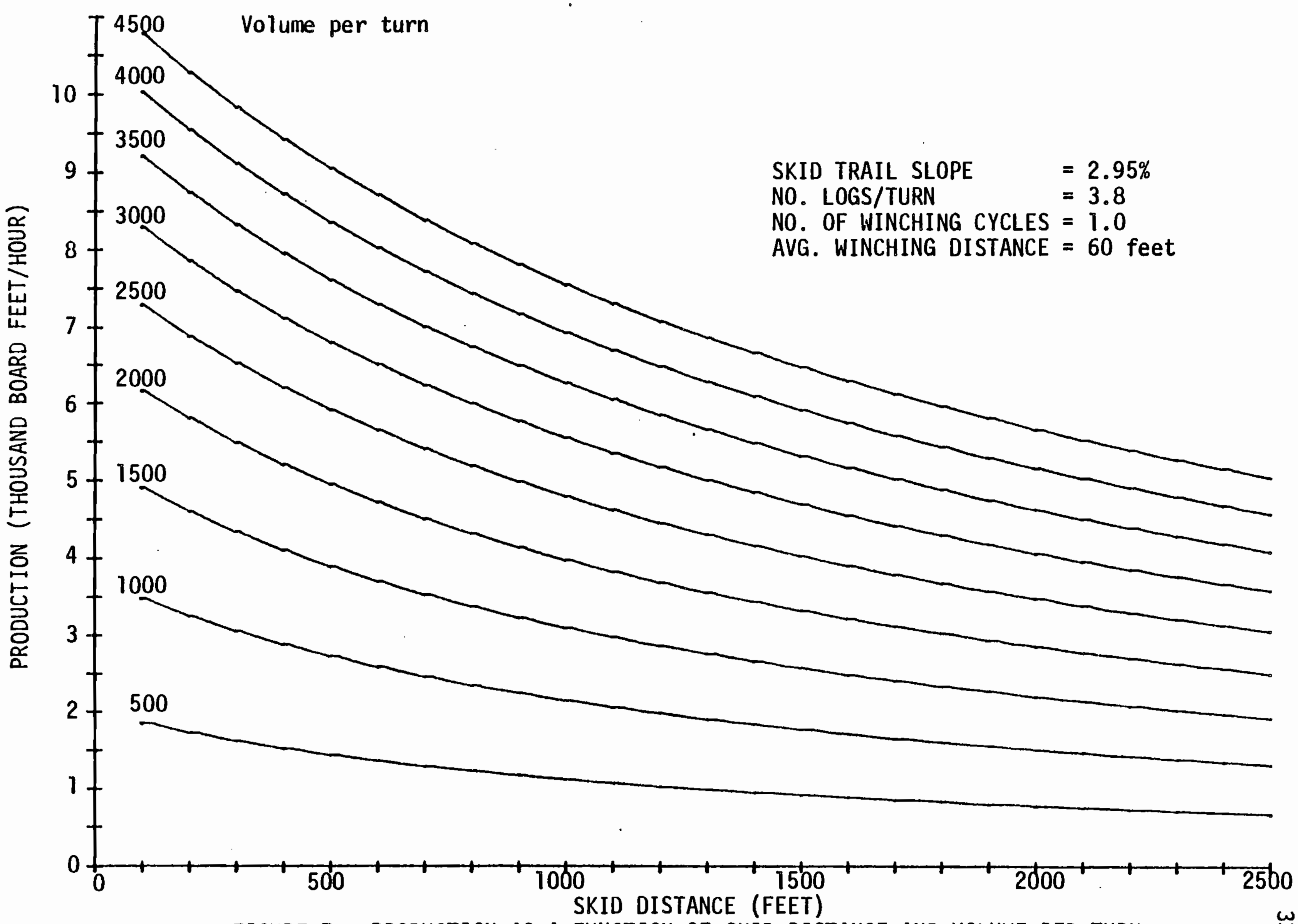

FIGURE 7. PRODUCTION AS A FUNCTION OF SKID DISTANCE AND VOLUME PER TURN.

