Return to E. Olsen

SKYLINE THINNING PRODUCTION RATE EQUATIONS USING THE THIN SIMULATION MODEL

by

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ABSTRACT

This paper shows how ten easy-to-use linear skyline thinning production rate equations were obtained by transforming existing but more cumbersome turn time equations using the THIN simulation model [11]. The equations provide reasonable approximations of delay-free hourly production for several cable yarders operating skyline thinnings under a variety of conditions. The equations have been limited to three independent variables which can be influenced by management decisions. The independent variables are relatively easy to obtain and include: cut volume per acre, average slope yarding distance, and average log volume. The production equations which were linearly regressed for user simplicity have an inherent source of error since some of the data is nonlinear. A log bucking model is presented which aids in the determination of average log volume. Suggestions for future transformations are offered.

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DEFINITION OF VARIABLES

ASYD - Average Slope Yarding Distance. Average inhaul distance of turns hooked using 100 foot (32.8 meter) incremental ranges of setting length measured in feet slope distance.

CUTVOL - Cut Volume. The average cut and yarded volume per acre in cubic feet.

LOGVOL - Average log volume in cubic feet of all logs yarded.

EYD - External Yarding Distance. The maximum inhaul distance of all turns within a setting as measured in feet slope distance along the center of the skyline corridor.

SL - Setting Length. The length in feet slope distance of a rectangular setting assumed to be 150 feet (49.2 meters) in width.

L - Setting Length. The length in feet horizontal distance of a rectangular setting assumed to be 150 feet (49.2 meters) in width.

TREEVOL - Average tree volume in cubic feet of all trees which were felled, bucked and yarded to the landing in log lengths. The term does not refer to tree length logging in this paper.

I. Introduction

This paper documents an investigation of the hypothesis that easy-to-use linear skyline thinning production rate equations can be obtained by transforming existing but more cumbersome turn time regression equations using the THIN simulation model [11]. Ten production rate equations are developed using THIN and linear regression techniques. The equations are yarder specific. Equation A is an example of a turn time equation expressed in minutes. Equation B is the transformed version of Equation A. Equation B is the delay free production rate equation for the West Coast tower rigged for uphill yarding using a standing, single span skyline and mechanical slack pulling carriage with haulback and three chokers. Equation B is expressed in cubic feet per hour.

Equation A: [9]

$$\begin{aligned}
\text{Turn time} = 2.77 &+ .0222\,(\text{volume per turn in cubic feet}) \\
&- .0492\,\left(\frac{\text{volume per turn in cubic feet}}{\text{number of logs in turn}}\right) \\
&- .634\,\left(\frac{\text{numbers of logs in turn}}{\text{number of chokers flown}}\right) \\
&+ .463\,\left(\frac{1}{\text{sin lead angle}}\right) \\
&+ .000144\,(\text{lateral distance in feet squared}) \\
&+ .243 \times 10^{-5}\,(\text{slope yarding distance in feet squared}) \\
&+ .0364\,(\text{carriage height in feet})
\end{aligned}$$

Equation B:

$$\text{Production} = 230.17 - .366208\ (\text{ASYD}) + 32.3200\ (\text{LOGVOL}) + .0286246\ (\text{CUTVOL})$$

Forest and logging managers often need to predict production rates of yarders in various configurations to analyze forest harvest cost problems. Although many delay free turn time equations similar to Equation A have been developed [1], forest and logging managers find most of these equations very difficult to use. The equations are difficult to use for several reasons. These include:

1. Independent variables such as volume per turn and logs per turn are difficult to estimate. Peters developed a load curve method for determining average volume per turn; however, time study data is required to construct the curve [17].

2. Definitions for the same independent variable are not always the same for all equations, requiring the user to become familiar with the original research.

3. The range of values for independent variables over which the equation is valid can usually only be obtained by reviewing the original research.

4. The equations usually give estimates in time per turn. The user must convert time per turn into volume per hour.

5. The user must conduct further research to know how to adjust time per turn for various delays.

The methodology of transforming seven existing turn time equations into ten linear production rate equations is presented. The THIN simulation model which was developed by LeDoux and Butler is briefly described. Some of the assumptions necessary to limit the equations to three independent variables are covered in considerable detail. The resulting equations are analyzed to determine the correctness of the hypothesis. Use of the equations is discussed including an adjustment procedure for delays and road changes. Finally, suggestions for future transformations are offered.

II. OBJECTIVE

The objective of the study is to obtain equations which forest and logging managers can more readily apply to economic analyses. The equations are to represent an array of yarder configurations operating over a range of conditions. To be truly useful, input information (independent variables) must be relatively easy for managers to obtain. Independent variables to be tested in the hypothesis include cut volume per acre in cubic feet (CUTVOL), average log volume in cubic feet (LOGVOL), and average slope yarding distance (ASYD). Individual terms within the equations are to be linear for user simplicity. The equations are to be versatile and simple; providing forest and logging managers with a source of approximations for hourly skyline thinning production rates.

III. SCOPE

The scope of the project is limited to transforming existing delay free turn time regression equations which have been developed for thinning young growth stands found in the mountains of western Oregon and Washington. [7] [9] [10] [14] [15] [18] [19]. Only log length thinning is addressed. Yarder configurations are limited to the following:

Full Cycle Yarding

Yarder	Carriage	System
Mini Alp	Igland Jones single and multispan carriages	Standing skyline, single and multispan, uphill with haulback, 3 chokers
Koller with and without skidder swing	Koller SKA-1	Standing skyline, single and multispan, uphill, gravity outhaul, 3 chokers
Peewee	Unknown	Running skyline, single span, uphill with some downhill, 3 chokers
Skagit SJ-2	Christy	Live skyline, singlespan, uphill, gravity outhaul, 3 chokers
West Coast	West Coast	Standing skyline, single-span, uphill with haulback, 3, 4 and 5 chokers

Prebunch and Swing Yarding

Yarder	Carriage	System
Skagit GU-10 mounted in dump truck	None	Yarder mounted in dump truck, block in tree, 2 chokers, prebunching
Schield Bantam T-350	Maki	Live skyline, singlespan, uphill, gravity outhaul, swinging

Detailed equipment specifications are listed in the Appendix.

IV. PROJECT DESIGN

The project design consisted of the following steps:

1. Literature review

The Oregon State University Library Information Retrieval Service (LIRS) was utilized to search the AGRICOLA* and the CAB** Abstracts for easy-to-use, yarder specific skyline thinning production rate equations. None were found.

It was decided that the THIN simulation model developed by LeDoux and Butler [11] should be tested to see if existing but more cumbersome turn time equations could be transformed into easy-to-use production rate equations. The simulation model uses random variates as input to existing turn time equations. It predicts production in either cubic feet per hour or board feet per hour for these conditions.

At this point it is appropriate to describe the THIN simulation model in more detail. The following description consists of selected excerpts from Simulating Cable Thinning in Young-Growth Stands by LeDoux and Butler [11]:

> "THIN, written in FORTRAN IV, combines Monte Carlo and system simulation techniques and uses the subroutines of the GASP IV simulation language (Pritsker 1974) to collect and report data. Specifically, the model evaluates how alternative diameter classes, stand densities,

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*AGRICOLA is the cataloging and indexing data base for the U.S. National Agricultural Library (NAL).

**CAB Abstracts is a comprehensive file of agricultural and biological information containing all records in the main abstract journals published by Commonwealth Agricultural Bureaux.

yarding efficiencies, external and lateral yarding distances, spatial log distributions, and prebunch-and-swing strategies affect production rates and related direct costs.

The simulation comprises three main routines. The first distributes logs over the cutting unit; the second yards or prebunches logs; and the third swings prebunched logs to a central landing."

The Log-Distribution Routine

"THIN assumes that the cutting unit is a rectangle of given dimensions. The spatial distribution of logs in the cutting unit is determined by dividing the unit into a rectangular grid. Each rectangle in the grid is approximately square, and exactly one log is assigned to each square. The number of squares (i.e., number of logs) in the grid is an input to the model and is determined from stand density, average tree size, bucking rules, and thinning intensity.

Initially, the butt end of each log is located at the center of the square to which it is assigned. The butt location is then perturbed in both coordinates by random amounts which are distributed normally with a zero mean and standard deviation computed by multiplying the length of one square by a fraction called the spatial distribution coefficient (SPC). The value of SPC is entered as a model parameter. The volume of each log is then assigned by taking a pseudorandom observation from a truncated normal distribution. The parameters (mean, variance, minimum, maximum) of the log-size distribution are specified on the GASP control cards."

<u>The Yarding/Prebunching Routine.</u> "To build a turn, THIN first scans the logs in the first few rows to determine which one is closest to the yarder. This log becomes the first log in the turn, with additional logs hooked in order of increasing distance from the first-hooked log. As each log is hooked, checks ensure that it is in fact close enough to the other logs to be hooked, that a choker is available with which to hook it, and that it can be hooked without exceeding the yarder's payload capacity. If

a log is too big to be added to the current turn of logs, it will be skipped and yarded in a later turn.

The simulator then uses a regression equation to compute turn time for the turn of logs just hooked. Regression coefficients are obtained from field studies such as those mentioned earlier, each field study yielding particular coefficient values; thus, any choice of values is related to a base set of operating and stand conditions. Independent variables in the regressions vary with the equipment and forest conditions being simulated but typically include slope yarding distance, number of logs per turn, lateral yarding distance, and turn volume. After each turn is yarded, its attributes are collected and stored; the process is repeated until no more logs remain to be yarded. Upon completion, summary statistics of the yarding operation are reported.

The prebunch-and-swing logic of the simulator handles prebunching of logs in a fashion similar to that of single-stage yarding. However, logs on the left and right sides of the cutting unit are yarded to separate decks.

The number of decks on either side is determined by an input parameter that specifies the distance between successive decks."

The Swing Routine. "Once the prebunch routine has yarded all the logs to decks, THIN initiates the swing operation, starting with the decks closest to the landing. Logs are removed from a deck in roughly the reverse order to which they arrived. As each turn is built, the simulator checks that sufficient chokers are available and that turn volume is within the swing machine's payload. If a log is too large to be added to those already hooked, it may be skipped. The simulator then tries hooking the log placed on the deck just before the one skipped. An input parameter governs how many logs may be skipped in building any one turn. When a complete turn has been built, logs are transported to the central landing. Again, the turn time is computed via a regression equation specific to the swing system of interest."

An unpublished users' manual for THIN has been prepared by Butler and LeDoux [5].

2. Selection of Independent Variables

In order to limit the number of THIN simulation runs required per equation to a reasonable number, it was desirable to limit the number of independent variables per equation to three. The independent variables selected were CUTVOL, LOGVOL, and ASYD as previously defined on page vii. These variables were selected because they meet three important criteria:

- Their values are relatively easy for managers to obtain.
- Their values can often be influenced by management decisions.
- They significantly affect production.

3. Simplifying Assumptions

To limit the number of independent variables to three, simplifying assumptions for THIN were necessary in the following areas:

Stand data
Initial entry thinnings
Thinning intensity
Bucking rule
Log pertubation parameters
Lead angle parameters
Setting dimensions
Maximum distance from first hooked log to succeeding logs
Wood density
System payload of yarder
Number of chokers flown
Crew
Carriage height
Maximum number of logs which can be skipped in a prebunch deck or any one turn

See Section v, page 15, for additional information concerning the simplifying assumptions.

4. <u>Generation of Stochastic Production Data</u>

Stochastic production data was generated by the THIN model for 5 different thinning intensities in 5 different age classes at 10 different average slope yarding distances for each configuration. A range in CUTVOL data from 355 to 7535 was achieved by considering 5 different thinning intensities ranging from 10 to 50 percent. A range in LOGVOL data from 6.2 to 30.0 was achieved by considering 5 different age classes ranging from 40 to 120 years. See Table 15 page 69. A total of 250 data points were developed for each full cycle yarding configuration. It was necessary to omit data points including LOGVOL values in the range of 18.2 to 30.0 for the prebunch and swing configurations due to an inconsistency which sometimes occurs in the present version of the THIN model when maximum log weight exceeds allowable payload.

5. <u>Regression</u>

The data for each configuration was regressed into a linear production rate equation. It was decided that accuracy would be sacrificed if necessary to obtain linear equations. The reason for the decision was user simplicity. An example regression file consisting of 250 data points for the West Coast configuration with 4 chokers is listed in the Appendix. Note that logs per setting was converted to cut volume per acre. The production equations resulting from regression are listed in Table 7, page 26.

V. SIMPLIFYING ASSUMPTIONS

Stand Data

USFS Technical Bulletin 201 [13] stand and height tables were used to construct five fully stocked McArdle Site III Douglas-fir (pseudotsuga menziesii (Mirb.) Franco) stands at the age classes 40, 60, 80, 100, and 120 years. Each stand was then "thinned" at intensities of 10, 20, 30, 40 and 50 percent for a total of 25 different cutting senarios. It was assumed that each thinning was an initial entry. It was assumed that an equal percentage of stems were removed from each two-inch (5.1 centimeters) diameter class. The smallest diameter class was 6.5 inches (16.5 centimeters). Table 1 is a summary of the stand and bucking data. Form class estimates were obtained by comparing tree volumes obtained from the BUCK model to Table C-2, Conversion Factors for the Pacific Northwest Forest Industry [8].

TABLE 1. Douglas-fir Site III Stand Data by Age and Diameter Class Including Log Bucking Summary

DBH	AGE 40 Years #TREES	TOTHT*	FC**	60 Years #TREES	TOTHT	FC	80 Years #TREES	TOTHT	FC	100 Years #TREES	TOTHT	FC	120 Years #TREES	TOTHT	FC
6.5	75	62	.68	54	67	.72	14	70	.72	-	-	-	-	-	-
8.5	129	71	.68	67	78	.72	29	84	.74	15	86	.74	6	86	.75
10.5	54	79	.73	73	87	.77	35	95	.80	21	99	.81	10	101	.81
12.5	16	85	.75	55	95	.79	39	104	.82	24	109	.83	16	114	.84
14.5				39	102	.80	37	111	.82	26	118	.82	19	123	.83
16.5				18	107	.80	32	117	.81	26	125	.81	19	130	.82
18.5				9	111	.78	22	122	.80	23	130	.80	20	138	.81
20.5							14	127	.79	21	136	.80	18	144	.78
22.5							10	134	.78	13	140	.76	15	148	.77
24.5										8	145	.75	13	153	.76
26.5										7	149	.74	7	157	.75
28.5													5	160	.74
30.5													4	164	.73

	40 Years	60 Years	80 Years	100 Years	120 Years
MEAN LOG VOLUME (CuFT)	6.21	11.92	18.09	24.30	30.04
MIN LOG VOLUME (CuFt)	3.90	4.20	3.55	3.43	3.48
MAX LOG VOLUME (CuFt)	18.63	47.54	72.05	94.63	124.27
STD DEV OF LOG VOLUME	3.17	9.31	15.74	21.46	27.18
AVG DBH (inches)	8.02	10.80	13.69	16.22	18.36
TOT BUCK VOL ***	3556	7665	10,925	13,221	15,080
# LOGS ****	573	642	604	544	502
MEAN LOG LENGTH (ft)	29.1	31.6	32.4	33.9	34.4
MEAN TREE VOLUME (CuFt)	9.5	24.3	47.1	71.9	99.3

* TOTHT is defined as total tree height in feet

** FC is defined as Girard form class

*** TOT BUCK VOL is defined as the total volume in cubic feet of the entire stand when bucked into logs having a minimum small and diameter of 4 inches inside bark.

**** #LOGS is defined as the total number of logs obtained when the entire stand is felled and bucked.

Log Parameters

The following log parameters are required to operate the THIN simulation model:

- mean log volume
- minimum log volume
- maximum log volume
- standard deviation of log volume
- total number of logs in the setting

These parameters were obtained by "bucking" the previously described cut trees into logs. A log bucking simulation model, BUCK, was developed by the author for this purpose. The model can be executed on the Hewlett Packard 41CV hand held computer. Inputs include tree diameter at breast height, total tree height, Girard form class and number of trees in each diameter class. The model determines the merchantable length (M) of each tree from a 1 foot stump to a 4 inch top. The merchantable length (M) is then bucked into log lengths according to the following bucking rule:

Merchantable Length (M) in feet	No. Logs per tree	Butt log length	2nd lot length	3rd log length	4th log length
$M \leq 40.6$	1	M	-	-	-
$40.6 < M \leq 81.2$	2	M/2	M/2	-	-
$81.2 < M \leq 121.8$	3	40.6	$\frac{M-40.6}{2}$	$\frac{M-40.6}{2}$	-
$121.8 < M \leq 162.4$	4	40.6	40.6	$\frac{M-81.2}{2}$	$\frac{M-81.2}{2}$

Log volume and number of logs are accumulated until all trees are bucked. Butt and upper bole log volumes are computed using equations developed by David Bruce [3] [4]. The model determines inside bark diameters at both ends of each upper bole log by assuming a paraboloid bole. Stump diameter inside bark is determined using a relationship between it and diameter breast height [2]. Complete documentation of the log bucking model can be found in the Appendix.

<u>Log Purterbation Parameters in x and y Directions</u>

mean	0.0 feet
minimum	-10.0 feet
maximum	10.0 feet
standard deviation	1.0 feet
spacial distribution coefficient	.2 feet

LeDoux and Butler [11] define log purterbation and spacial distribution coefficient as follows:

> "Initially the butt end of each log is located at the center of the square to which it is assigned during the THIN log-distribution routine. The butt location is then perturbed in both coordinates by random amounts which are distributed normally with a zero mean and standard deviation computed by multiplying the length of one square by a fraction called the spacial distribution coefficient."

Lead Angle Parameters

A lead angle term was included in four of the original turn time equations. Lead angle is treated as a stochastic variable by the THIN model when a lead angle term is included in the turn time equation. Assumed lead angle parameters are listed in Table 2.

TABLE 2. Assumed Lead Angle Parameters (degrees)

	Lead Angle			
Yarder Configuration	Mean	Minimum	Lead Angle Maximum	Standard Deviation
West Coast	51.0	0.1	118.0	21.9
Peewee	51.0	0.1	118.0	21.9
Skagit SJ-2	51.0	0.1	118.0	24.0
Schield-Bantam T-350	110.8	65.0	158.0	21.9
Others	The lead angle term did not appear in the turn time equation.			

Setting Dimensions

Settings were assumed to be 150 feet (45.7 meters) in width by 1000 feet (304.8 meters) in length slope distance. This yields an area of 3.35 acres (1.39 hectares) when the dimensions are converted to horizontal distances. Data for the assumed ground profile is listed in Table 5 on page 23.

Maximum Distance Permitted From First Hooked Log to Succeeding Logs

A value of 45 feet (13.7 meters) was assumed because LeDoux and Butler used the same value with good results during THIN validation tests [11].

Wood Density

A value of 53.7 pounds per cubic foot (689.7 kilograms per cubic meter) was assumed because Gabrielli used the same value during his original time study [7].

System Payload of Yarder

An assumption was made that one representative ground profile would be a valid means of comparision for all yarder configurations. Payloads were computed for each yarder configuration. Payloads were computed on the Hewlett Packard 9845 desk top computer utilizing the USFS Forest Engineering Institute skyline analysis programs SAP and MSAP. Line sizes used in the payload analysis were the same as those used during the original time studies. (Yarder specifications are listed in the Appendix.) Results of the payload analysis are listed in Table 3. Data for the assumed ground profile is listed in Table 4.

TABLE 3. Results of Payload Analysis

	System	Intermediate Support Height (feet)	Intermediate Support Height (meters)	Tall Tree Height (feet)	Tall Tree Height (meters)	Payload (lbs)	Payload (kg)
Full Cycle Yarding:							
Mini Alp	standing multispan	35	10.7	13	4.0	3291	1493
Koller	standing multispan	35	10.7	13	4.0	2817	1278
Peewee	running	NA				3655	1658
Skagit SJ-2	live singlespan	NA		40	12.2	3051	1384
West Coast	standing singlespan	NA		40	12.2	8609	3905
Swing Yarding:							
Schield Bantam T-350	live singlespan	NA		40	12.2	4036	1831

A payload of 2500 pounds (1134 kg) was assumed for the prebunch configuration.