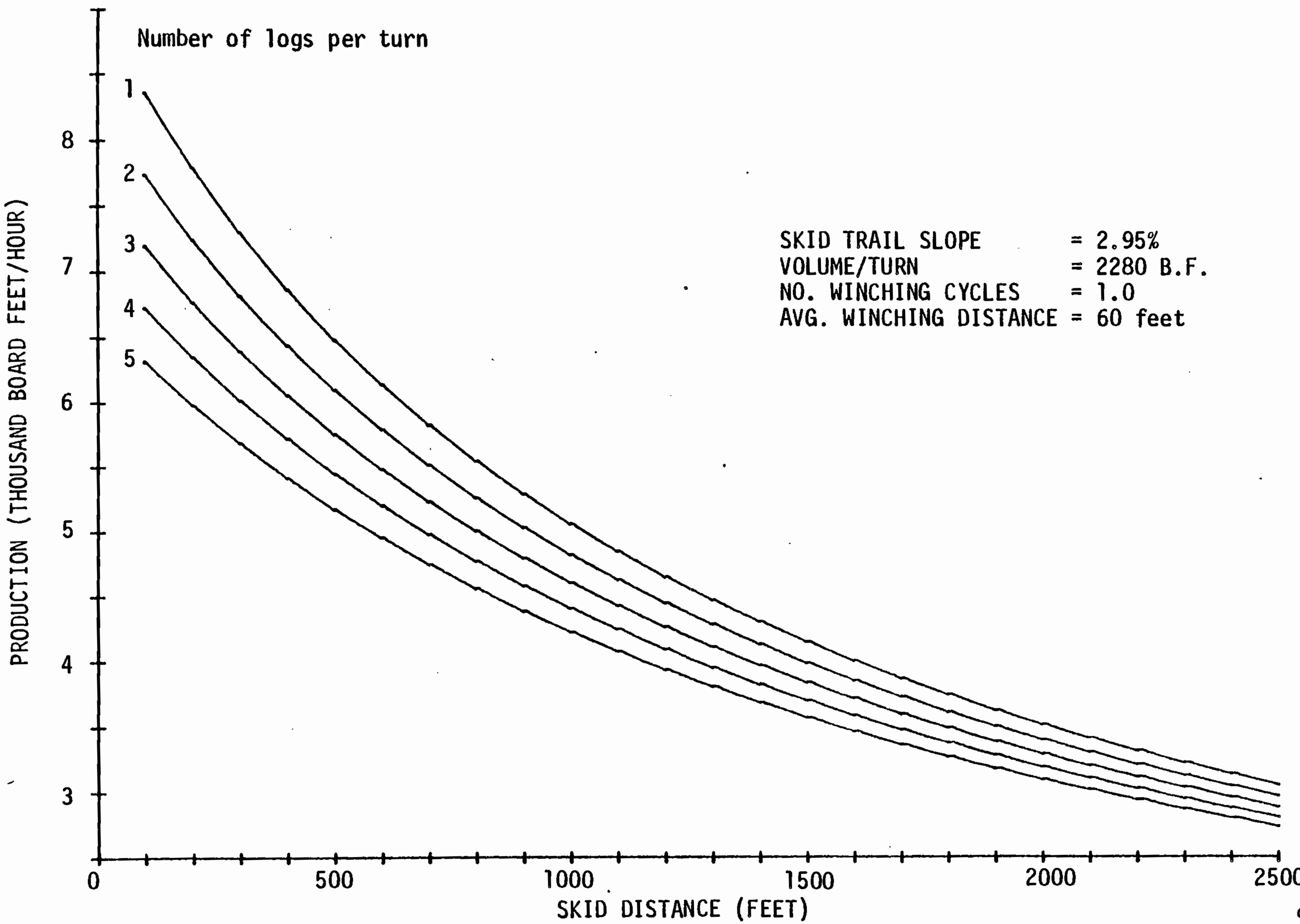

FIGURE 8. PRODUCTION AS A FUNCTION OF SKID DISTANCE AND NUMBER OF LOGS PER TURN.

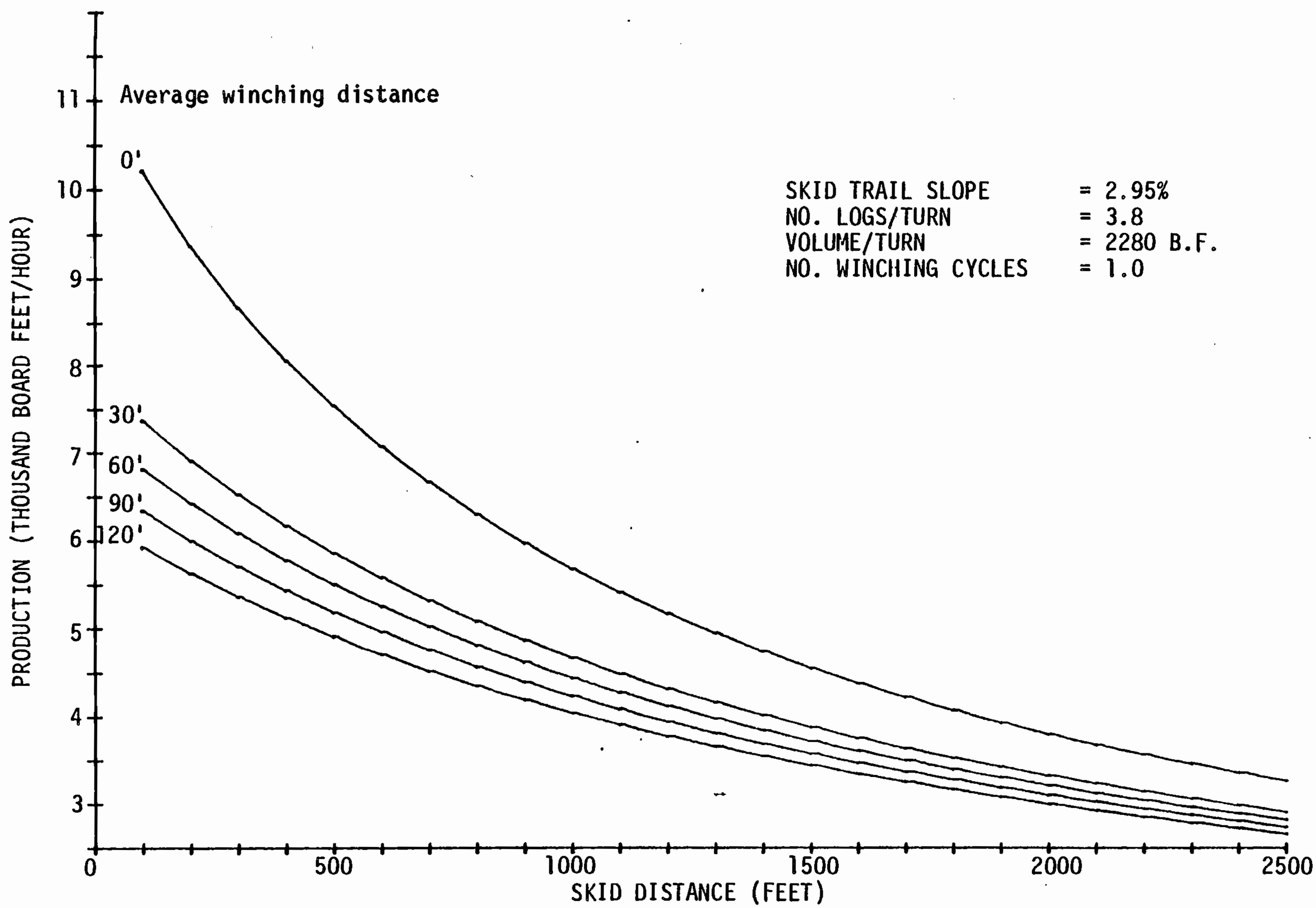

FIGURE 9. PRODUCTION AS A FUNCTION OF SKID DISTANCE AND AVERAGE WINCHING DISTANCE.

Soil Disturbance and Compaction

Three samples were collected for laboratory analysis during the study. The procedure for soil analysis consisted of:

1) Grain size analysis using U.S. Standard sieves with oven dried soil samples.
2) Atterberg limits using the standard procedures for liquid and plastic limits.
3) Determination of the soil class in the Unified Soil Classification System.

Table V shows the results of the laboratory soil analysis. The soil was identified as an SM which represents a silty sand or silty sand mixture. The Atterberg limits analysis determined that the material finer than the No. 200 sieve was non-plastic. This soil is classified by the U.S.D.A. Soil Conservation Service as a sandy loam.

TABLE V. SUMMARY OF THE SOIL ANALYSIS.

	SAMPLE NUMBER		
	1	2	3
Grain Size Analysis			
Percent Passing			
Sieve #			
4	100	100	100
8	98	96	94
16	90	87	77
30	76	69	60
50	61	51	45
100	46	35	31
200	37	25	22
USDA Soil Texture	sandy loam	sandy loam	sandy loam
Plasticity Index	N.P.	N.P.	N.P.
Unified Soil Classification	SM	SM	SM

The area of soil disturbance caused by major skid trails is presented below. Both units were serviced by the same landing and access road (3N01C). The road and landing were contained entirely within Unit 1A and represent 3.34 percent of the total unit area.