TABLE 4. Assumed Ground Profile Data
(distances in feet)

Terrain Point	Slope Dist.	% Slope	x Coordinate	y Coordinate	Remarks
1	30	0	0.00	1000.00	landing
2	170	-40	30.00	1000.00	
3	200	-20	187.84	936.86	
4	200	-30	383.96	897.64	intermediate support location for Mini Alp and Koller. Height = 35 feet.
5	200	-15	575.52	840.17	
6	200	-5	773.31	810.50	
7			973.06	800.52	tail spar location

Number of Chokers Flown

Three chokers were assumed for all full cycle configurations except that three, four and five chokers were assumed for the West Coast yarder. Three chokers were assumed for the swing configuration and two chokers were assumed for the prebunch configuration. Table 5 lists number of chokers flown during the original time study and the number of chokers assumed during THIN simulation.

TABLE 5. Number of Chokers Flown During the Original Time Studies and Number of Chokers Assumed During Simulation

	Original Time Study	Simulation
Mini Alp	2	3
Koller with and without Skidder swing	2	3
Peewee	3	3
Skagit SJ-2	3	3
West Coast	4	3, 4 and 5
Prebunch	2	2
Swing	2	3

Crew

Only one turn time equation included a term for crew size. When a turn time equation does not include a term for crew size, it is not necessary to assume a crew size to operate the THIN model. The size of the crew which logged during the original time study is inherent to the equation. Table 6 lists assumed crew sizes for simulation and actual crew sizes used during the time studies [7] [9] [10] [14] [15] [17] [18].

TABLE 6. Assumed and Actual Crew Size

	Assumed Crew Size for Simulation	Actual Crew Size
Mini Alp	NA	2 to 3
Koller with and without skidder	landing crew 1 rigging crew 2	2 to 5
Peewee	NA	unknown
Skagit SJ-2	NA	4
West Coast	NA	4
Schield Bantam (swinging)	NA	3 to 4
Skagit GU-10 (Prebunching)	NA	3

Carriage Height

10 feet (3.3 meters)

Maximum Number of Logs Which Can Be Skipped in a Prebunch Deck When Building A Swing Turn

4 logs

VI. EQUATIONS, NOMOGRAPHS and GRAPHS

Table 7 lists production rate equations resulting from the transformation process. For convenience, nomographs have been constructed which yield graphical solutions to the equations. All of the production rate equations are based on McArdle site class III. The original turn time equations are listed in the Appendix.

TABLE 7. Skyline Thinning Production Rate Equations for Several Cable Yarders

YARDER CONFIGURATIONS	LINEAR PRODUCTION EQUATION IN CUFT/HR (DELAY FREE)
Mini Alp, standing, single and multispan with haulback, uphill, 3 chokers Igland Jones single and multispan carriages	Production = 338.200 - 0.293377 (ASYD) + 6.19002 (LOGVOL) + 0.0103255 (CUTVOL) R^2 = .7827 $CI_{.95}$ = 292-310 when AYD = 450, LOGVOL = 12, CUTVOL = 2000
Koller K-300, standing, single and multispan, gravity outhaul, uphill, 3 chokers, Koller SKA-1 carriage, without skidder	Production = 412.205 - 0.382514 (ASYD) + 9.28024 (LOGVOL) + 0.007906 (CUTVOL) R^2 = .8310 $CI_{.95}$ = 357-377 when AYD = 450, LOGVOL = 12, CUTVOL = 2000
Koller K-300, standing, single and multispan, gravity outhaul, uphill, 3 chokers, Koller SKA-1 carriage, with John Deere 440-C choker skidder swing away from Koller landing.	Production = 462.303 - 0.456691 (ASYD) 10.5027 (LOGVOL) .00877636 (CUTVOL) R^2 = .8346 $CI_{.95}$ = 389-412 when AYD = 450, LOGVOL = 12, CUTVOL = 2000
Peewee, running, single, up and down 3 chokers	Production = 409.360 - 0.407874 (ASYD) + 9.76918 (LOGVOL) + 0.0137733 (CUTVOL) R^2 = .8044 $CI_{.95}$ = 359-383 when AYD = 450, LOGVOL = 12, CUTVOL = 2000

YARDER CONFIGURATIONS	LINEAR PRODUCTION EQUATION IN CUFT/HR (DELAY FREE)
Skagit SJ-2, live, single-span, gravity outhaul, uphill, 3 chokers, Christy carriage	Production = 354.997 − 0.200124 (ASYD) + 5.95503 (LOGVOL) + 0.01044 (CUTVOL) R^2 = .6240 $CI_{.95}$ = 347-368 when ASYD = 450, LOGVOL = 12, CUTVOL = 2000
West Coast, standing, single-span, haulback, uphill, 3 chokers, West Coast carriage	Production = 230.170 − 0.366208 (ASYD) + 32.3200 (LOGVOL) + 0.0286246 (CUTVOL) R^2 = .8876 $CI_{.95}$ = 492-529 when ASYD = 450, LOGVOL = 12, CUTVOL = 2000
West Coast, standing, single-span, haulback, uphill, 4 chokers, West Coast carriage	Production = 333.169 − 0.389712 (ASYD) + 31.2752 (LOGVOL) + 0.0391625 (CUTVOL) R^2 = .8950 $CI_{.95}$ = 593-630 when ASYD = 450, LOGVOL = 12, CUTVOL = 2000
West Coast, standing, single-span, haulback, uphill, 5 chokers, West Coast carriage	Production = 384.671 − 0.381842 (ASYD) + 27.8719 (LOGVOL) + 0.0551664 (CUTVOL) R^2 = .8743 $CI_{.95}$ = 638- 677 when ASYD = 450, LOGVOL = 12, CUTVOL = 2000

YARDER CONFIGURATIONS	LINEAR PRODUCTION EQUATION IN CUFT/HR (DELAY FREE)
Prebunch with truck mounted Skagit GU-10, block rigged in tree, 2 chokers	Production = 483.729 - 0.780594 (ASYD) + 41.0603 (LOGVOL) + 0.0247655 (CUTVOL) R^2 = .8707 $CI_{.95}$ = 654-695 when AYD = 450, LOGVOL = 12, CUTVOL = 2000
Swing with Schield Bantam T-350, live, singlespan, gravity outhaul, 3 chokers, Maki carriage	Productivity = 445.268 - 0.98319 (ASYD) + 47.8492 (LOGVOL) + 0.0238875 (CUTVOL) R^2 = .9738 $CI_{.95}$ = 827-866 when AYD = 450, LOGVOL = 12, CUTVOL = 2000

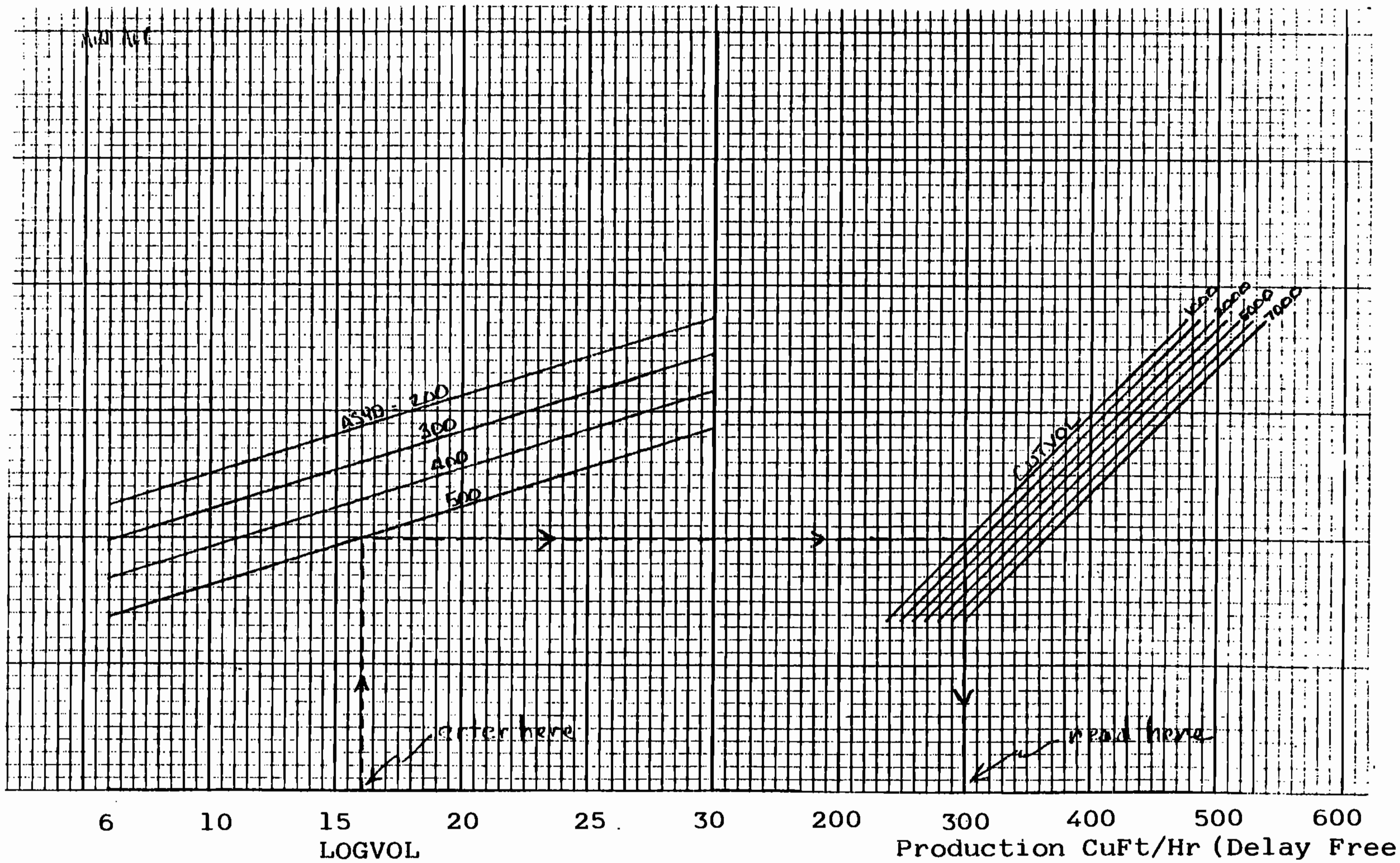


Figure 1. Skyline Thinning Production Rate Nomograph for the Mini Alp Configuration

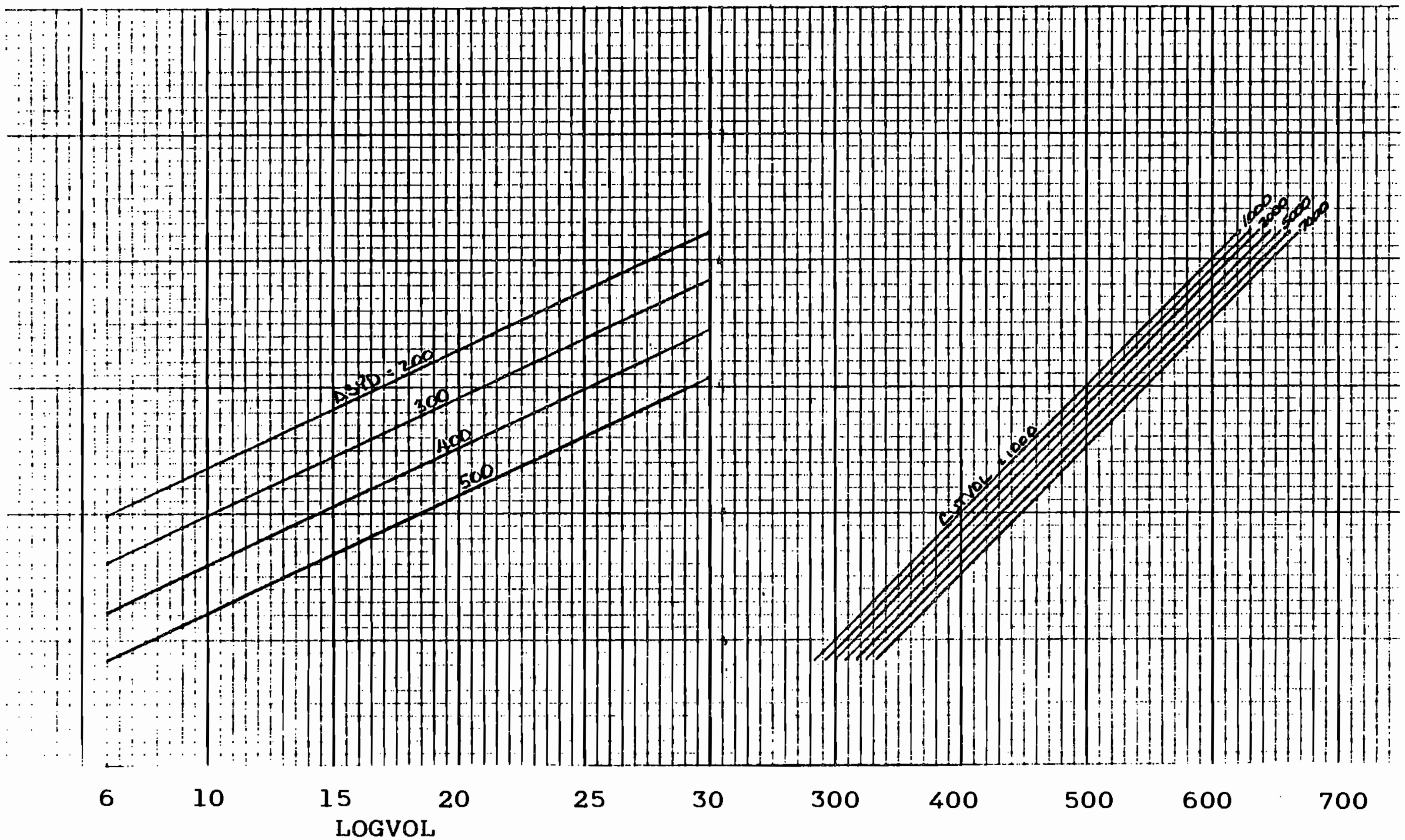


Figure 2. Skyline Thinning Production Rate Nomograph for the Koller K-300 without Skidder

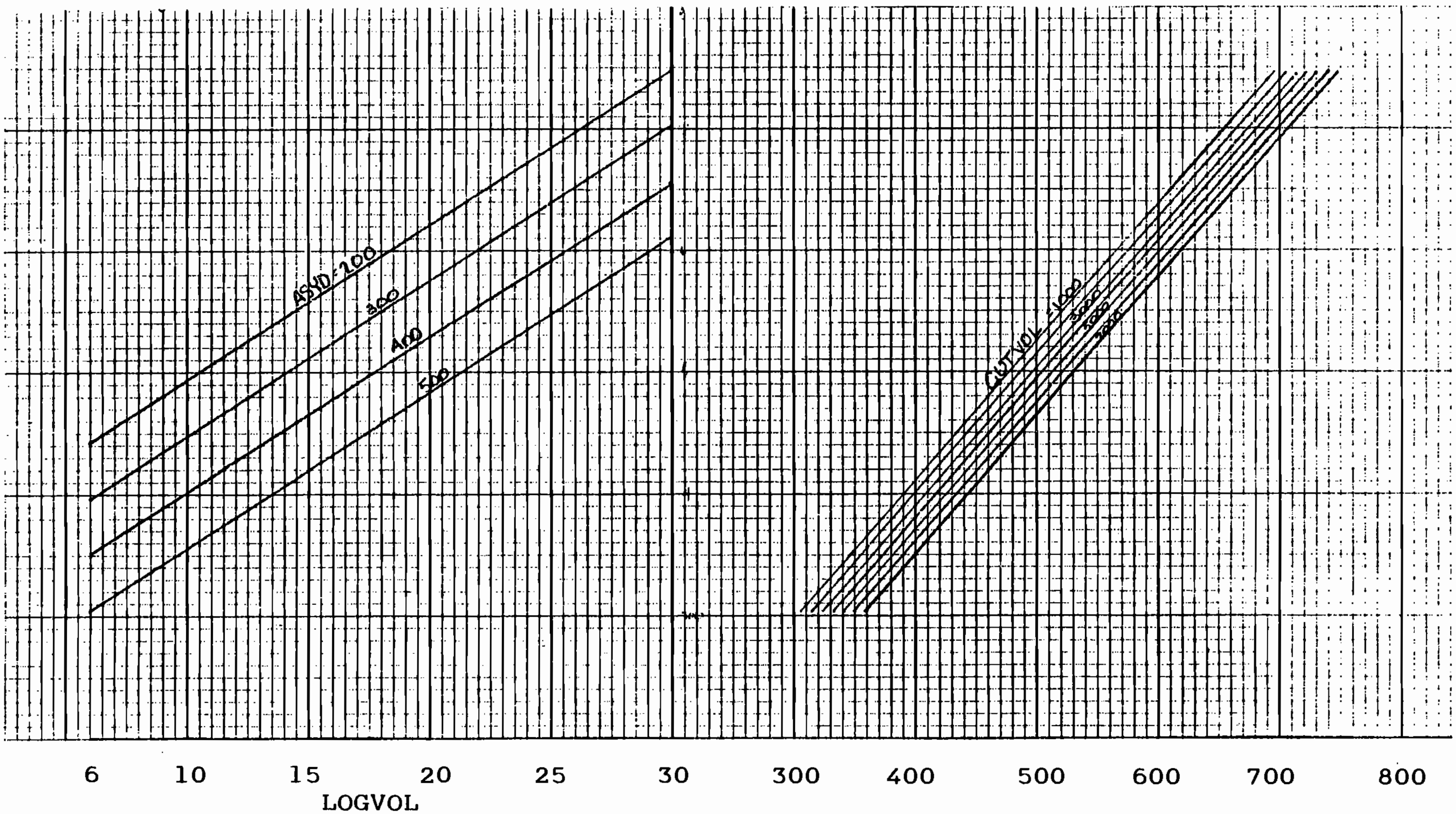


Figure 3. Skyline Thinning Production Rate Nomograph for the Koller K-300 with Skidder Swing