TABLE VI. SUMMARY OF THE AREA DISTURBED BY MAJOR SKID TRAILS.

Unit 1A (20.95 acres)

	Length	Average Width		% Area
Skid trails	2302 feet	16 feet		4.04%
	Total Area Disturbed		=	4.04%

Unit 1B (2.45 acres)

	Length	Average Width		% Area
Skid trails	1441 feet	16 feet		22.11%
	Total Area Disturbed		=	22.11%

Density measurements for the undisturbed areas and major skid trails are presented in Table VII. Thirty-two measurements were taken on skid trails in Unit 1A. Five of the thirty-two were on undisturbed sites adjacent to the skid trails. In Unit 1B, a total of 21 measurements were taken of which four were on undisturbed sites. Moisture content of the soil at the time of logging ranged from eight to 12 percent. The soil density values shown are the average values obtained from the two study units. The most significant increase (21 percent) in densities occurred in the upper two inches of the soil layer. Below the six inch depth, a significant increase in the soil density was not apparent.

TABLE VII. SUMMARY OF SOIL DENSITIES IN DISTURBED AND UNDISTURBED AREAS.

UNIT 1A

Depth	Undisturbed n = 5		Disturbed n = 27		Percent Increase
	Lbs/ft^3	g/cc	Lbs/ft^3	g/cc	
2"	62.50	1.00	77.17	1.24	24
4"	70.43	1.13	82.23	1.32	17
6"	74.53	1.19	83.07	1.33	11
8"	75.43	1.21	83.43	1.34	11

UNIT 1B

Depth	Undisturbed n = 4		Disturbed n = 21		Percent Increase
	Lbs/ft^3	g/cc	Lbs/ft^3	g/cc	
2"	58.75	0.94	69.54	1.11	18
4"	60.85	0.97	72.03	1.15	18
6"	66.10	1.06	74.07	1.19	12
8"	67.75	1.09	75.97	1.22	12

DISCUSSION

Skidding Production and Costs

The regression analysis has led to an equation for making estimates of skidding production rates and costs for a D-7F crawler tractor partial cut operation. The skidding cost, is often the largest single item on an appraisal. A complete cost analysis would also include felling, loading, hauling and environmental costs. Skidding production and cost was dependent on skidding distance, skid trail slope, number of logs per turn, volume per turn, number of winching cycles and the average winching distance. Aulerich et al. (1974) also found these variables significant plus two others which were not varied in the present study.

Hook time accounted for more than 63 percent (9.86 minutes) of the total productive time and 40.4 percent of the total cycle time. McDonald (1972) found that hook time represented 40 percent of the total skidding cycle (productive and non-productive time). This can become a costly item when one considers that a large, expensive piece of equipment is idle during this time. The chokersetters on this study utilized only one set of chokers which left them unproductive while the tractor returned to the landing with a turn of logs. The chokersetters were idle for an average of 5.7 minutes per turn; the combined time of the inhaul, unhook and outhaul components. If the average hooktime was reduced by this amount, an average of 11 additional turns per day would be possible (a 57 percent increase in production). Preset chokers would significantly decrease the amount of time necessary for the hooking component. While the tractor was returning to the landing with a turn of logs, the chokersetters could be setting chokers on the next turn of logs.

The winching cycle is another significant factor affecting the hook time. Winching was involved in 56 percent of the 107 total turns timed. The average hook time for turns with winching (12.54 minutes) averaged 6.11 minutes longer than the times without winching (6.43 minutes). The size of timber involved made it necessary to winch only one log at a time to minimize damage to the residual stand. Often logs, already winched to the skid trail, would have to be moved to allow the remaining logs to be winched in.

The measured daily production in Unit 1A averaged 44,020 board feet (gross) for a 9-hour workday compared to an average of 49,350 board feet in Unit 1B; a 10.8 percent increase. This increase can be attributed to the elimination of the winching requirement and allowing the tractor to drive up to each log. Skidding costs for Unit 1A ($17.04 per MBF) were 29 percent higher than those for Unit 1B ($13.17 per MBF); a $3.87 per MBF difference. The cost of the additional chokersetter required to pull the winch line accounted for $2.24 per MBF. The remaining $1.63 per MBF was attributed to the decrease in production caused by the requirement for winching.

Soil Disturbance and Compaction

Unit 1A had a total area of 20.95 acres of which 4.04 percent was in skid trails and 3.34 percent in a landing and access roads. The total area of Unit 1B was 2.45 acres with 22.17 percent in skid trails. Both units were serviced by the same landing and access road. The total area disturbed in Unit 1A was 7.38 percent which yields a relative difference of 14.79 percent between the two units. Unit 1B had a greater area disturbed as the tractor was driven to every log rather than winching the log to the skid trails. The soil disturbance of Unit 1B (22.17 percent) is comparable to 26 percent found by Steinbrenner and Gessel (1955) and 18-28 percent found by Froehlich (1976).

The soil in the two study units was classified as a silty-sand which is a sandy loam soil of granitic origin. The densities averaged 0.94 to 1.21 g/cc in the undisturbed areas and 1.11 to 1.34 g/cc in the disturbed and compacted areas. An increase of 21 percent in the density was observed in the top two inches (5.08 cm) of soil. The density increases at depths of 4 (10.16 cm), 6 (15.24 cm) and 8 (20.32 cm) inches were determined to be 18, 12 and 12 percent respectively. The degree of compaction on the skid trails was found to be similar for both Units 1A and 1B. Recall that the single probe nuclear densometer only gives average density reading from the ground surface to the depth of the probe. Therefore, point densities below the top two inch layer will be lower than those measured with the single probe nuclear densometer. From the results shown in Table VII, it appears there wasn't a significant change in densities below the six inch depth.

CONCLUSIONS

A harvest unit with preplanned skid trails and winching (Unit 1A) was compared to a conventional harvest unit (Unit 1B) with respect to the influence on skidding production, skidding cost, soil disturbance and soil compaction. Skidding production for Unit 1A was 11 percent less than for Unit 1B with a resulting increase in the skidding cost per unit volume of 29 percent. Unit 1A had only four percent of the area disturbed by skid trails compared to 22 percent of the area in Unit 1B. Compaction within skid trails was not significantly different in comparing Unit 1A to Unit 1B.

A combined equation for estimating cycle times with or without winching was obtained with a coefficient of determination (R^2) of 0.72. Equations for estimating cycle times with and without winching were also obtained with coefficients of determination (R^2) of 0.62 and 0.69, respectively. Cycle time with winching was a function of skidding distance, skid trail slope, number of logs per turn, volume per turn, number of winching cycles and the average winching distance.

Preset chokers should be considered as a technique to increase production and lower unit costs. In the present study in which preset chokers were not used, hook time was 63 percent of the productive cycle time and the chokersetters were idle while the tractor traveled to and from the landing.

RECOMMENDATIONS

This section presents a recommended procedure to follow in a partial cut or thinning operation in order to minimize the residual stand damage and soil disturbance.

1) Preplan all skid trails prior to the felling operation.

2) Use directional felling where necessary to fell trees into lead with the skidding direction.

3) Use stage felling where trees can be felled into the same bed and minimize damage to the residual trees and seedlings.

4) Require limbing to be accomplished before the log is winched into the skid trail.

5) Winch one log at a time if the size is such that two logs will damage the residual stand.

6) Do not allow the turning of logs in the stand. If necessary to turn them, do it on the skid trail.

7) Require that the tractor remain on the main skid trail.

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APPENDICES

APPENDIX A

SKID COST CALCULATIONS

APPENDIX A

SKID COST CALCULATION

This appendix presents a method to calculate the skid costs using the regression equation obtained in analyzing the time data from Unit 1A. A 40 minute effective hour was used in the cost analysis to determine the hourly production. Daily costs used in the analyses were those supplied by Cal Sierra Logging.

1. Calculate Total Turn Time using the regression equation presented on page 24.

SKID DISTANCE:	515'	NO. WINCHING CYCLES	= 2
SKID TRAIL SLOPE:	3%	AVG. WINCHING DISTANCE	= 60'
NO. LOGS/TURN:	3.8		
AVG. VOL/TURN:	2280 B.F.		

Total Turn Time = 19.12 min.