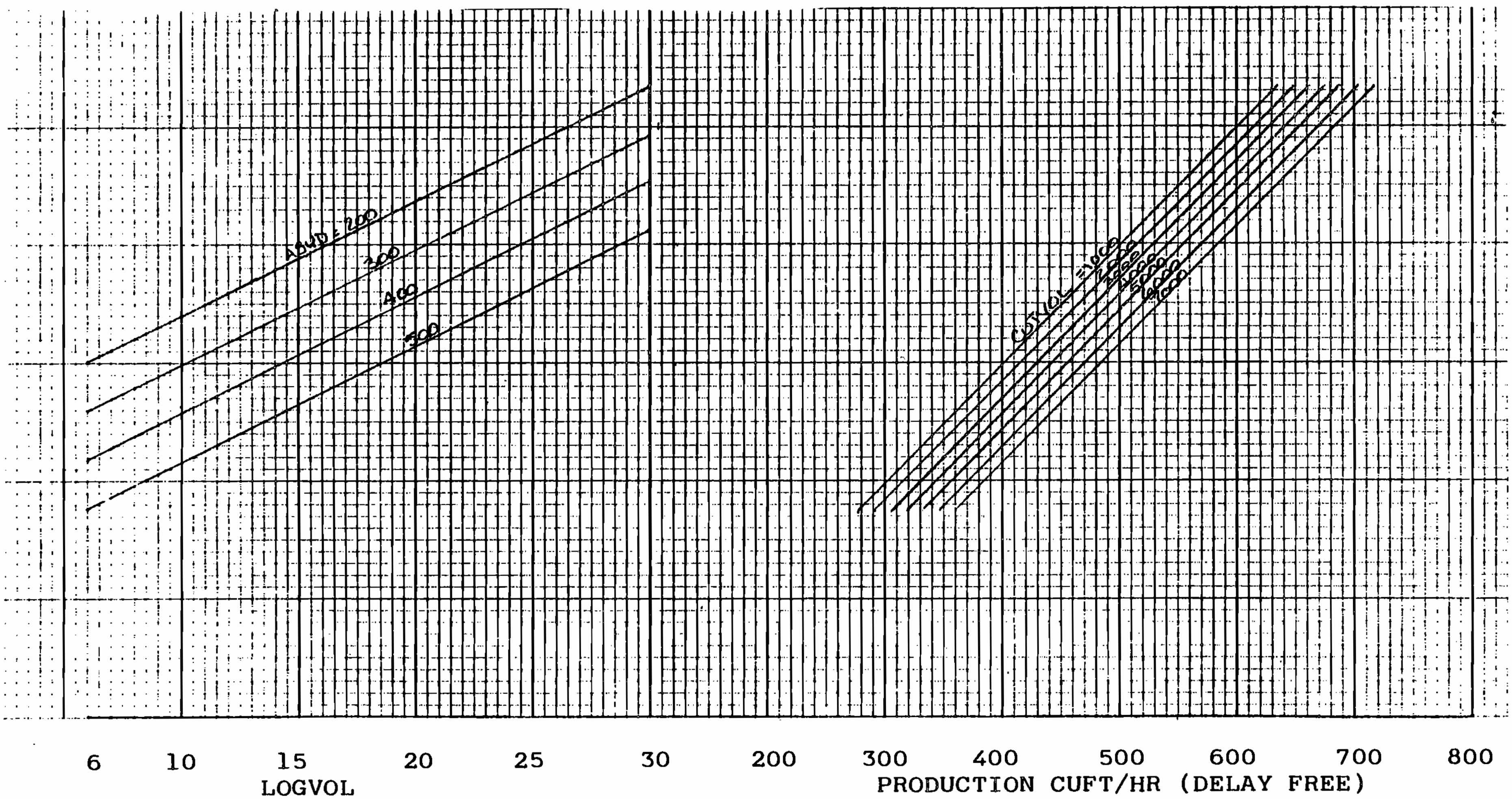


Figure 4. Skyline Thinning Production Rate Nomograph for the Peewee Configuration

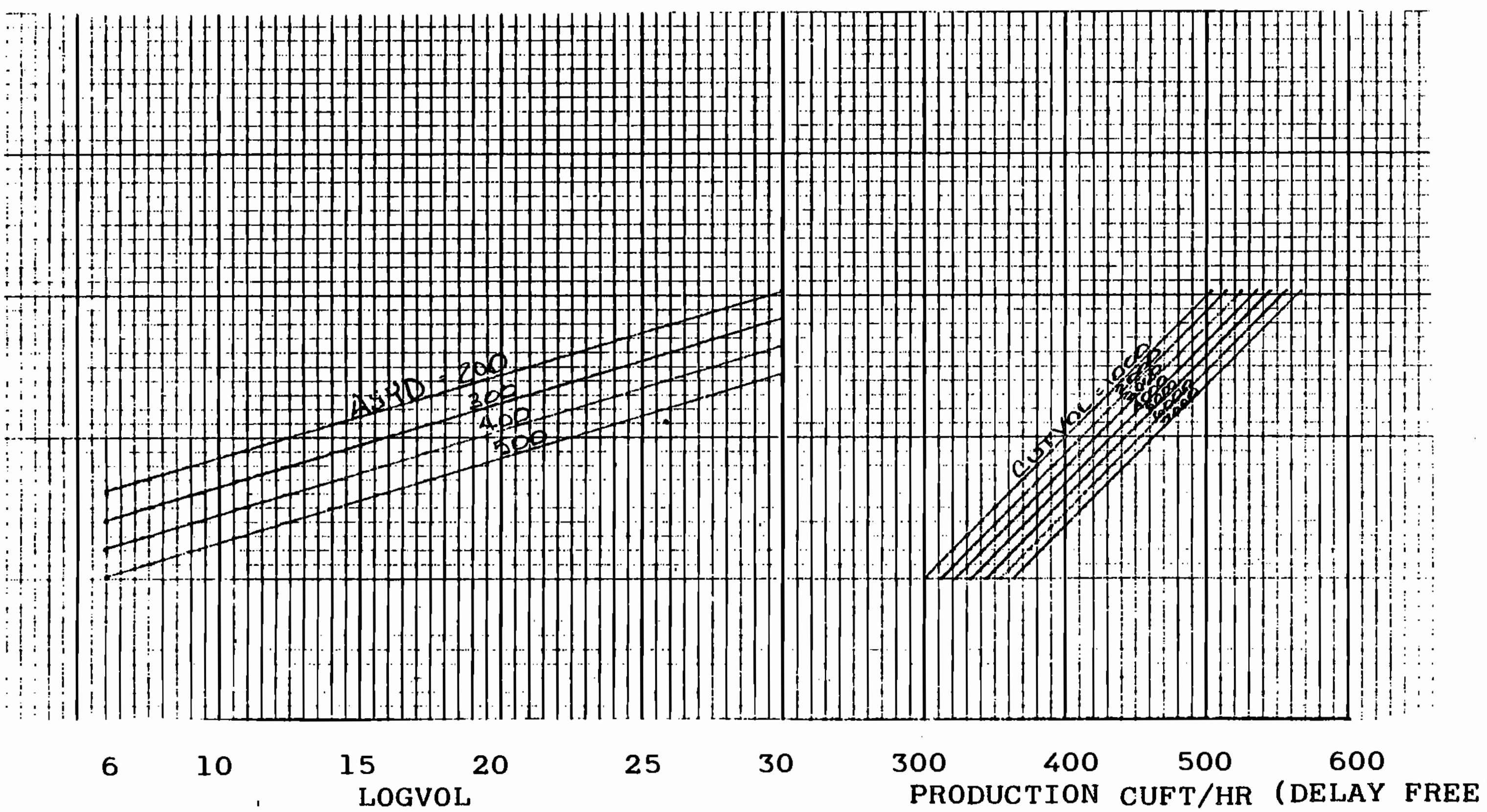


Figure 5. Skyline Thinning Production Rate Nomograph for the SJ-2 Configuration

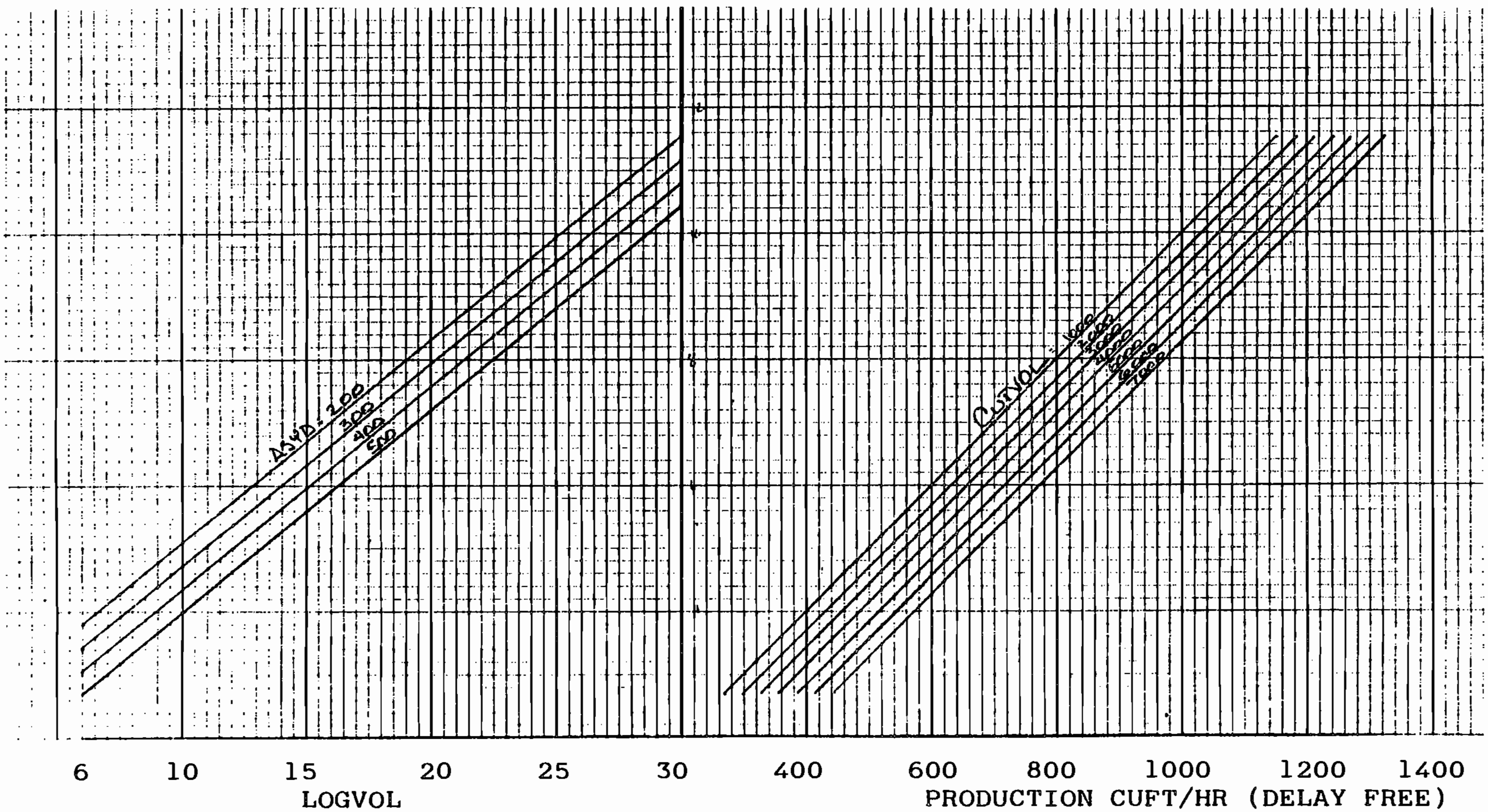


Figure 6. Skyline Thinning Production Rate Nomograph for the West Coast Configuration with 3 Chokers

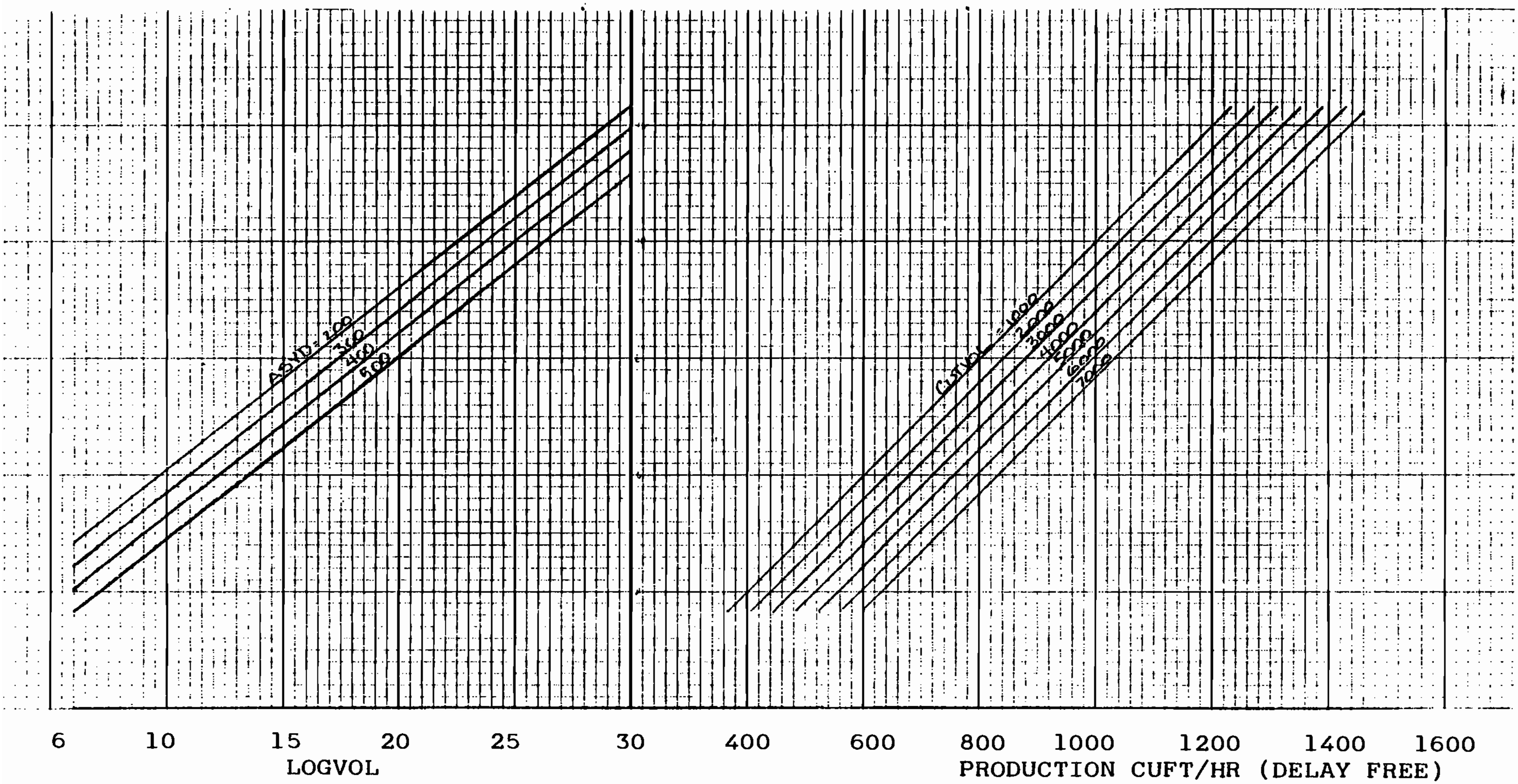


Figure 7. Skyline Thinning Production Rate Nomograph for the West Coast Configuration with 4 Chokers

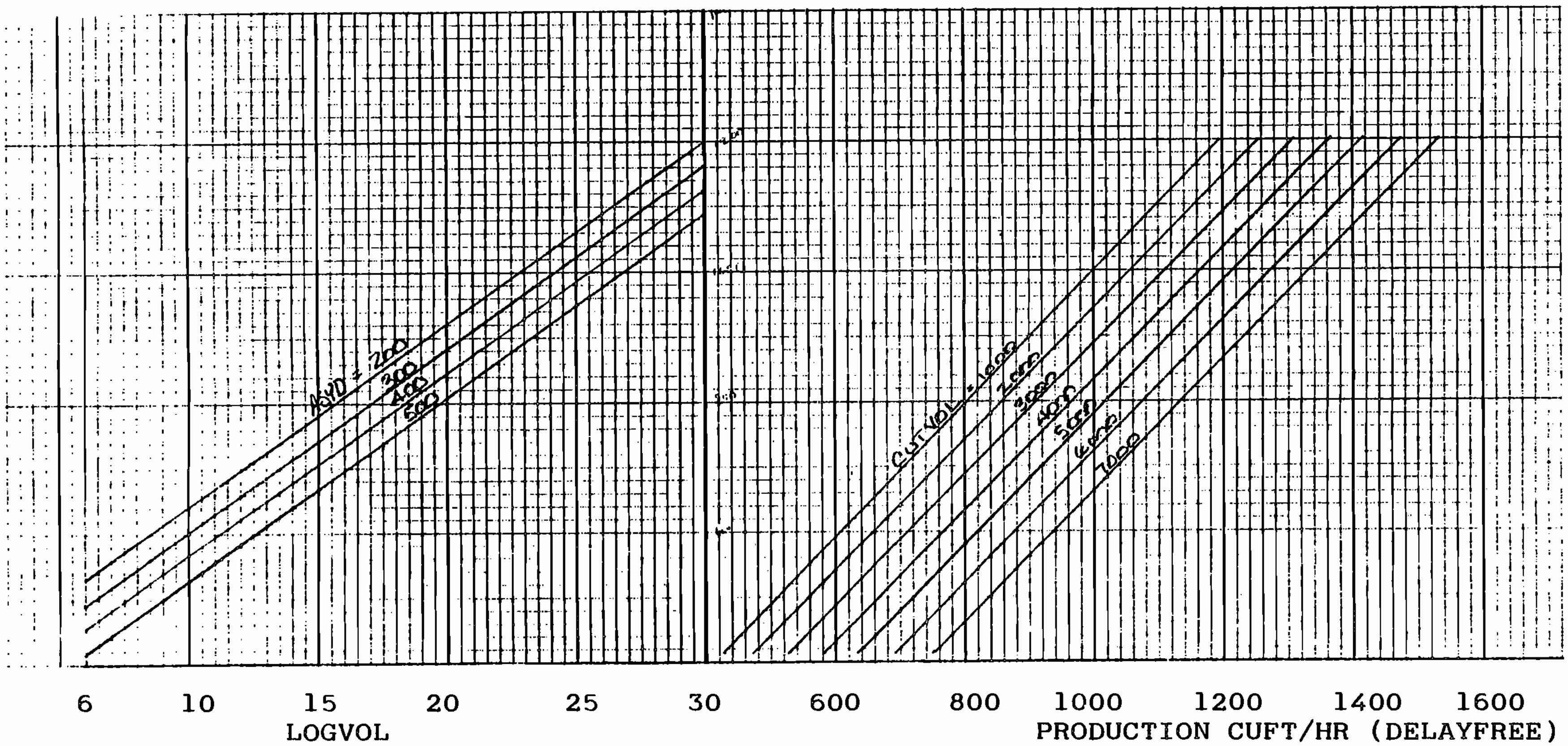


Figure 8. Skyline Thinning Production Rate Nomograph for the West Coast Configuration with 5 Chokers