T.T.T. = 19.12 minutes

2. Calculate the No. of Turns/Hour

Effective Hour = 40 min.

$$\frac{40}{\text{T.T.T.}} = \frac{40}{19.12} = 2.09 \text{ TURNS/HOUR}$$

3. Calculate the Daily Production Rate

$$\frac{\text{TURNS}}{\text{HR}} \times \frac{\text{AVG. VOL}}{\text{TURN}} \times \frac{\text{HRS}}{\text{DAY}} = \frac{\text{VOLUME}}{\text{DAY}}$$

$$2.09 \times 2280 \times 9 = 42{,}887\ \frac{\text{B.F.}}{\text{DAY}}$$

$$\underline{42.9\ \text{MBF}}$$

4. Calculate the Cost Per Unit-Volume

$$\frac{\text{COST/DAY}}{\text{VOLUME/DAY}} = \frac{\$}{\text{MBF}}$$

$$\frac{\$750}{42.9} = \underline{\$17.48\ \text{per MBF}}$$

APPENDIX B

TOTAL CYCLE TIME FOR TRACTOR SKIDDING WITHOUT WINCHING

APPENDIX B

TOTAL CYCLE TIME FOR TRACTOR SKIDDING WITHOUT WINCHING

This appendix presents a regression equation for turn times on a tractor logging operation without winching. The equation was determined by analyzing the turns from Unit 1A that didn't require any winching.

Total Cycle Time (minutes)

H_o: Total Cycle Time = f (SKDIST, SKTRSL, NLGTN, VOLTN)

$$\text{Total Cycle Time} = 2.02770 + 0.00677454\,(\text{SKDIST})^{*} + 0.275633\,(\text{SKTRSL})^{*} + 0.00103249\,(\text{VOLTN})^{*} + 0.881077\,(\text{NLGTN})^{***}$$

$n = 47$ $R^2 = 0.6892$

	Average	Minimum	Maximum
Skid distance	506 feet	50 feet	2550 feet
Skid trail slope	2.30%	-2%	25%
Logs per turn	3.9	1	6
Volume per turn	2140 B.F.	340 B.F.	5250 B.F.

* Significant at the 0.005 level.
***Significant at the 0.025 level.

APPENDIX C

TOTAL CYCLE TIME FOR TRACTOR SKIDDING WITH WINCHING EVERY TURN

APPENDIX C

TOTAL CYCLE TIME FOR TRACTOR SKIDDING WITH WINCHING EVERY TURN

This appendix presents a regression equation for a tractor logging operation with winching required on every turn. The equation was determined by analyzing the turns in Unit 1A that involved winching.

Total Cycle Time (minutes)

H_0: Total Cycle Time = f (SKDIST, SKTRSL, NLGTN, VOLTN, NWC, AWD, GRDSL)

Total Cycle Time = 0.787646

+ 0.0149847 (SKDIST)*

+ 0.00174106 (VOLTN)*

+ 3.45519 (NWC)*

$n = 60$ $R^2 = 0.6231$

	Average	Minimum	Maximum
Skid distance	521 feet	75 feet	1050 feet
Volume/per turn	2390 B.F.	550 B.F.	4600 B.F.
No. winching cycles	1.7	1	5

*Significant at the 0.005 level.

APPENDIX D

WINCHING TIME PER CYCLE

APPENDIX D

WINCHING TIME PER CYCLE

This appendix presents a regression to calculate winching time. The equation was determined by analyzing the time data recorded for all the winching cycles.

Winching Time Per Cycle (minutes)

H_0: Winching Time per Cycle = f (AWD, GRDSL, NLGCYC, VOLCYC)

Winching Time Per Cycle = - 0.02279
+ 0.0156084 (AWD)*
+ 0.00126563 (VOLCYC)*

n = 116 $R^2 = 0.8105$

	Average	Minimum	Maximum
Avg. winching distance	62.5 feet	11 feet	192 feet
Volume per cycle	1012 B.F.	30 B.F.	3250 B.F.

*Significant at the 0.005 level.

APPENDIX E

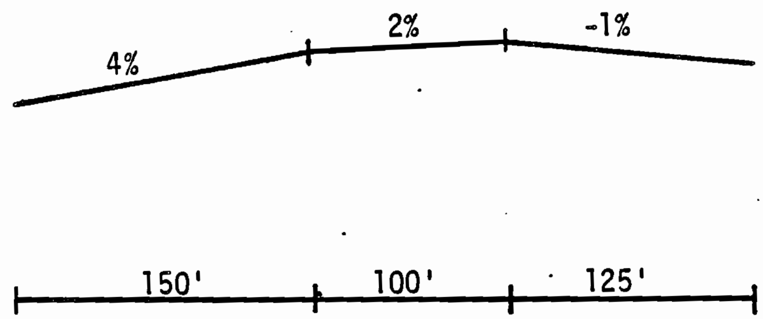
SKID TRAIL SLOPE DETERMINATION

APPENDIX E

SKID TRAIL SLOPE DETERMINATION

This appendix presents the method used to calculate the skid trail slope used in the regression analysis. The skid trail slope determined is a weighted average of the slopes over the skid distance.

Example:



$$\text{Skid trail slope} = \frac{4(150) + 2(100) + (-1)(125)}{150 + 100 + 125}$$

Skid trail slope = 1.8%, adverse

APPENDIX F

GLOSSARY OF TERMS

APPENDIX F

GLOSSARY OF TERMS

Desirable and Acceptable Trees: These two classes make up growing stock trees which includes all live trees of commercial species that are now or may be expected to become suitable for use as industrial wood.

Equipment Delays: This category of delay time involved any time attributed to broken chokers, winch line hangups and having to reset chokers.

Experimental Delays: This category of delay time involved any time lost due to study planning or data measurement.

Landing Delays: This involved the delay time caused by trucks entering or leaving the landing, thus blocking the tractor from reaching the landing.

Must Cut Trees: Presently, merchantable trees not expected to produce net volume growth. These include non-cull trees that are obviously dying, decaying, or likely to decay at a rate exceeding cubic foot growth over the next 10 years.

<u>Personal and Unexplained Delays</u>: These delays were not actually measured. They involve breaks and other miscellaneous delays.

<u>Stage Felling</u>: To fall the timber in several rounds or successive cuts in order to reduce residual stand damage. This involves using the same bed created by the first tree that was fell.

APPENDIX G

COMPARTMENT INVENTORY ANALYSIS DATA

TABLE G-I. UNIT 1A
NUMBER TREES/ACRE
(% STAND COMPOSITION)

	DBH GROUPS							
(1975)	1-5	6-10	11-17	18-24	25-29	30-39	40+	TOTAL
Desirable & Acceptable	26.43 (78)*	14.92 (44)	8.67 (26)	2.34 (7)	2.89 (8)	0.46 (1)	0.77 (2)	
Must Cut	35.21 (104)	2.61 (8)	3.99 (12)	0.90 (3)	0.50 (2)	0.19 (1)	0.12 (1)	
	61.64	17.53	12.66	3.24	3.39	0.65	0.89	= 100%
(1978)								
Desirable & Acceptable	45.82 (118)	27.82 (72)	5.42 (14)	1.48 (4)	1.19 (3)	1.68 (4)	0 (0)	
Must Cut	12.88 (33)	2.75 (7)	0.90 (2)	0 (0)	0 (0)	0 (0)	0 (0)	
	58.70	30.57	6.38	1.48	1.19	1.68	0	= 100%

*Number in parentheses is the actual number of trees.

TABLE G-II. UNIT 1B
NUMBER TREES/ACRE
(% STAND COMPOSITION)

	DBH GROUPS							
(1975)	1-5	6-10	11-17	18-24	25-29	30-39	40+	TOTAL
Desirable & Acceptable	33.48 (29)*	29.73 (15)	7.04 (6)	4.07 (4)	3.49 (3)	3.97 (3)	0.72 (1)	
Must Cut	4.79 (4)	7.15 (6)	3.60 (3)	1.12 (1)	0.48 (1)	0.30 (0)	0.06 (0)	
	38.27	36.88	10.64	5.19	3.97	4.27	0.78	= 100%
(1978)								
Desirable & Acceptable	62.71 (191)	10.40 (32)	3.70 (11)	0 (0)	1.57 (5)	0.58 (2)	0.06 (1)	
Must Cut	17.03 (52)	3.88 (12)	0 (0)	0 (0)	0 (0)	0 (0)	0.07 (0)	
	79.74	14.28	3.70	0	1.57	0.58	0.13	= 100%

*Number in parentheses is actual number of trees.