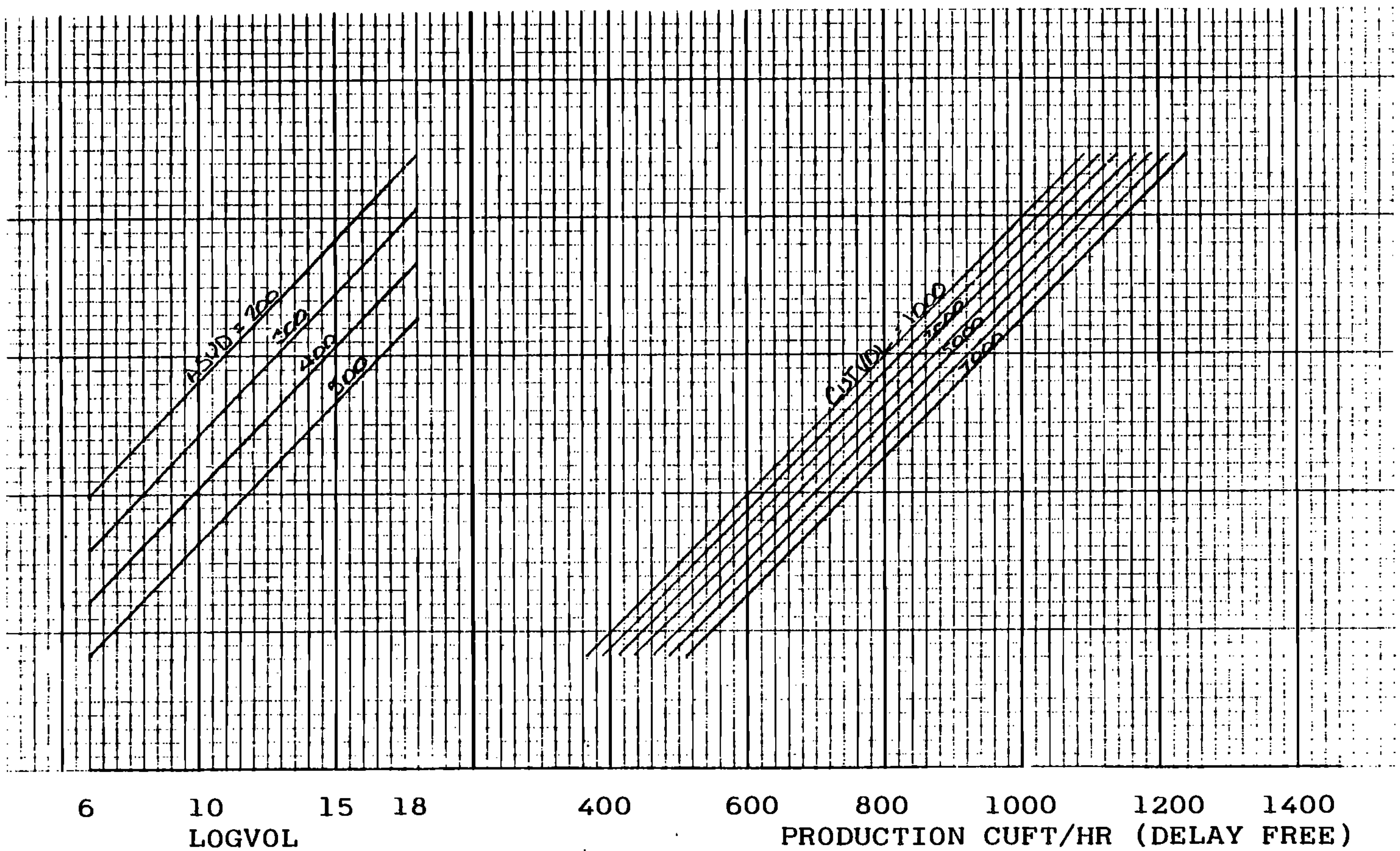


Figure 9. Skyline Thinning Production Rate Nomograph for the Skagit GU-10 Prebunching Configuration

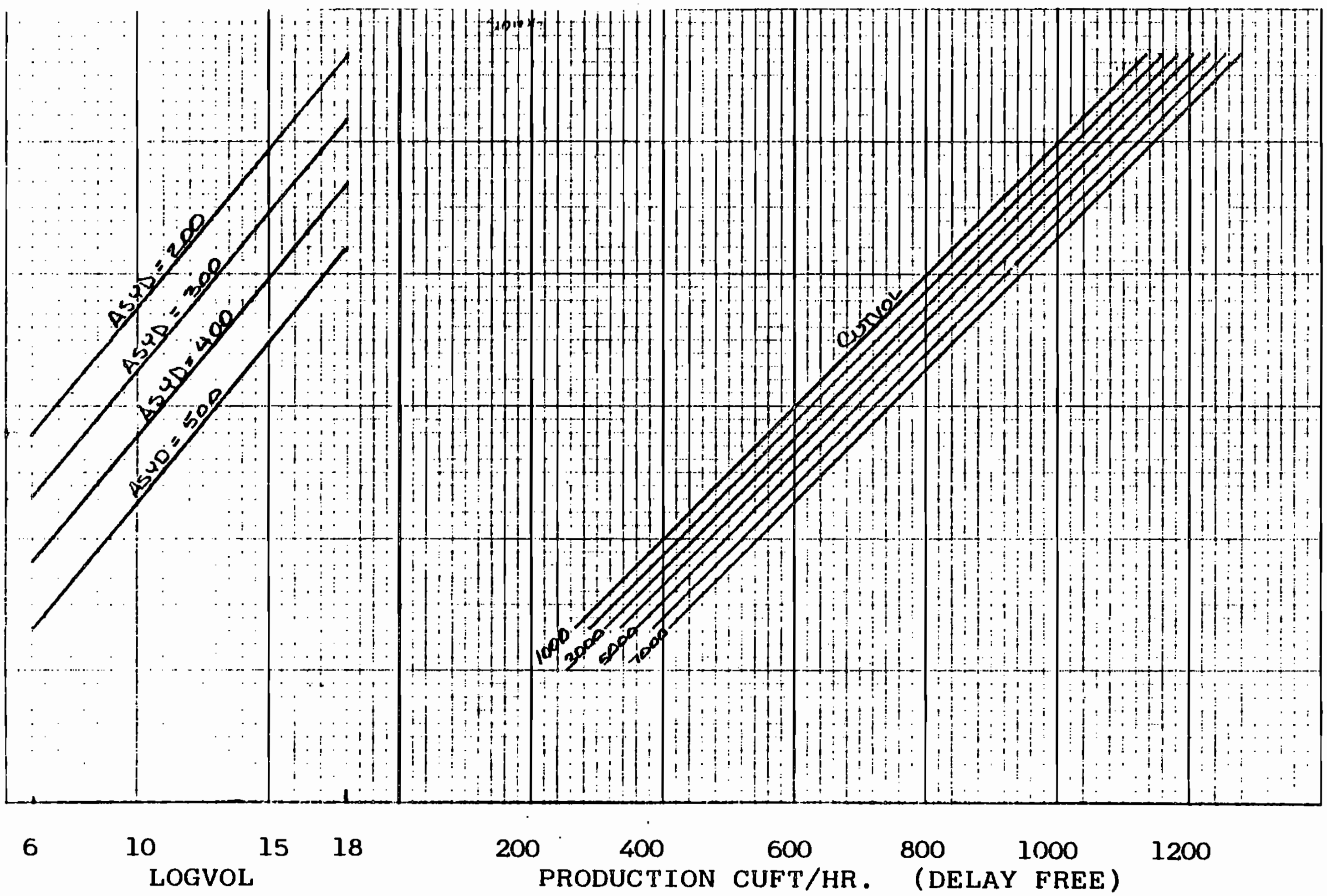


Figure 10. Skyline Thinning Production Rate Nomograph for the Schield Bantum Swing Configuration.

Graphs

Figures 11 through 15 are graphs of production in cubic feet per hour (unadjusted) based on the linear production rate equations. The absissa of the graphs represent ranges of values for LOGVOL, ASYD or CUTVOL while the remaining two independent variables are held constant. The independent variables take on the following values when held constant:

LOGVOL = 10 or 20 cubic feet

ASYD = 450 feet

CUTVOL = 3500 cubic feet per acre

The graphs indicate that the equations behave in accordance with the following expected engineering principles:

- Production increases when LOGVOL is increased
- Production decreases when ASYD is increased
- Production increases when CUTVOL is increased
- Production increases as chokers are added until payload capacity is reached provided additional logs are available for hooking.

The differences between yarder configurations indicated in Figures 11 through 15 are not solely due to hardware. Differences in crew training, experience level and supervision make it difficult to make pure comparisons between the yarder configurations. The fact that the original time studies were not all conducted under identical stand, terrain and weather conditions may also be responsible for some of the differences.

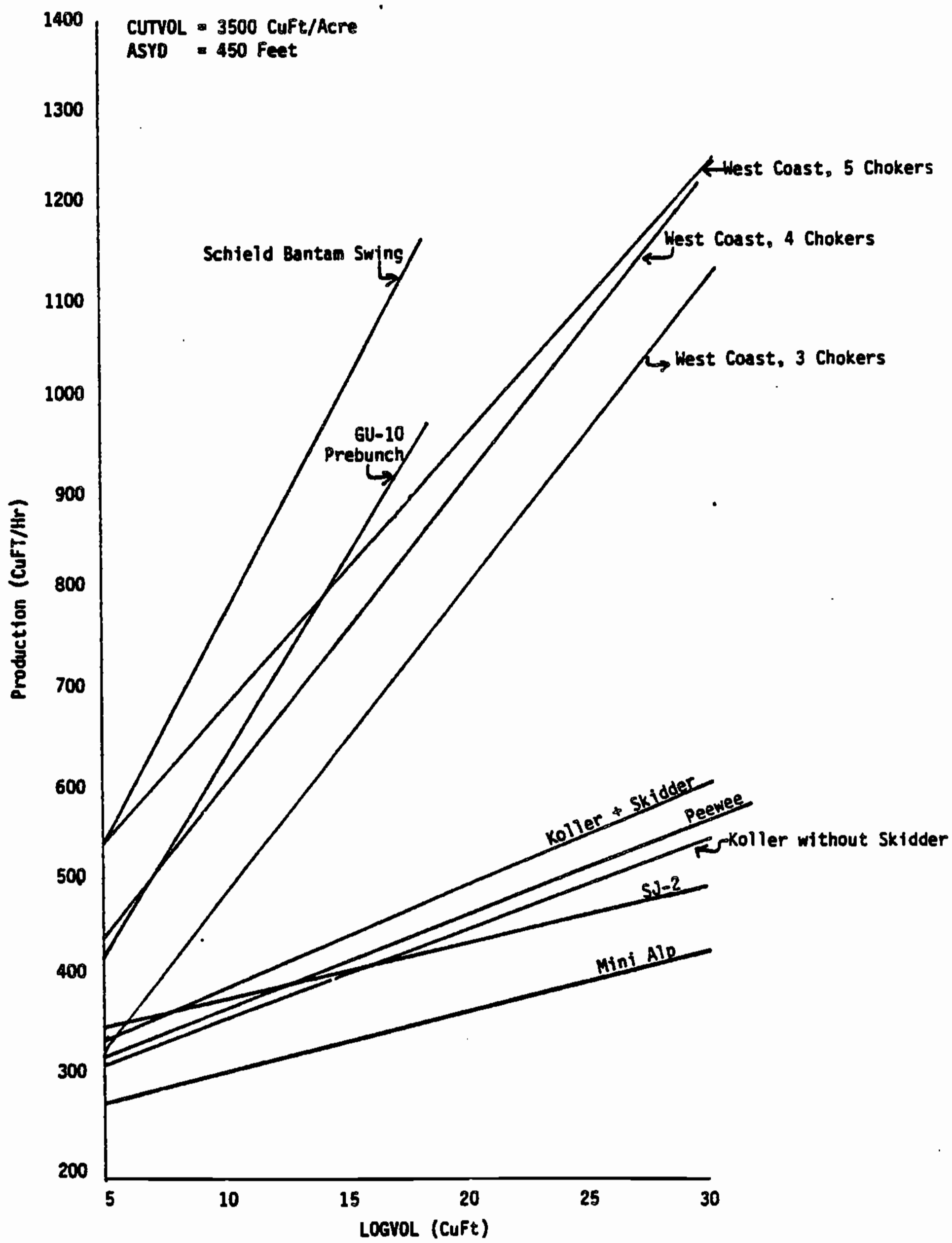


Figure 11. Production Versus LOGVOL Based on Linear Production Equations

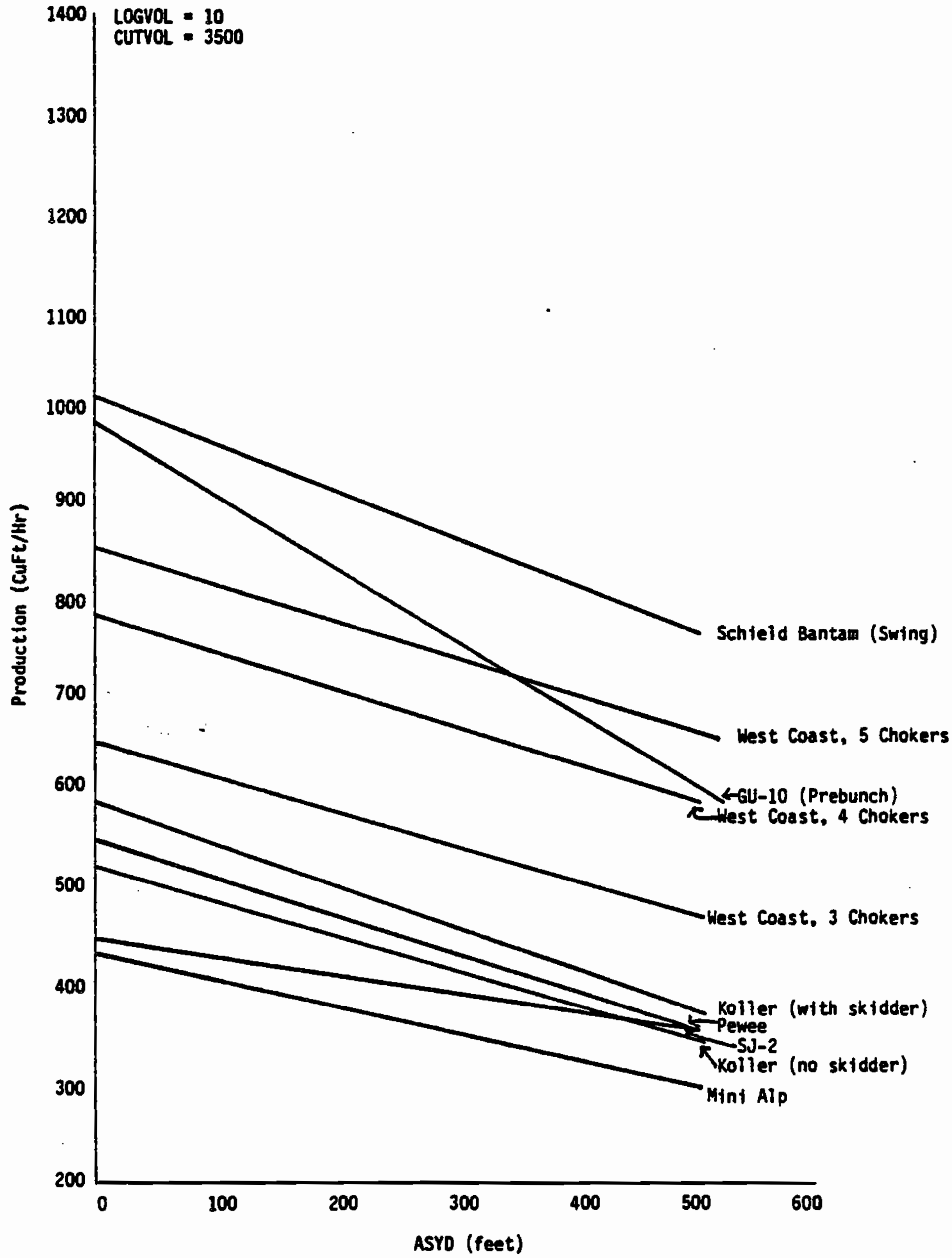


Figure 12. Production Versus ASYD Based on Linear Production Equations

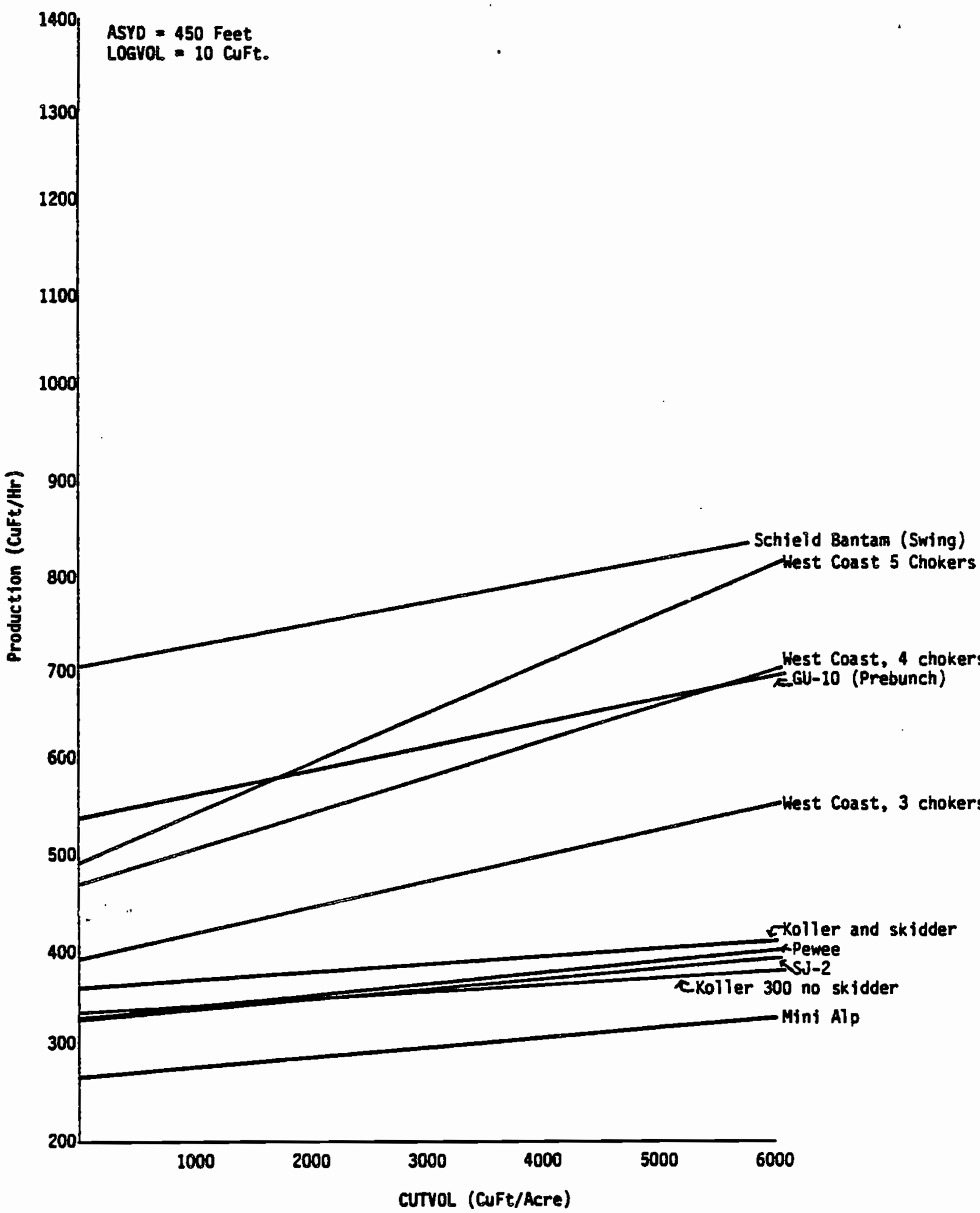


Figure 13. Production Versus CUTVOL Based on Linear Production Equations

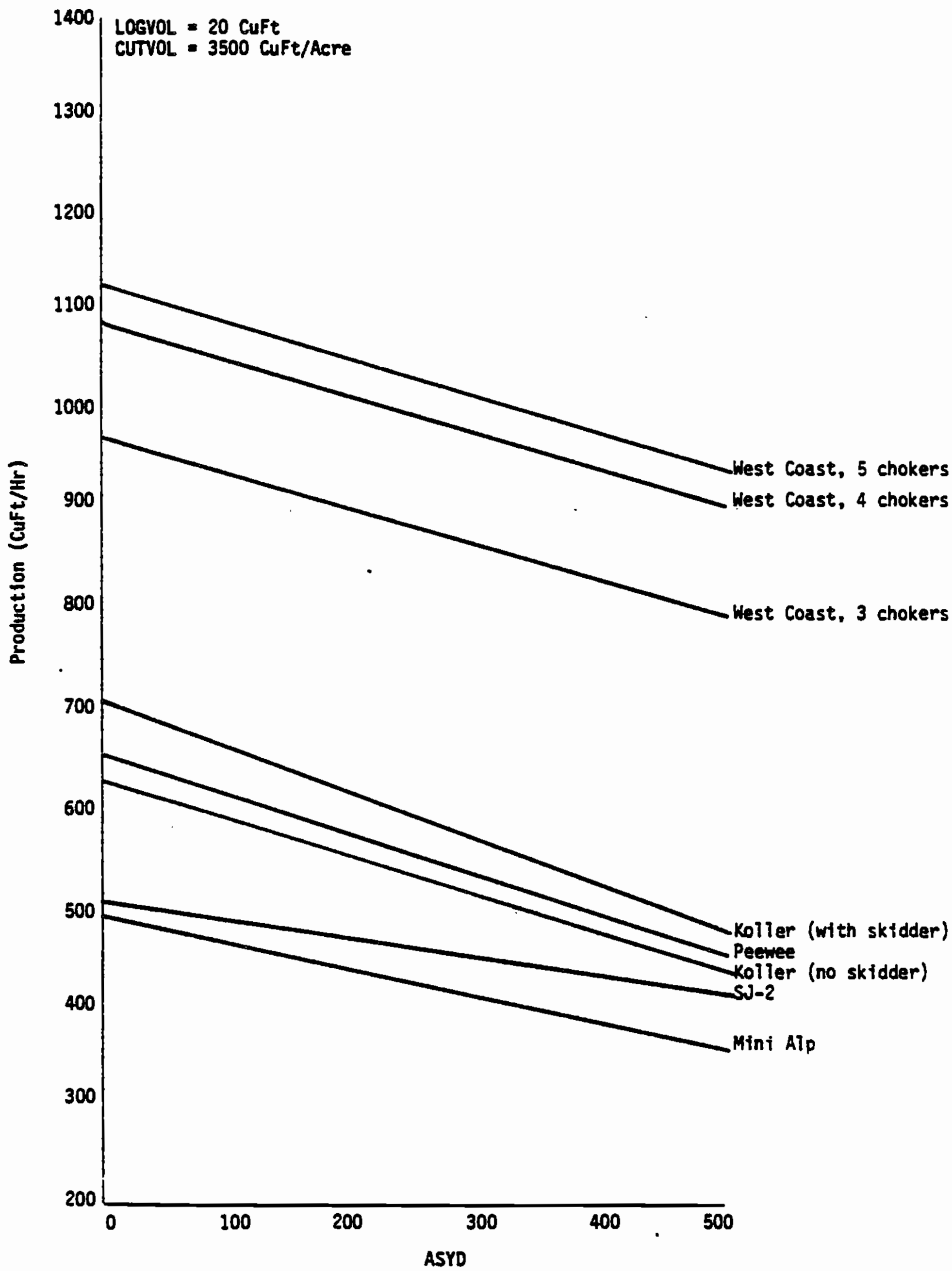


Figure 14. Production Versus ASYD Based on Linear Production Equations

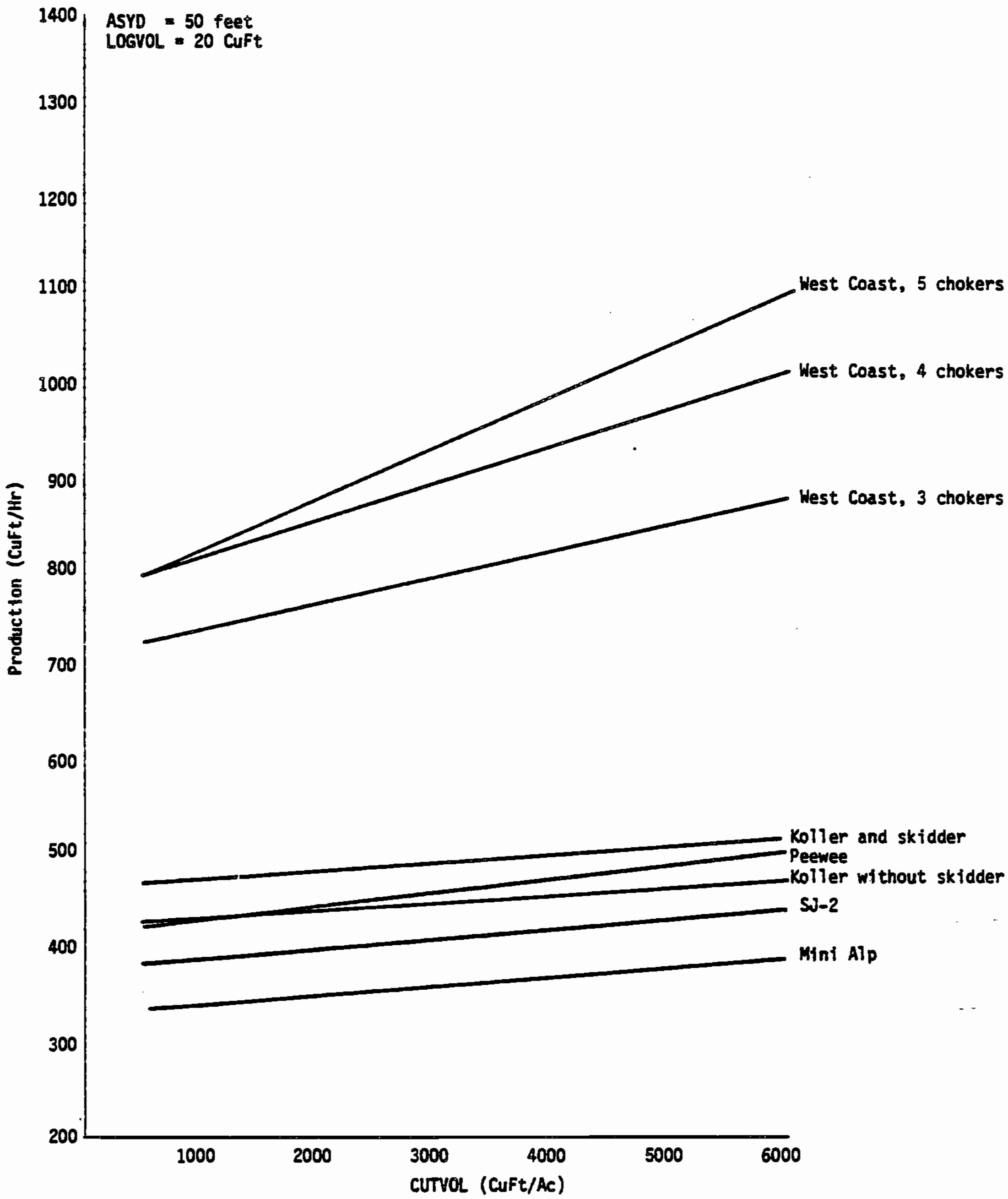


Figure 15. Production Versus CUTVOL Based on Linear Production Equations

R^2 Values

There are two R^2 values associated with each yarder configuration. The R^2 value for the original turn time equation is a measure of how much variation between predicted and observed turn times is explained by the turn time equation. The R^2 value for the newly developed production rate equation is a measure of how much variation between predicted and observed THIN production rates is explained by the production rate equation. The R^2 values listed in Table 7 are a measure of only the latter.

Confidence Limits

There are two confidence levels associated with each configuration. Confidence limits for the turn time equations can be obtained from the original research [7] [9] [10] [14] [15] [17] [18]. Confidence limits for the production rate equations as related to the THIN production data are listed in Tables 8, 9, and 10. The tabulated production rate confidence limits are at the 95% level. Tables 8, 9, and 10 list confidence limits for production when two independent variables are held constant and the third is varied over a range of values approximately corresponding to the same values which were fed into the THIN model. When held constant, the values of the independent variables were as follows:

ASYD = 450 feet
CUTVOL = 1800 cubic feet per acre
LOGVOL = 12 cubic feet

TABLE 8. 95% Confidence Interval for Production (delay free) Over Range of Average Slope Yarding Distance (100-500 feet) When Average Log Volume Equals 12 Cubic Feet and Cut Volume Per Acre Equals 1800 Cubic Feet Per Acre

YARDER CONFIGURATION	100 FT	200 FT	300 FT	400 FT	500 FT
Mini Alp	385-415	361-384	333-353	304-323	275-293
SJ-2	409-441	391-419	373-397	354-376	335-336
Peewee	493-529	454-485	415-443	394-418	376-401
Koller	485-515	448-474	412-435	374-395	337-357
Koller + Skidder	541-576	498-528	454-480	409-433	364-387
West Coast, 3 Chokers	605-660	572-620	539-581	504-542	468-505
West Coast, 4 Chokers	713-767	677-724	641-686	604-641	566-602
West Coast, 5 Chokers	750-810	716-768	681-727	645-686	608-647
Bunch GU-10	908-978	835-895	762-812	687-731	610-652
Swing Schield Bantam	976-1050	832-996	888-942	844-888	799-834

TABLE 9. 95% Confidence Intervals for Production (Delay free) Over Range of Cut Volume 1000-7500 Cubic Feet Per Acre When ASYD Equals 450 Feet and LOGVOL Equals 12 Cubic Feet

YARDER CONFIGURATION	1000	2000	3000	4000	5000	6000	7000
Mini Alp	280-301	292-310	302-321	309-334	316-348	323-362	352-384
SJ-2	335-359	347-368	356-379	364-393	370-407	376-423	384-446
Peewee	343-371	359-383	371-397	382-415	391-433	399-452	411-482
Koller	348-371	357-377	364-386	369-397	373-409	377-421	381-440
Koller + Skidder	378-405	389-412	397-422	402-434	406-447	410-461	415-483
West Coast, 3 Chokers	461-503	492-529	519-559	542-593	546-629	584-666	614-722
West Coast, 4 Chokers	551-593	593-630	631-670	665-715	697-761	728-808	774-880
West Coast, 5 Chokers	579-625	638-677	691-734	741-795	788-858	834-922	902-1019
Bunch GU-10	621-679	654-695	675-724	687-762	696-802	Not Available	
Swing Schield Bantam	799-845	827-866	848-892	865-923	880-956	(Beyond THIN data range)	

TABLE 10. 95% Confidence Intervals for Production (delay free) Over Range of Log Volume (10-30 CUFT) When ASYD Equals 450 Feet and CUTVOL Equals 1800 Cubic Feet per Acre

YARDER CONFIGURATION	10	15	20	25	30
Mini Alp	277-297	309-326	338-359	366-393	392-429
SJ-2	331-355	363-383	391-415	416-449	441-484
Peewee	335-362	386-409	432-460	476-513	519-568
Koller	336-358	384-403	429-451	471-502	512-553
Koller + Skidder	365-391	419-441	470-496	517-553	564-611
West Coast, 3 Chokers	420-461	584-619	742-784	879-953	1049-1124
West Coast, 4 Chokers	521-561	680-715	833-874	982-1038	1129-1204
West Coast, 5 Chokers	569-613	711-749	847-892	978-1040	1108-1189
Bunch GU-10	865-942	764-822		Not Available	
Swing Schield Bantam	725-766	962-1009		(Beyond THIN data range)	

The value of yarder specific production equations can be partially appreciated by noting that very little overlapping of production rates occurs between the yarder configurations listed in Tables 8, 9, and 10.

Significance of Variables

The variables ASYD, LOGVOL, and CUTVOL are significant at the 95% level in all of the production equations. The most significant variable in the West Coast Yarder and Schield Bantam Swing equations is LOGVOL. ASYD is the most significant variable in the other equations. CUTVOL is the least significant variable in all of the equations. Table 11 lists the t-values for each regression term in the equations.

TABLE 11. t-values Indicating the Significance of Variables at the 95% Level

YARDER CONFIGURATION	CONSTANT	LOGVOL	ASYD	CUTVOL
Mini Alp	31.779	11.447	-23.300	4.431
SJ-2	28.031	9.254	-13.356	3.765
Peewee	28.498	13.384	-23.999	4.379
Koller	34.426	15.253	-27.001	3.016
Koller + Skidder	33.471	14.964	-27.946	2.902
West Coast, 3 Chokers	10.463	28.914	-14.071	5.943
West Coast, 4 Chokers	15.343	28.345	-15.169	8.238
West Coast, 5 Chokers	16.201	23.101	-13.592	10.612
Bunch GU-10	14.996	15.437	-22.195	2.771
Swing Schield Bantum	16.976	29.121	-17.220	4.264

VII. USE OF THE PRODUCTION EQUATIONS

Limitations and Warnings

The equations have an inherent source of error and are only approximations of hourly production. The user must understand that the equations have the following limitations:

- The production estimates obtained from the equations are delay free. (See Adjustment for Delays)
- The equations are linear approximations of non-linear data, and some error is inherent to the equations as a result.
- Values of independent variables must not be outside of the data base ranges used during THIN simulation. These ranges are listed in Table 15.
- An error may occur when it is assumed that ASYD for the setting equals SL/2. This error occurs when the log distribution within the setting is not uniform. For example, it was found that ASYD = 497 feet instead of 500 feet when SL = 1000 feet during the simulation runs for the West Coast Tower configuration with four chokers.
- The production equations are based on assumptions which have been stated in Section V, page 15. The equations may not be valid when applied to conditions which differ from the stated assumptions.

Adjustments for Delays

Production estimates obtained from the linear production equations presented in this paper and listed in Table 7 are unadjusted for delays. The user may wish to adjust the estimates for various types of delays. Figure 16 defines several broad categories of delays as well as productive time.

A =	experimental delay time
B =	initial move in and rig up time
C =	final rig down and move out time
D =	road and landing change time
E =	other delay time attributed to delays such as: personal mechanical resetting chokers to free hangup sorting rigging landing delays repositioning turn on deck moving carriage stop breaking line line fouled on drum
F =	productive time attributed to the following activities: outhaul lateral out hook lateral in inhaul unhook

Figure 16. Definitions of Delay and Production Time Categories (Time in Minutes)

Table 12 lists suggested correction factors for type E delays when the desired total time basis equals E+F. The correction factors are based on delays observed during the time studies. [7] [9] [10] [14] [15] [17] [18].

Equation 1 can be used to find the hourly production rate in cubic feet adjusted for type E delays.

$$PROD_E = PROD \left[1 - \left(\frac{E}{E+F}\right) \right] \qquad \text{Equation 1}$$

Where $PROD_E$ = Hourly production rate in cubic feet adjusted for type E delays.

PROD = Delay free hourly production rate in cubic feet.

E = (Defined in Figure 16)

F = (Defined in Figure 16)

The use of Equation 1 is demonstrated in the following example:

Given: LOGVOL = 19

CUTVOL = 2500

SL = 1000

Required: Find the hourly skyline thinning production rate of the West Coast tower configuration with 4 chokers adjusted for type E delays.

Solution: First determine ASYD for the rectangular setting by assuming:

$ASYD \simeq SL/2$ (See section VII, page 51 concerning this assumption)

$ASYD \simeq 500$

Using the production rate equation listed in Table 7 for the West Coast configuration with 4 chokers, find the delay free hourly production rate:

$PROD = 333.169 - 0.389712(500)+31.2752(19)+0.0391625(2500)$

$PROD = 830$ cuft/hr

Next find the correction factor for type E delays in Table 12:

$1 - (\frac{E}{E+F}) = 0.78$

Finally, solve Equation 1 to obtain the hourly production rate adjusted for type E delays:

$PROD_E = 830(0.78)$

$PROD_E = \underline{\underline{647 \text{ cuft/hr}}}$

TABLE 12. Suggested Adjustment Factors for Type E Delays When Desired Total Time Basis Equals Type E Delays Plus Productive Time

Configuration	Correction Factor = $1-(\frac{E}{E+F})$
Mini Alp	.76
SJ-2	.79
Peewee	.83
Koller without skidder swing	unknown
Koller with skidder swing	unknown
West Coast	.78
Prebunch	unknown
Swing	.81

Equation 2 can be used to adjust production for type D and E delays when the desired total time basis equals D+E+F.

$$PROD_{D+E} = \frac{0.00344*CUTVOL*L}{\frac{0.00344*CUTVOL*L}{PROD*G} + \frac{\text{Road change time in Minutes}}{60}} \quad \text{Equation 2}$$

where $PROD_{D+E}$ = Hourly production rate in cubic feet adjusted for type E and D delays

L = Length in feet of rectangular setting (horizontal distance)

$G = \left[1 - (\frac{E}{E+F})\right]$ = Correction factor listed in Table 12.

PROD = Delay free hourly production rate in cubic feet.

The use of Equation 2 is demonstrated in the following example:

Given: LOGVOL = 19

CUTVOL = 2500

SL = 1000

L = 973

Required: Find the hourly skyline thinning production rate of the West Coast tower configuration with 4 chokers adjusted for type D and E delays.

Solution:

From the previous example: PROD = 830

From the previous example:

$$G = 1-\left(\frac{E}{E+F}\right) = 0.78$$

Next find the average road change time from Table 13.

average road change time = 253 minutes

Finally, solve Equation 2 to obtain the hourly production rate adjusted for type D and E delays.

$$PROD_{D+E} = \frac{.00344\ (2500)(973)}{\frac{.00344\ (2500)(973)}{830\ (0.78)} + \frac{253}{60}}$$

$$PROD_{D+E} = \underline{\underline{488\ \text{cuft/hr}}}$$

Equation 3 can be used to adjust production for type D and E delays when the desired total turn time basis equals D+E+F. Equation 3 is helpful when delay percentages quoted in the literature [18] include road change times;

however, some error is likely to occur unless the average SL of the time study equals the SL of the setting in question.

$$PROD_{D+E} = \left[1 - \left(\frac{D+E}{D+E+F}\right)\right] PROD \qquad \text{Equation 3}$$

The term $\left(\frac{D+E}{D+E+F}\right)$ = .39 for the GU-10 prebunch configuration when average SL = 802 feet (244.4 meters).

The use of Equation 3 is demonstrated in the following example:

Given: LOGVOL = 18
CUTVOL = 3500
SL = 800

Required: Find the approximate hourly production rate of the Skagit GU-10 rigged for prebunching and adjusted for type D and E delays.

Solution: First determine ASYD:
ASYD ≃ SL/2
ASYD ≃ 400
Using the production rate equation listed in Table 7 for the Skagit GU-10 prebunching configuration, find the delay free hourly production rate:

PROD=483.729 - 0.780594(400) + 41.0603(26) + 0.0247655(3500)
PROD=997 cuft/hr

Finally, solve Equation 3 using the suggested value of 0.39 for the term $\left(\frac{D+E}{D+E+F}\right)$ found on page 57.

$$PROD_{D+E} = \left[1 - .39\right] 997$$

$$PROD_{D+E} = \underline{\underline{608 \text{ cuft/hr}}}$$

Road change time was found to vary with EYD for the Mini Alp Configuration [15]. It is logical to suspect that the same may be true for the other configurations; however, regression equations for road change times were not developed during the original time studies. Table 13 is a summary of road change time data collected during the time studies. [7] [9] [9] [15] [18]

TABLE 13. Road Change Time Data

Configuration	Average Road Change Time (Min)
Mini Alp	46.5455 ln(EYD)-162
Koller	unknown
Peewee	216
SJ-2	84
West Coast	253
Skagit GU-10 prebunching	108
Schield Bantam Swinging	unknown

Cubic Feet to Board Feet Conversion

The problems of attempting to convert production in cubic feet per hour to production in board feet per hour are many. Some loss in accuracy is nearly assured during the conversion. If a conversion between cubic feet and board feet is necessary, one approach suggested by Dykstra [6] is to consider the relationship between average log size and the conversion ratio. Dykstra has included some helpful average log volume data from 15 different stands in his article [6]. An excerpt of a portion of the data from seven Douglas-fir stands with the smallest reported average log volumes in Dykstra's Table 1 follows:

Average Log Volume		Conversion Ratio
Cubic Feet (Smalian)	Board Feet (Scribner)	
12.9	51.5	4.0
15.5	61.6	4.0
15.9	72.2	4.5
20.1	89.7	4.5
25.2	117.9	4.7
24.0	102.6	4.3
32.6	168.8	4.2

If average log volume in cubic feet is regressed against conversion ratios, the following equation results with an $R^2 = .76$:

Conversion ratio = 3.34 + .053 (LOGVOL)

Obtaining LOGVOL

The BUCK model can be used to determine LOGVOL for any timber stand. Inputs include dbh, total height in feet, Girard form class* and the number of trees in each dbh class.