TABLE G-III. UNIT 1A
VOLUME PER ACRE (SCRIBNER)
(% STAND COMPOSITION)

	DBH GROUPS								
(1975)	1-5	6-10	11-17	18-24	25-29	30-39	40+		TOTAL
Desirable & Acceptable	0.96 (372)*	5.07 (1970)	11.26 (4375)	8.13 (3157)	27.65 (10740)	5.76 (2236)	20.92 (8126)		
Must Cut	0.08 (33)	0.35 (137)	4.45 (1728)	2.90 (1128)	5.01 (1948)	3.83 (1487)	3.63 (1412)		
	1.04	5.42	15.71	11.03	32.66	9.59	24.55	=	100% (38849)
(1978)									
Desirable & Acceptable	1.94 (404)	11.96 (2494)	13.77 (2870)	6.73 (1403)	7.46 (1556)	53.66 (11184)	0 (0)		
Must Cut	0.21 (40)	1.64 (342)	2.63 (549)	0 (0)	0 (0)	0 (0)	0 (0)		
	2.15	13.60	16.40	6.73	7.46	53.66	0	=	100% (20842)

*Number in parentheses is the actual volume in board feet (Scribner).

TABLE G-IV. UNIT 1B
VOLUME PER ACRE (SCRIBNER)
(% STAND COMPOSITION)

	DBH GROUPS							
(1975)	1-5	6-10	11-17	18-24	25-29	30-39	40+	TOTAL
Desirable & Acceptable	0.28 (49)*	5.15 (904)	6.11 (1073)	9.35 (1640)	15.77 (2766)	36.84 (6464)	13.05 (2290)	
Must Cut	0.33 (57)	1.58 (277)	3.66 (642)	2.70 (475)	1.51 (266)	3.42 (600)	0.25 (44)	
	0.61	6.73	9.77	12.05	17.28	40.26	13.30	= 100% 17547
(1978)								
Desirable & Acceptable	4.44 (541)	6.04 (735)	11.62 (1415)	0 (0)	22.56 (2748)	35.37 (4308)	8.0 (974)	
Must Cut	0.55 (67)	3.03 (369)	0 (0)	0 (0)	0 (0)	0 (0)	8.39 (1022)	
	4.99	9.07	11.62	0	22.56	35.37	16.39	= 100% 12783

*Number in parentheses is actual volume in board feet.

TABLE G-V. UNIT 1A
BASAL AREA/ACRE
(% STAND COMPOSITION)

	DBH GROUPS							
(1975)	1-5	6-10	11-17	18-24	25-29	30-39	40+	TOTAL
Desirable & Acceptable	4.16 (7.5)*	10.25 (18.5)	17.17 (31.0)	9.70 (17.5)	18.84 (34.0)	4.98 (9.0)	13.02 (23.5)	
Must Cut	1.39 (2.5)	1.11 (2.0)	7.76 (14.0)	3.60 (6.5)	3.60 (6.5)	2.22 (4.0)	2.22 (4.0)	
	5.55	11.36	24.93	13.30	22.44	7.20	15.22	= 100%
(1978)								
Desirable & Acceptable	10.27 (12.2)	23.74 (28.2)	15.99 (19)	7.91 (9.4)	10.44 (12.4)	23.90 (28.4)	0 (0)	
Must Cut	2.69 (3.2)	2.53 (3)	2.53 (3)	0 (0)	0 (0)	0 (0)	0 (0)	
	12.96	26.27	18.52	7.91	10.44	23.90	0	= 100%

*Number in parentheses is the actual area in square feet.

TABLE G-VI. UNIT 1B
BASAL AREA/ACRE
(% STAND COMPOSITION)

	DBH GROUPS							
(1975)	1-5	6-10	11-17	18-24	25-29	30-39	40+	TOTAL
Desirable & Acceptable	3.31 (2.8)*	12.06 (10.2)	8.98 (7.6)	10.17 (8.6)	14.66 (12.4)	27.42 (23.2)	7.80 (6.6)	
Must Cut	0.47 (0.4)	3.31 (2.8)	4.49 (3.8)	2.84 (2.4)	1.89 (1.6)	2.13 (1.8)	0.47 (0.4)	
	3.78	15.37	13.47	13.01	16.55	29.55	8.27	= 100%
(1978)	19.02 (16.7)	13.33 (11.7)	15.72 (13.8)	0 (0)	21.98 (19.3)	13.33 (11.7)	2.39 (2.1)	
Must Cut	5.69 (5)	5.69 (5.0)	0 (0)	0 (0)	0 (0)	0 (0)	2.85 (2.5)	
	24.71	19.02	15.72	0	21.98	13.33	5.24	= 100%

*Number in parentheses is actual area in square feet.