* Girard form class in this paper is defined as the ratio of the diameter inside bark at the top of the first 32 foot log above the stump to dbh.

VIII. ANALYSIS

How Well Do Graphs of the Equations Appear to Fit Plots of Data?

The R^2 values and confidence limits listed in Tables 7, 8, 9 and 10 are two indications of goodness of fit. A third indication can be obtained by comparing data plots with graphs of the equations. Figure 17 compares plots of data points with the graph of the Mini Alp equation. Additional comparative plots and graphs can be found in the Appendix. Only 5 or 10 data points can be plotted for comparison with graphs of the equation using this technique. Based on this small sample size; however, one may suspect that some of the data is nonlinear which hampers goodness of fit.

The equations for the Mini Alp, Koller, Peewee and Skagit SJ-2 configurations tend to over estimate delay free production when LOGVOL = 6.2 and ASYD = 450. An under estimate tends to occur when LOGVOL = 11.9 and ASYD = 450. The West Coast equations are apparently least hampered by this problem.

AYD = 450
CUT VOL/ACRE - 1800

LEGEND

ʘ Stochastic data
____ Linear equation

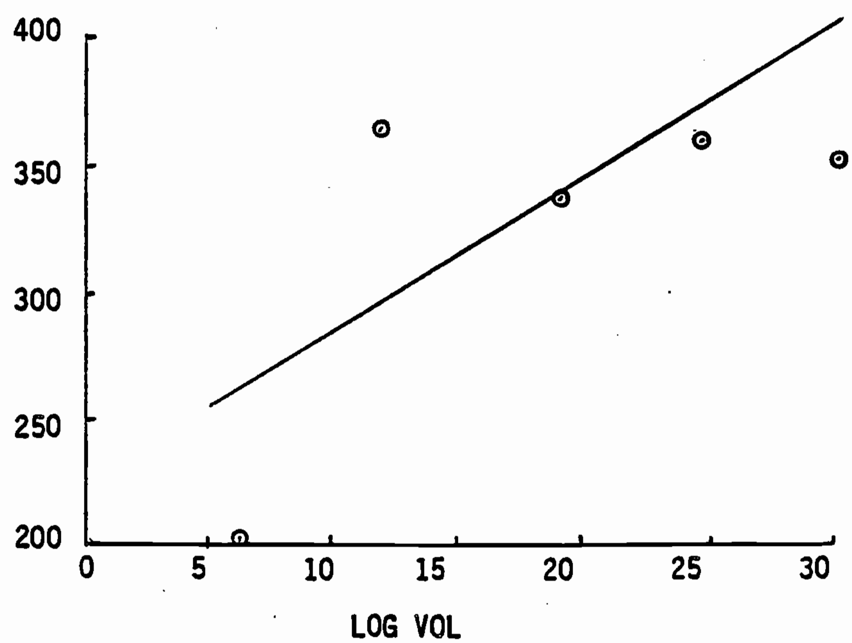


Figure 17. Comparison Between Observed and Predicted Production for the Mini Alp Configuration when LOGVOL is Varied. Production Data was Generated by the THIN Model.

Multicolinearity

Some multicolinearity exists between CUTVOL and LOGVOL. Multicolinearity can be detected by observing a change in the LOGVOL coefficient when CUTVOL enters the linear production equation. For example the LOGVOL coefficient changed from 10.4098 to 9.2803 when CUTVOL entered the equation for the Koller configuration without the skidder. The correlation value between the two variables was .6156. Figure 18 is a scattergram of the two variables.

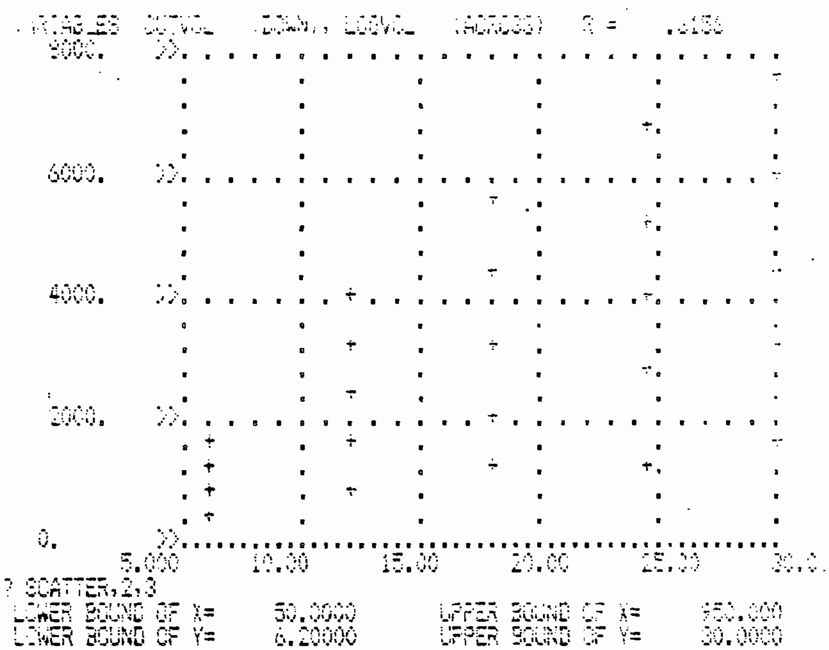
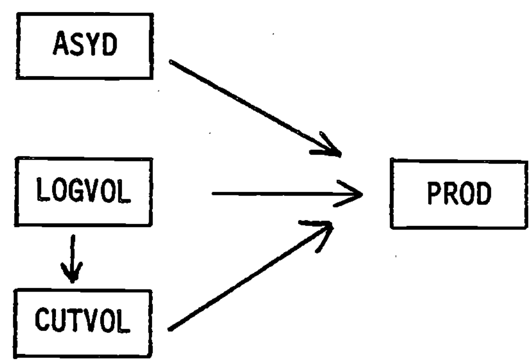


Figure 18. Scattergram Indicating the Presence of Multicolinearity Between the Variables CUTVOL and LOGVOL in Site III Stands

A diagram of the effects which the three independent variables have on production and on each other is as follows:



Do Linear or Nonlinear Relationships Exist Between Production and the Independent Variables?

Data trends can often be detected by plotting all existing data on a two dimensional coordinate system. Such graphs are sometimes referred to as scattergrams [16]. Scattergrams are especially helpful when only a small number of data points would result if all but one of the independent variables are held constant. This is the case for the data sets representing the yarder configurations. Figures 30 through 35 are scattergrams for the Koller configuration without the skidder swing, the West Coast configuration with 4 chokers and the Skagit GU-10 prebunching configuration. Figures 30 through 35 can be found in the Appendix. A visual inspection of the scattergrams leads one to suspect that some of the data is nonlinear.

How Much Accuracy is Sacrificed with Linear Production Equations Since Some of Data is Nonlinear?

One must ask how much accuracy is sacrificed with linear production equations when some of the data is nonlinear. One way to evaluate this question is to develop a nonlinear equation and compare it with its linear counterpart.

A nonlinear form for the Mini Alp configuration follows:

$$\begin{aligned}\text{Production (CuFt.Hr)} = 259.414 &- .486089\ \text{ASYD} \\ &+ 18.6834\ \text{LOGVOL} \\ &+ .0300731\ \text{CUTVOL} \\ &+ .000192712\ \text{ASYD SQ} \\ &- .344172\ \text{LOGVOL SQ} \\ &- .000002859\ \text{CUTVOL SQ}\end{aligned}$$

The R^2 value for the nonlinear form is .8430 while the R^2 value for the linear form is .7827. By using the linear form a sacrifice in R^2 value of .0603 occurs.

Figure 19 is a graphic comparison of the linear and nonlinear production equations for the Mini Alp when ASYD = 450 feet, CUTVOL = 2000 cubic feet per acre and LOGVOL is varied from 6.2 to 30.0 cubic feet. Under these conditions, a maximum difference of 34 cubic feet per hour in delay free production occurs when LOGVOL = 6.2 cubic feet.

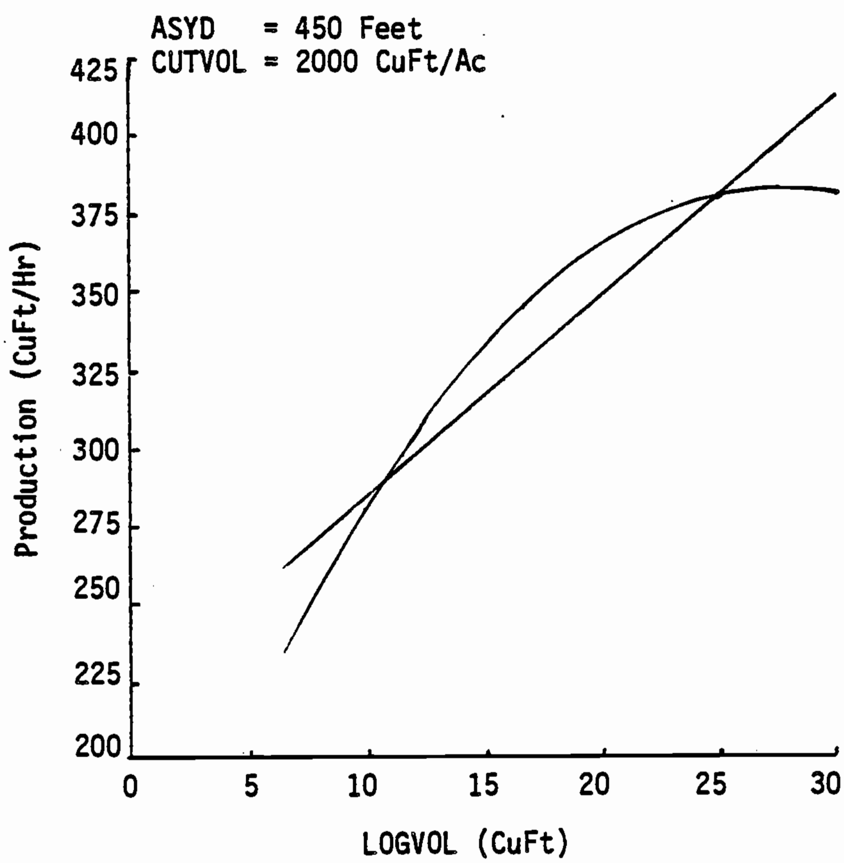


Figure 19. Comparison Between Linear and Nonlinear Production Equations for the Mini Alp Configuration

Would the Accuracy of the Equations be Adversely Affected by Selecting the Independent Variable TREEVOL in Lieu of LOGVOL?

The selection of the independent variable TREEVOL in lieu of LOGVOL will adversely affect the accuracy of the linear production rate equations. Figure 20 is a graph of TREEVOL versus LOGVOL which illustrates that TREEVOL and LOGVOL are not linearly related. The THIN model generates stochastic production data based on log volume parameters and not tree volume parameters. Therefore, a loss in accuracy occurs during the regression process when TREEVOL values are substituted for the corresponding LOGVOL values. Table 14 is a measure of the loss in accuracy which occurs when the independent variable TREEVOL is regressed in lieu of LOGVOL against production for the West Coast configuration with four chokers. The equation for the West Coast configuration with four chokers using TREEVOL as an independent variable follows:

$$\underset{(\text{CuFt/Hr})}{\text{Production}} = 487.128 - .389712\ \text{ASYD} + 7.84875\ \text{TREEVOL} + .044582\ \text{CUTVOL}$$

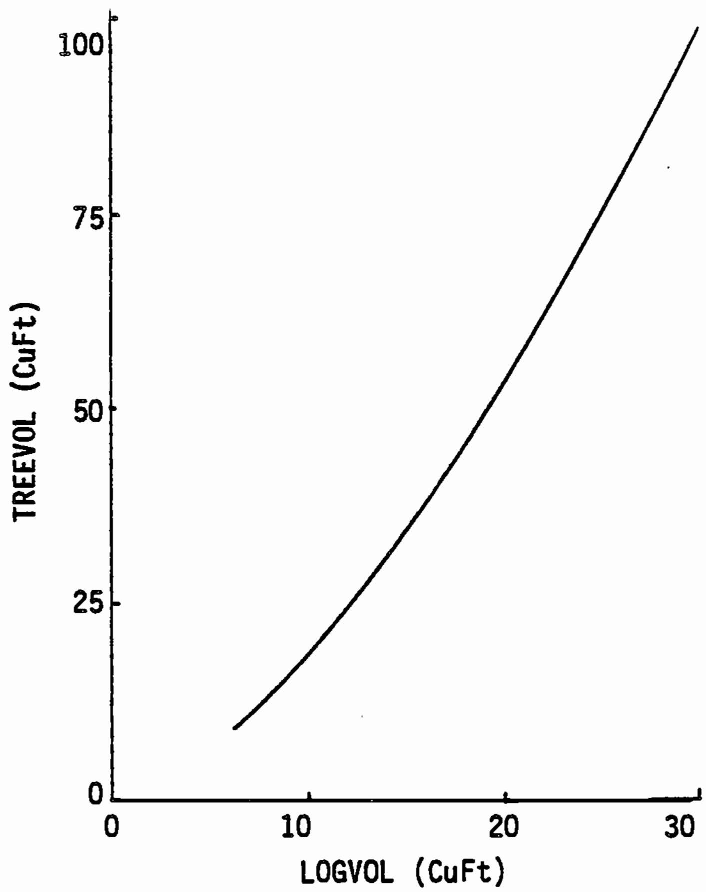


Figure 20. The Nonlinear Relationship Between TREEVOL and LOGVOL

TABLE 14. Difference in Production Estimate Which Occurs When TREEVOL in Lieu of LOGVOL is Regressed Against Production (West Coast Tower with 4 Chokers, ASYD Equals 450 Feet, CUTVOL Equals 2000 CuFt/Hr)

Stand Age	LOGVOL (CuFt)	Correspondeng TREEVOL (CuFt/Hr)	Independent Variable in Equation: LOGVOL Production (CuFt/Hr)	Independent Variable in Equation: TREEVOL Production (CuFt/Hr)	Difference (CuFt/Hr)
40	6.21	9.51	430	476	-46
60	11.92	24.30	609	592	17
80	18.09	47.09	802	771	31
100	24.30	71.86	996	965	31
120	30.04	99.21	1176	1180	-6

What Range of Values of ASYD, LOGVOL and CUTVOL were Regressed Against Production to Obtain the Production Equations?

The ASYD values linearly regressed against production ranged from 50 to 950 feet. The range of LOGVOL and CUTVOL values linearly regressed against production are listed in Table 15 for site III stand data.

TABLE 15. Range of LOGVOL and CUTVOL Values Linearly Regressed Against Production for Site III Stand Data.

Stand Age	LOGVOL	CUTVOL				
		THINNING INTENSITY				
		10%	20%	30%	40%	50%
40	6.2	355	711	1066	1421	1776
60	11.9	764	1528	2292	3056	3820
80	18.1	1093	2186	3280	4374	5466
100*	24.3	1322	2644	3966	5288	6610
120*	30.0	1506	3012	4518	6024	7530

*Data for stand ages 100 and 120 years is not included in the prebunch and swing equations.

How Much Error Results When ASYD is Assumed to Equal SL/2?

To be useful for most economic analysis, the production equations must apply to entire settings and not to just one turn of logs. To apply the equations in this paper to entire rectangular settings, it is convenient to assume that ASYD $\simeq$ SL/2. Two conditions must be met if this assumption is to be valid. First, the relationship between production and ASYD must be linear; secondly, the log distribution must be uniform. The first condition has been met by virtue of linear regression. All of the production equations have linear ASYD terms. The second condition will rarely be met; however, the error may be tolerable in homogenous stands. For example it was found that ASYD = 497 feet instead of 500 feet when SL = 1000 feet during the simulation runs for the West Coast Tower configuration with 4 chokers.

Does the Independent Variable LOGVOL have a Symmetrical Distribution?

Figures 21, 36, 37, 38 and 39 are the histograms of log volume for site III stands of Douglas-fir (Psuedotsuga menziesii (Mirb.) Franco) at age classes 40, 60, 80, 100 and 120 years, respectively, when thinned at 50 percent intensity and bucked in accordance with the previously described bucking rule. These figures indicate that LOGVOL has a nonsymmetrical distribution. See Appendix for Figures 36, 37, 38 and 39.

It is helpful to know the distribution of independent variables. Obviously, a mid-range value of LOGVOL would not be the correct weighted average value to use in a linear regression term. The correct mean LOGVOL value to be used in linear regression terms can be obtained by using the previously described log bucking model BUCK.

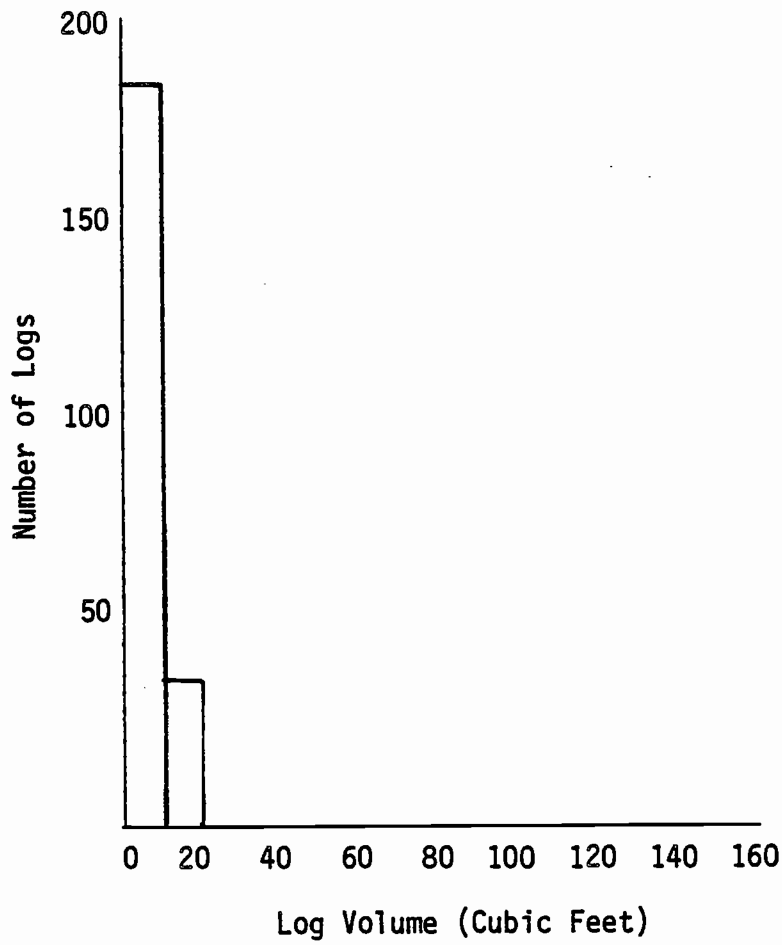


Figure 21 . Log Volume Histogram of a 40 Year Old Douglas-fir Stand Thinned at 50 Percent Intensity

IX. CONCLUSIONS

The THIN model was successfully used to generate yarder-specific stochastic production data which were subsequently regressed into ten linear production rate equations. With one minor exception, the THIN model functioned well during its role in the transformation process. It was found that when maximum log volume exceeded allowable payload, turn weight sometimes exceeded maximum log weight. This occurred when prebunch and swing turns were being simulated, but did not occur when full cycle yarding turns were being simulated.

The linear equations suffer from an inherent inaccuracy in that much of the data is nonlinear. A strong nonlinear relationship exists between production and LOGVOL data at the low end of the LOGVOL range in several of the configurations. Goodness of fit has been hampered by linearly regressing this nonlinear data. The equations for the Mini Alp, Koller, Skagit SJ-2, and Peewee configurations tend to overestimate delay free production when LOGVOL equals either 6.2 or 30.0 and ASYD = 450. An under estimate tends to occur when LOGVOL = 11.9 and ASYD = 450. A difference of 34 cubic feet per hour was found to exist between linear and nonlinear equations for the Mini Alp configuration when ASYD = 450 feet, LOGVOL = 6.2 cubic feet and CUTVOL = 2000 cubic feet per acre.

X. SUGGESTIONS FOR FUTURE TRANSFORMATIONS

Develop Two Linear Production Equations for Each Configuration Representing Different Ranges of LOGVOL Values

The purpose of two equations is improved accuracy. The principle is illustrated in Figure 22.

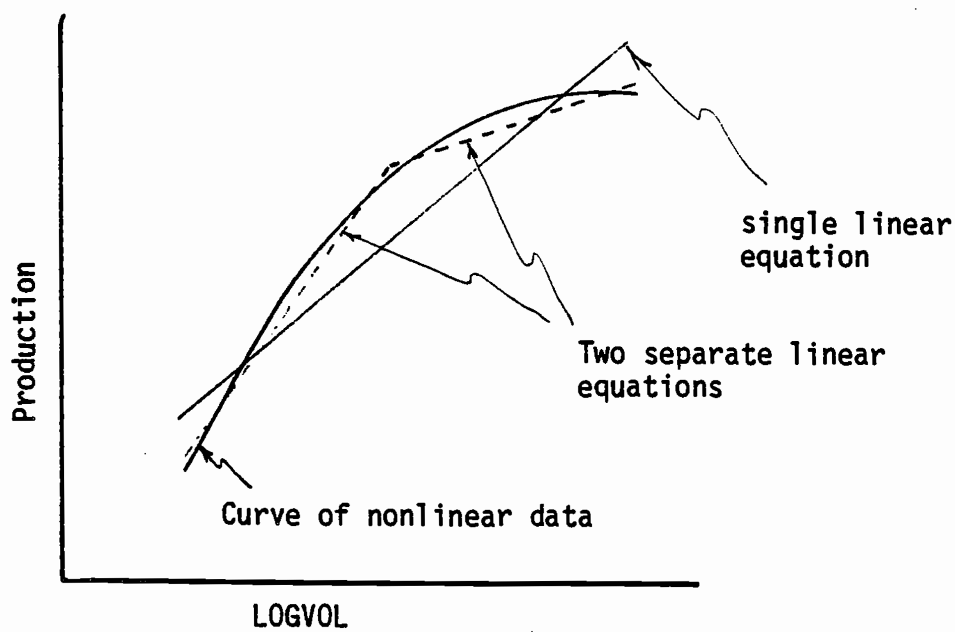


Figure 22. Principle of Fitting Two Linear Equations to Nonlinear Data for Improved Prediction Accuracy

Omit Low Intensity Thinning Data to Avoid the Stronger Nonlinear Relationship Which Occurs Between Production and CUTVOL at the Low End of the CUTVOL Range

It is suspected that the accuracy of the production equations presented in this paper could have been improved if the 10% thinning intensity had been omitted.

Assume More Than Three Chokers When Making THIN Runs

The effect would be to more fully utilize the allowable system payload when operating in small timber. LeDoux has used the THIN model to answer the question of how many chokers to fly in cable thinnings. [12]

Develop Equations with Nonlinear LOGVOL and CUTVOL terms while leaving the ASYD Term Linear

A considerable sacrifice of user simplicity would occur if a nonlinear ASYD term were included.

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APPENDIX

Equipment Specifications

DETAILED EQUIPMENT SPECIFICATIONS FOR

YARDER CONFIGURATIONS USED DURING SIMULATION

Yarders/Towers								Carriages			
Make	Yarder Tower	System	Tower Height # Guylines	Length/Diameter SL	ML	HB	Other	Make	Name Model No.	Yarder Drums Used	Weight
Igland Jones	Trailer Alp powered by John Deere 2640 70 h.p. farm tractor	Standing skyline, single and multi-span with haulback, uphill, 3 chokers	23.7 ft. (7.2 meters) 3	2600 ft. 5/8 ins. (800 meters) (16 mm)	1800 ft. 3/8 ins. (550 meters) (9.5 mm)	1800 ft. 3/8 ins. (550 meters) (9.5 mm)		Igland Jones Igland Jones	Single span Multispan	3 3	35 lbs. (16 kg. 80 lbs. (36 kg.
Koller	Koller 300	Standing skyline, single and multi-span gravity out-haul, uphill, 3 chokers	20 ft. (6 meters) 2	1100 ft. 5/8 ins. (340 meters) (16 mm)	1300 ft. 3/8 ins. (400 meters) (9.5 mm)			Koller	SKAI	2	330 lbs. (150 kg.
Same as above	Same as above	Same as above but with skidder swing to truck landing using John Deere 440-C skidder	Same as above	Same as above				Same as above			
Experimental USFS	Peewee	Running skyline, single span, uphill and downhill, 3 chokers	37 ft. (11.3 meters)		1200 ft. 1/2 ins. (365 meters) (12.5 mm)	1200 ft. 1/2 ins. (365 meters) (12.5 mm)	1200 ft. 1/2 ins. (365 meters) (12.5 mm)	Unknown		3	
Skagit	SJ2-R Mobile Thinning Yarder	Line skyline, single span, gravity outhaul, uphill, 3 chokers	40 ft. (12.2 meters) 2		700 ft. 5/8 ins. (213 meters) (16 mm)	1000 ft. 9/16 ins. (304 meters) (14.3 mm)		Christy	Regular (hand slack pulling)	2	340 lbs. (154 kg.
Interstate Tractor, Inc.	West Coast Falcon	Standing skyline, singlespan, haul-back, uphill, 3,4, or 5 chokers	49 ft. (14.9 meters) 3	2000 ft. 1 ins. (610 meters) (25.4 mm)	1200 ft. 3/4 ins. (365 meters) (19.1 run)	2200 ft. 9/16 ins. (670 meters) (14.3 mm)	1600 ft. 7/16 ins. (488 meters) (11.1 mm)	West Coast	West Coast (dropline)	4	1430 lbs. (649 kg.
Skagit	GU-10 Rigged Tree	Prebunch with truck mounted GU-10, block rigged in tree, 2 chokers	No tower		not used	1100 ft. 7/16 ins. (335 meters) (11.1 mm)		No carriage used			
Schield-Bantam	T-350	Swing, line skyline, gravity outhaul, 3 chokers	30 ft. (9.1 meters)	1000 ft. 3/4 ins. (305 meters) (19.1 mm)	900 ft. 5/8 ins. (275 meters) (16 mm)	1600 ft. 7/16 ins. (488 meters) (11.1 mm)		Maki		2	

BUCK Model

BUCKING PROGRAM

LBL: BUCK
SIZE: 024
HP 41CV + PRINTER IF AVAILABLE

March 28, 1983
L.W. Starnes

The program simulates bucking a stand of second growth Douglas-fir trees into logs following an assumed bucking rule. The intended use of the program is to determine log volume statistical parameters and number of logs which are required to operate the THIN simulation model [11]. A one foot stump height and a 4 inch diameter inside bark top are assumed for merchantability standards. Upper stem taper follows that of a paraboliod. Cubic foot log volumes are computed using equations developed by Bruce [3] [4] after assumptions are made for diameter inside bark at a one foot stump height. A sample printout follows:

```
[illegible]
[illegible]
HT=60.00
NUMTREES=3.[illegible]
MER[illegible]=43.[illegible]
[illegible].04
[illegible]22=4.27
DSTUMP=7.84
DS21=7.68

FC=0.76
DBH=14.00
HT=90.00
NUMTREES=1.00
MERCHT=73.70
V21=24.62
V22=10.99
DSTUMP=13.71
DS21=10.03


TOTVOL=69.53
NUMLOGS=8.00
LENGTH=25.47
MEAN=8.69
MIN=4.27
MAX=24.6[illegible]
[illegible]
```

Inputs include the following:

FC	- Form class expressed as decimal (enter form class 72 as .72)
DBH	- Diameter breast height inches
HT	- Total tree height in feet
NUMTREES	- Number of trees with DBH, Ht. and FC as input above

Outputs include the following:

TOTVOL	- Total volume of all logs bucked
NUMLOGS	- Total number of all logs bucked
LENGTH	- Average length of logs bucked
MEAN	- Average log volume
MIN	- Minimum log volume
MAX	- Maximum log volume
SDEV	- Standard deviation of log volume about the mean

Storage register assignments:

01	FC
02	DBH
03	HT
04	D STUMP
05	M
06	NO. LOGS IN TREE
07	DS31 OR DS21 OR DS41
08	DS32 OR DS42
10	MIN LOGVOL
11	Statistical Register
12	"
13	"
14	"
15	"
16	"
17	MAX LOG VOLUME
19	TOTAL MERCH LENGTH ALL TREES
20	DS43
21	ISG Register (Current)
23	Original ISG Register

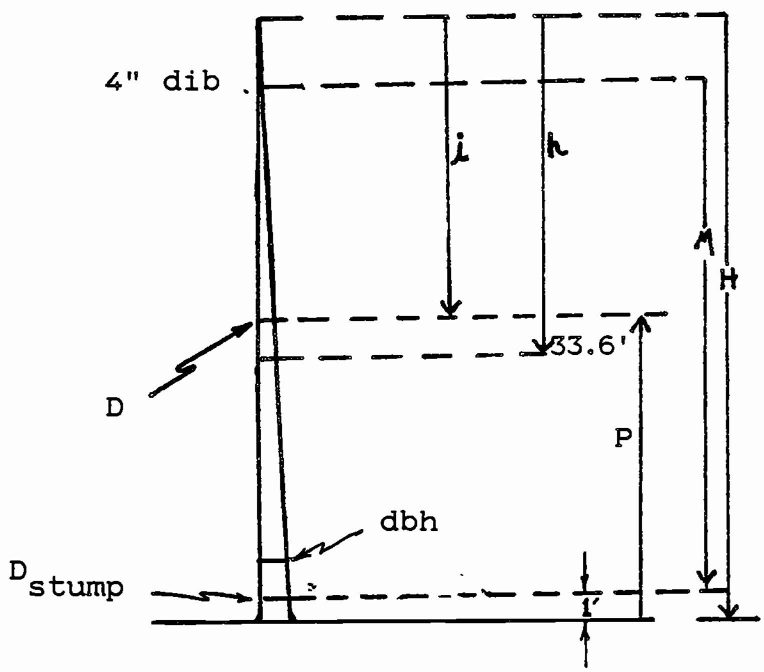
Example Problem: Find the log volume parameters, total volume, total number of logs, and average log length for the following four trees:

Diameter Class	Total Height	Form Class	Number of Trees
8	60	.74	3
14	90	.76	1

KEYS	DISPLAY	PRINTER
[XEQ] [ALPHA] BUCK [ALPHA]	FC?	FC=0.74
		DBH=8.00
.74 [R/S]	DBH?	HT=60.00
8 [R/S]	HT?	NUMTREES=3.00
60 [R/S]	NUMTREES?	MERCHT=43.35
3 [R/S]		V21=7.04
		V22=4.27
		DSTUMP=7.84
	MORETREES?	DS21=7.68
Y [R/S]	FC?	
.76 [R/S]	DBH?	FC=0.76
14 [R/S]	HT?	DBH=14.00
90 [R/S]	NUMTREES?	HT=90.00
1		NUMTREES=1.00
		MERCHT=73.70
		V21=24.62
		V22=10.99
		DSTUMP=13.71
		DS21=10.83
		TOTVOL=69.53
		NUMLOGS=8.00
		LENGTH=25.47
		MEAN=8.69
		MIN=4.27
		MAX=24.62
		SDEV=6.82

BUCKING MODEL EQUATIONS

Diagram and definition of notation:



H	=	Total tree height from ground to tip
dbh	=	Diameter breast height measured 4.5 feet above the ground
M	=	Merchantable length measured from 1 foot stump to 4 inch inside bark top.
P	=	Distance from ground to point of interest on the stem
i	=	Length measured downward from tip to point of interest
h	=	Distance from tip to top of first 32 foot log (trim allowance = 0.6 feet)
ℓ	=	ratio of i/h
d	=	diameter expressed as decimal fraction of diameter of top of first log. d is used to obtain diameter inside bark in inches at the first point of interest.
D	=	diameter inside bark at point of interest
FC	=	Girard form class expressed as decimal fraction for 32 foot logs.
D_{stump}	=	Diameter inside bark at the top of the stump. Assumed stump height = 1 foot.

<u>Formulation</u>:

To find D:

$d = \ell^{3/4}$ equ 1*

$D = d(dbh)(FC)$ equ 2

$i = H-P$ equ 3

$\ell = i/h$ equ 4

substituting 3 into 4:

$\ell = \frac{H-P}{h}$ equ 5

$h = H-33.6$ equ 6

substituting 6 into 5:

$\ell = \frac{H-P}{H-33.6}$ equ 6

substituting 1 into 2:

$D = \ell^{3/4}(dbh)(FC)$ equ 8

substituting 7 into 8:

$D = \left(\frac{H-P}{H-33.6}\right)^{3/4}(dbh)(FC)$ equ 9

To find M:

$4 = \left(\frac{H-P}{H-33.6}\right)^{3/4} dbh(FC)$ equ 10

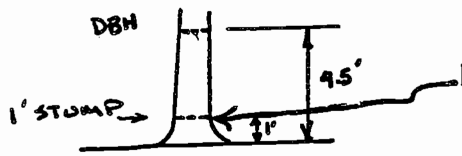
$M = P-1 \rightarrow P = M+1$ equ 11

substituting 11 into 10 and rearranging:

$M = H-1-(H-33.6)\left[\frac{4}{dbh(FC)}\right]^{4/3}$ equ 12

*Equation 1 is an approximation of stem diameter expressed as a decimal fraction of the diameter of the top of the first 32 foot log. The equation approximates a paraboloid which describes the stem diameter of second growth Douglas-fir from 17.6 feet above the ground to a 4 inch top. The equation was suggested by David Bruce during a telephone conversation 1/4/83.

Determination of Stump Diameter Inside Bark:



$$D_{stump_{dib}} = \frac{DBH_{ob}}{1.021} \qquad \text{equ 13}$$

Bucking Rule:

Let M = Merchantable Length (From 1' Stump to 4" top)

Merchantable Length (Ft)		# Logs	Buttlog Length	2nd Log Length	3rd Log Length	4th Log Length
Case 1	$M \leq 40.6$	1	M	-	-	-
Case 2	$40.6 < M \leq 81.2$	2	M/2	M/2	-	-
Case 3	$81.2 < M \leq 121.8$	3	40.6	$\frac{M-40.6}{2}$	$\frac{M-40.6}{2}$	-
Case 4	$121.8 < M$	4	40.6	40.6	$\frac{M-81.2}{2}$	$\frac{M-81.2}{2}$

Determination of Log Diameter Inside Bark at Small End:

Notation same as before except:

Psjk = Point of interest at small end of log k in case j

Dsjk = Diameter inside bark at small end of log k in case j

Vjk = Volume (CuFT) of log k in case j

Determination of Small End Log Diameter

Case 1: $D_{S11} = 4$

Case 2: $P_{S21} = \frac{M}{2} + 1$

$$D_{S21} = \left[\frac{H - \frac{M}{2}+1}{H-33.6}\right]^{3/4} (dbh)(FC) = 4$$

$$P_{S22} = M+1$$

$$D_{S22} = \left[\frac{H- M+1}{H-33.6}\right]^{3/4} (dbh)(FC)$$

Case 3: $P_{S31} = 40.6 + 1 = 41.6$

$$D_{S31} = \left(\frac{H-41.6}{H-33.6}\right)^{3/4} (dbh)(FC)$$

$$P_{S32} = \frac{M-40.6}{2} + 41.6$$

$$D_{S32} = \left[\frac{H - \frac{M-40.6}{2} + 41.6}{H-33.6}\right]^{3/4} (dbh)(FC)$$

$$P_{S33} = M+1$$

$$D_{S33} = \left[\frac{H- M+1}{H-33.6}\right]^{3/4} (dbh)(FC) = DS_{22} = 4$$

Case 4: $P_{S41} = 40.6 + 1 = 41.6$

$$D_{S41} = \left[\frac{H-41.6}{H-33.6}\right]^{3/4} (dbh)(FC)$$

$$P_{S42} = 40.6 + 40.6 + 1.0 = 82.2$$

$$D_{S42} = \left[\frac{H-82.2}{H-33.6}\right]^{3/4} (dbh)(FC)$$

$$P_{S43} = 82.2 + \frac{M-81.2}{2}$$

$$D_{S43} = \left[\frac{H- 82.2+ \frac{M-81.2}{2}}{H-33.6}\right]^{3/4} (dbh)(FC)$$

$$P_{S44} = M+1$$

$$D_{S44} = \left[\frac{H-(M+1)}{H-33.6}\right]^{3/4} (dbh)(FC)$$

Note that $D_{S11} = D_{S22} = D_{S33} = D_{S44} = 4$

Determination of Log Volume:

Case 1:

$$V_{11} = .005454154\ M\ [.75(4)^2 + .25\ (D_{stump})^2]$$

Case 2:

$$V_{21} = .005454145(\frac{M}{2})[.75(D_{S21})^2 + .25\ (D_{stump})^2]$$

$$V_{22} = .005454145(\frac{M}{2})[.4][16 + \frac{4D_{S21}}{2} + D_{S21}^2]$$

Case 3:

$$V_{31} = .005454154\ (40.6)[.75(D_{S31})^2 + .25\ (D_{stump})^2]$$

$$V_{32} = .005454154\ (\frac{M-40.6}{2})(.4)[(D_{S32})^2 + \frac{(D_{S32})(D_{S31})^2}{2} + (D_{S31})^2]$$

$$V_{33} = .005454145\ (\frac{M-40.6}{2})(.4)[16 + (4)(D_{S32}) + (D_{S32})^2]$$

Case 4:

$$V_{41} = .005454145\ (40.6)[.75(D_{S41})^2 + .25\ (D_{stump})^2]$$

$$V_{42} = .005454145\ (40.6)(.4)[(D_{S42})^2 + \frac{(D_{S42})(D_{S41})}{2}\ (D_{S41})^2]$$

$$V_{43} = .005454154\ (\frac{M-81.2}{2})(.4)[\frac{(D_{S43})(D_{S42})}{2} + (D_{S42})^2]$$

$$V_{44} = .005454154\ (\frac{M-81.2}{2})(.4)[(D_{S44})^2 + \frac{(4)(D_{S43})}{2} + (D_{S43})^2]$$

Note that: $D_{S11} = D_{S22} = D_{S33} = D_{S44} = 4$

PROGRAM LISTING BUCK 5/18/83 lws

```
01◆LBL "BUCK"
02◆LBL 11
03 CLRG
04 FIX 2
05 1000
06 STO 10
07 CLΣ
08 0
09 ENTER↑

10◆LBL 01
11 0
12 STO 21
13 ADV
14 "FC?"
15 PROMPT
16 "FC="
17 ARCL X
18 AVIEW
19 STO 01
20 "DBH?"
21 PROMPT
22 "DBH="
23 ARCL X
24 AVIEW
25 STO 02
26 "HT"
27 PROMPT
28 "HT="
29 ARCL X
30 AVIEW
31 STO 03
32 "NUMTREES?"
33 PROMPT
34 "NUMTREES="
35 ARCL X
36 AVIEW
37 1000
38 /
39 .001
40 -
41 STO 21
42 STO 23
43 RCL 02
44 1.021
45 /
46 STO 04
47 4
48 RCL 02
49 /
50 RCL 01
51 /
52 1.3333
53 Y↑X
54 RCL 03
55 33.6
56 -
57 *
58 CHS
59 1
60 -
61 RCL 03
62 +
63 STO 05

64◆LBL 12
65 RCL 05
66 ST+ 19
67 RCL 21
68 ISG 21
69 GTO 12
70 RCL 23
71 STO 21
72 RCL 05
73 "MERCHT="
74 XEQ 09
75 40.6
76 X<>Y
77 X<=Y?
78 GTO 02
79 81.2
80 X<>Y
81 X<=Y?
82 GTO 03
83 121.8
84 X<>Y
85 X<=Y?
86 GTO 05

87◆LBL 13
88 4
89 ST+ 06
90 RCL 21
91 ISG 21
92 GTO 13
93 RCL 23
94 STO 21
95 XEQ 10
96 "V41="
97 XEQ 09
98 ENTER↑
99 STO 22

100◆LBL 14
101 RCL 22
102 Σ+
103 RCL 21
104 ISG 21
105 GTO 14
106 RCL 23
107 STO 21
108 RCL 22
109 XEQ 08
110 RCL 03
111 82.2
112 -
113 RCL 03
114 33.6
115 -
116 /
117 .75
118 Y↑X
119 RCL 02
120 *
121 RCL 01
122 *
123 STO 08
124 X↑2
125 RCL 08
126 RCL 07
127 *
128 +
129 RCL 07
130 X↑2
131 +
132 .4
133 *
134 40.6
135 *
136 .00545415
137 *
138 "V42="
139 XEQ 09
140 STO 22

141◆LBL 15
142 RCL 22
143 Σ+
144 RCL 21
145 ISG 21
146 GTO 15
147 RCL 23
148 STO 21
149 RCL 22
150 XEQ 08
151 RCL 05
152 81.2
153 -
154 2
155 /
156 82.2
157 +
158 CHS
159 RCL 03
160 +
161 RCL 03
162 33.6
163 -
```

```
164 /
165 RCL 02
166 *
167 RCL 01
168 *
169 STO 20
170 X↑2
171 RCL 20
172 RCL 08
173 *
174 +
175 RCL 08
176 X↑2
177 +
178 .4
179 *
180 RCL 05
181 81.2
182 -
183 2
184 /
185 *
186 .005454154
187 *
188 "V43="
189 XEQ 09
190 STO 22

191♦LBL 16
192 RCL 22
193 Σ+
194 RCL 21
195 ISG 21
196 GTO 16
197 RCL 23
198 STO 21
199 RCL 22
200 XEQ 08
201 4
202 RCL 20
203 *
204 16
205 +
206 RCL 20
207 X↑2
208 +
209 .4
210 *
211 RCL 05
212 81.2
213 -
214 2
215 /
216 *
217 .005454154
218 *
219 "V44="
220 XEQ 09
221 STO 22

222♦LBL 17
223 RCL 22
224 Σ+
225 RCL 21
226 ISG 21
227 GTO 17
228 RCL 23
229 STO 21
230 RCL 22
231 XEQ 08
232 RCL 04
233 "DSTUMP="
234 XEQ 09
235 RCL 07
236 "DS41="
237 XEQ 09
238 RCL 08
239 "DS42="
240 XEQ 09
241 RCL 20
242 "DS43="
243 XEQ 09
244 "MORETREES?"
245 AON
246 PROMPT
247 AOFF
248 ASTO X
249 "Y"
250 ASTO Y
251 X=Y?
252 GTO 01
253 GTO 04

254♦LBL 05
255♦LBL 18
256 3
257 ST+ 06
258 RCL 21
259 ISG 21
260 GTO 18
261 RCL 23
262 STO 21
263 XEQ 10
264 "V31="
265 XEQ 09
266 STO 22

267♦LBL 19
268 RCL 22
269 Σ+
270 RCL 21
271 ISG 21
272 GTO 19
273 RCL 23
274 STO 21
275 RCL 22
276 XEQ 08
277 RCL 05
278 40.6
279 -
280 2
281 /
282 41.6
283 +
284 CHS
285 RCL 03
286 +
287 RCL 03
288 33.6
289 -
290 /
291 .75
292 Y↑X
293 RCL 02
294 *
295 RCL 01
296 *
297 STO 08
298 X↑2
299 RCL 07
300 X↑2
301 +
302 RCL 07
303 RCL 08
304 *
305 2
306 /
307 +
308 .4
309 *
310 RCL 05
311 40.6
312 -
313 2
314 /
315 *
316 .005454154
317 *
318 "V32="
319 XEQ 09
320 STO 22

321♦LBL 20
322 RCL 22
323 Σ+
324 RCL 21
325 ISG 21
326 GTO 20
327 RCL 23
328 STO 21
329 RCL 22
330 XEQ 08
331 RCL 08
332 X↑2
333 16
334 +
335 4
336 RCL 08
337 *
```

```
338 2
339 /
340 +
341 .4
342 *
343 RCL 05
344 40.6
345 -
346 2
347 /
348 *
349 .005454154
350 *
351 "V33="
352 XEQ 09
353 STO 22

354♦LBL 21
355 RCL 22
356 Σ+
357 RCL 21
358 ISG 21
359 GTO 21
360 RCL 23
361 STO 21
362 RCL 22
363 XEQ 08
364 RCL 04
365 "BSTUMP="
366 XEQ 09
367 RCL 07
368 "DS31="
369 XEQ 09
370 RCL 08
371 "DS32="
372 XEQ 09
373 "MORETREES?"
374 AON
375 PROMPT
376 AOFF
377 ASTO X
378 "Y"
379 ASTO Y
380 X=Y?
381 GTO 01
382 GTO 04

383♦LBL 03
384♦LBL 22
385 2
386 ST+ 06
387 RCL 21
388 ISG 21
389 GTO 22
390 RCL 23
391 STO 21
392 RCL 05
393 2
394 /
395 1
396 +
397 CHS
398 RCL 03
399 +
400 RCL 03
401 33.6
402 -
403 /
404 .75
405 Y↑X
406 RCL 02
407 *
408 RCL 01
409 *
410 STO 07
411 X↑2
412 .75
413 *
414 RCL 04
415 X↑2
416 .25
417 *
418 +
419 RCL 05
420 2
421 /
422 *
423 .005454154
424 *
425 "V21="
426 XEQ 09
427 STO 22

428♦LBL 23
429 RCL 22
430 Σ+
431 RCL 21
432 ISG 21
433 GTO 23
434 RCL 23
435 STO 21
436 RCL 22
437 XEQ 08
438 RCL 07
439 X↑2
440 RCL 07
441 4
442 *
443 2
444 /
445 +
446 16
447 +
448 .4
449 *
450 RCL 05
451 2
452 /
453 *
454 .005454154
455 *
456 "V22="
457 XEQ 09
458 STO 22

459♦LBL 24
460 RCL 22
461 Σ+
462 RCL 21
463 ISG 21
464 GTO 24
465 RCL 23
466 STO 21
467 RCL 22
468 XEQ 08
469 RCL 04
470 "BSTUMP="
471 XEQ 09
472 RCL 07
473 "DS21="
474 XEQ 09
475 "MORETREES?"
476 AON
477 PROMPT
478 AOFF
479 ASTO X
480 "Y"
481 ASTO Y
482 X=Y?
483 GTO 01
484 GTO 04

485♦LBL 02
486♦LBL 25
487 1
488 ST+ 06
489 RCL 21
490 ISG 21
491 GTO 25
492 RCL 23
493 STO 21
494 RCL 04
495 X↑2
496 .25
497 *
498 4
499 X↑2
500 .75
501 *
502 +
503 RCL 05
504 *
505 .005454154
506 *
507 "V11="
508 XEQ 09
509 STO 22

510♦LBL 26
511 RCL 22
512 Σ+
513 RCL 21
514 ISG 21
515 GTO 26
516 RCL 23
517 STO 21
```

```
518 RCL 22
519 XEQ 08
520 RCL 04
521 "DSTUMP="
522 XEQ 09
523 "MORETREES?"
524 AON
525 PROMPT
526 AOFF
527 ASTO X
528 "Y"
529 ASTO Y
530 X=Y?
531 GTO 01

532+LBL 04
533 ADV
534 ADV
535 RCL 11
536 "TOTVOL="
537 XEQ 09
538 RCL 06
539 "NUMLOGS="
540 XEQ 09
541 RCL 19
542 X<>Y
543 /
544 "LENGTH="
545 XEQ 09
546 MEAN
547 "MEAN="
548 XEQ 09
549 RCL 10
550 "MIN="
551 XEQ 09
552 RCL 17
553 "MAX="
554 XEQ 09
555 SDEV
556 "SDEV="
557 XEQ 09
558 GTO 11

559+LBL 08
560 STO 18
561 RCL 10
562 X<>Y
563 X<=Y?
564 GTO 06
565 GTO 07

566+LBL 06
567 STO 10

568+LBL 07
569 RCL 17
570 RCL 18
571 X>Y?
572 STO 17
573 RTN

574+LBL 09
575 ARCL X
576 AVIEW
577 RTN

578+LBL 10
579 RCL 03
580 41.6
581 -
582 RCL 03
583 33.6
584 -
585 /
586 .75
587 Y↑X
588 RCL 02
589 *
590 RCL 01
591 *
592 STO 07
593 X↑2
594 .75
595 *
596 RCL 04
597 X↑2
598 .25
599 *
600 +
601 40.6
602 *
603 .005454154
604 *
605 RTN
606 END
```

Original Turn Time Equations

Original Turn Time Equations

YARDER CONFIGURATIONS	ORIGINAL TURN TIME EQUATION IN MINUTES (DELAY FREE)
Mini Alp, standing, single and multispan with haulback, uphill, 2 chokers, Igland Jones single and multi-span carriages	Turn Time = 1.6932 + .005119 (slope yarding distance in feet) + .025653 (lateral distance in feet) + .2783 (number of logs in turn) R^2 = .29
Koller K-300, standing, single and multispan, gravity outhaul, uphill, 2 chokers, Koller SKA-1 carriage, without skidder	Turn Time = 1.3969 + .00391347 (slope yarding distance in feet) + .0178717 (lateral distance in feet) + .429317 (number logs in turn) + .0151707 (turn volume in cubic feet) - .381483 (number in rigging crew) - .0941052 (number in landing crew) - .307468 (one for skidder) R^2 = .5369
Peewee, running, single, up and down, 3 chokers	Turn Time = .6144 + .00475 (slope yarding distance in feet) + .00053 (lateral distance in feew squared) + .28694 (number of logs in turn) + .00563 (lead angle) R^2 = .6157

YARDER CONFIGURATIONS	ORIGINAL TURN TIME EQUATION IN MINUTES (DELAY FREE)
Skagit SJ-2, live, single span, gravity outhaul, uphill, 3 chokers, Christy carriage	Turn Time = 2.1832 + .00248 (slope yarding distance in feet) + .00662 $\left(\frac{\text{perpendicular lateral distance in feet}}{\text{sin lead angle}}\right)$ + .32165 (number of logs in turn) R^2 = .3566
West Coast, standing, single-span haulback, uphill, 4 chokers, West Coast carriage	Turn Time = 2.77 + 0.222 (volume per turn in cubic feet) - .0492 $\left(\frac{\text{volume per turn in cubic feet}}{\text{number of logs in turn}}\right)$ - .634 $\left(\frac{\text{number of logs in turn}}{\text{number of chokers flown}}\right)$ + .463 $\left(\frac{1}{\text{sin lead angle}}\right)$ + .000144 (lateral distance in feet squared) + .243 x 10^{-5} (slope yarding distance in feet squared) + .0364 (carriage height in feet) R^2 = .565

YARDER CONFIGURATION	ORIGINAL TURN TIME EQUATION IN MINUTES (DELAY FREE)
Prebunch with truck mounted Skagit GU-10, block rigged in tree, 2 chokers, site III	Turn Time = 1.2142 + .0154 (lateral distance in feet) + .0016 (slope yarding distance in feet) R^2 = .43
Swing with Schield Bantam T-350, live, singlespan, gravity outhaul, 2 chokers, Maki carriage	Turn Time = 1.0935 + .0040312 (slope yarding distance in feet) + .00519 (lead angle) + .0092485 (turn volume in cubic feet) R^2 + .34

Example Input Data File for Regression

(West Coast tower configuration with 4 chokers)

Checked 6/24/93 LWS

FILE NAME: WC4LOG SHEET 1 OF 3 DATE 6/2/93

PROD	AGYD	LOGSIZE	CUTVOL/AC
283	050	06.2	0355
269	150		
332	250		
246	350		
245	450		
231	550		
280	650		
234	750		
205	850		
169	750		
437	050		0710
455	150		
377	250		
381	350		
406	450		
351	550		
328	650		
272	750		
262	850		
225	950		
447	050		1066
383	150		
374	250		
402	350		
361	450		
345	550		
317	650		
263	750		
274	850		
227	950		
447	050		1421
439	150		
398	250		
395	350		
387	450		
371	550		
335	650		
313	750		
273	850		
259	950		
447	050		1776
409	150		
408	250		
373	350		
395	450		
347	550		
333	650		
321	750		
289	850		
261	950		

PROD	AGYD	LOGSIZE	CUTVOL/AC
520	050	11.9	0764
734	150		
483	250		
495	350		
616	450		
699	550		
358	650		
493	750		
349	850		
378	950		
760	050		1527
699	150		
628	250		
669	350		
682	450		
623	550		
562	650		
666	750		
445	850		
477	950		
805	050		2291
692	150		
640	250		
733	350		
776	450		
644	550		
690	650		
561	750		
496	850		
479	950		
871	050		3058
789	150		
750	250		
727	350		
729	450		
668	550		
615	650		
643	750		
508	850		
449	950		
881	050		3821
776	150		
248	250		
739	350		
688	450		
644	550		
601	650		
522	750		
519	850		
481	950		

FILE NAME: **WC4 LOG** SHEET 2 OF 3 DATE

PROD	ASYD	LOGSIZE	CUTVOL/AC	PROD	ASYD	LOGSIZE	CUTVOL/AC
772	050	18.1	1091	965	050	24.3	1320
990	150			1040	150		
703	250			1240	250		
887	350			1072	350		
570	450			1015	450		
703	550			932	550		
1018	650			714	650		
708	750			636	750		
617	850			948	850		
549	950			694	950		
1239	050		2198	1193	050		2647
1027	150			1279	150		
960	250			1195	250		
988	350			1098	350		
1011	450			1082	450		
949	550			1056	550		
878	650			1019	650		
778	750			1022	750		
780	850			984	850		
602	950			946	950		
1010	050		3279	1331	050		3967
994	150			1882	150		
1161	250			1151	250		
950	350			1307	350		
932	450			1199	450		
885	550			1096	550		
854	650			1087	650		
753	750			974	750		
762	850			949	850		
773	950			822	950		
1076	050		4375	1390	050		5286
1106	150			1321	150		
1088	250			1355	250		
1159	350			1211	350		
1010	450			1213	450		
974	550			1123	550		
218	650			1134	650		
874	750			959	750		
661	850			969	850		
705	950			880	950		
1133	050		5466	1433	050		6,606
1026	150			1310	150		
1080	250			1334	250		
1123	350			1273	350		
987	450			1071	450		
915	550			1142	550		
888	650			1018	650		
816	750			996	750		
803	850			1002	850		
694	950			876	950		

FILE NAME: **WC4 LOG** | SHEET 3 OF 3 | DATE

PROD	ASYD	LOGSIZE	CUTVOL/AC
986	050	300	1504
1348	150		
1330	250		
973	350		
1060	450		
1257	550		
1020	650		
920	750		
818	850		
805	950		
1207	050		3008
1404	150		
1196	250		
1459	350		
1209	450		
1146	550		
1199	650		
1217	750		
1052	850		
856	950		
1375	050		4521
1522	150		
1262	250		
1193	350		
1175	450		
1267	550		
1221	650		
1051	750		
1054	850		
954	950		
1329	050		6025
1296	150		
1476	250		
1528	350		
1480	450		
1239	550		
1246	650		
999	750		
1033	850		
925	950		
1491	050		7529
1575	150		
1537	250		
1273	350		
1404	450		
1226	550		
1093	650		
1136	750		
1118	850		
972	950		

Comparative Plots and Graphs of Observed and Predicted Production

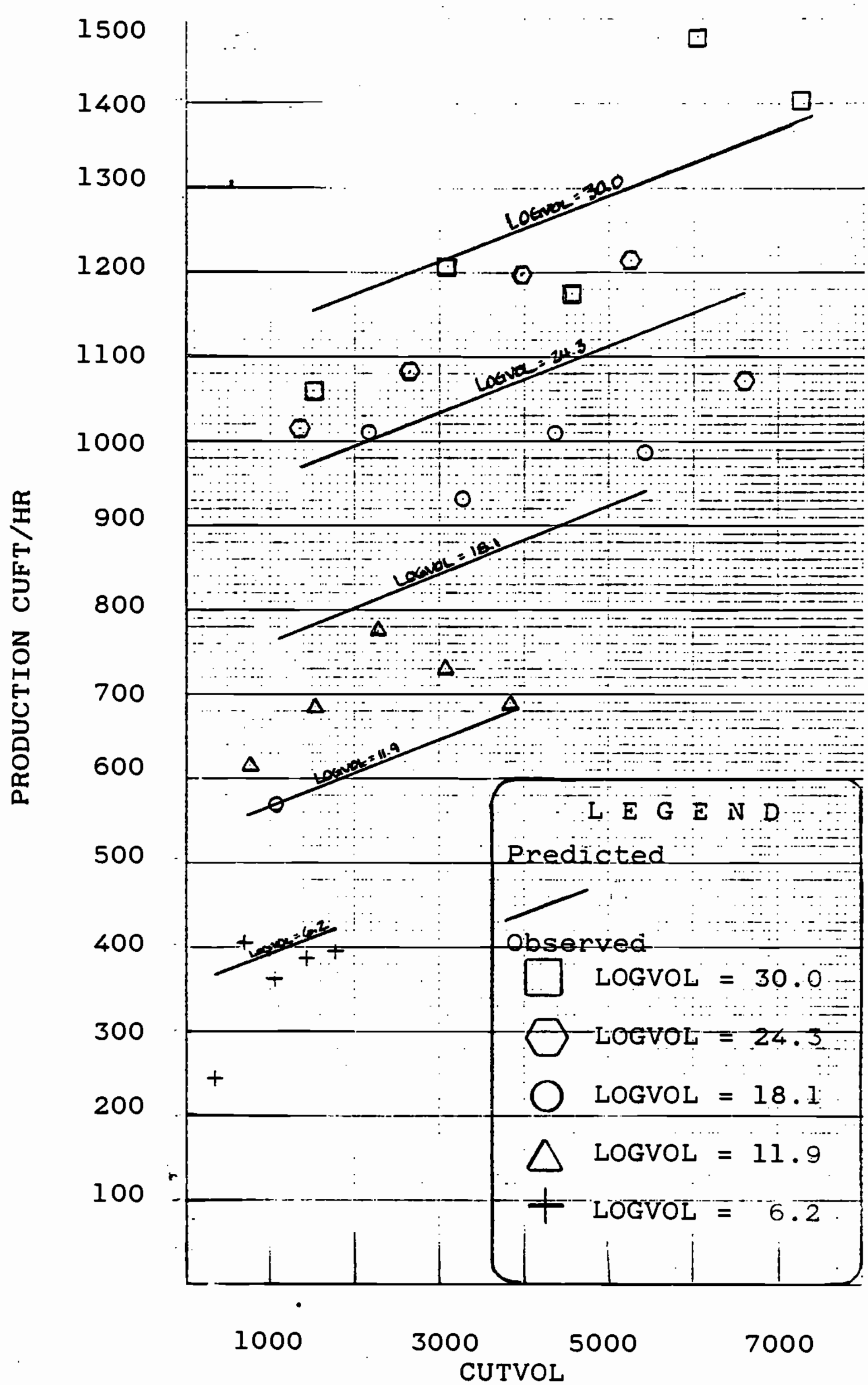


Figure 23. Comparison Between Observed and Predicted Production for the West Coast Configuration with 4 Chokers when CUTVOL is Varied (ASYD = 450)

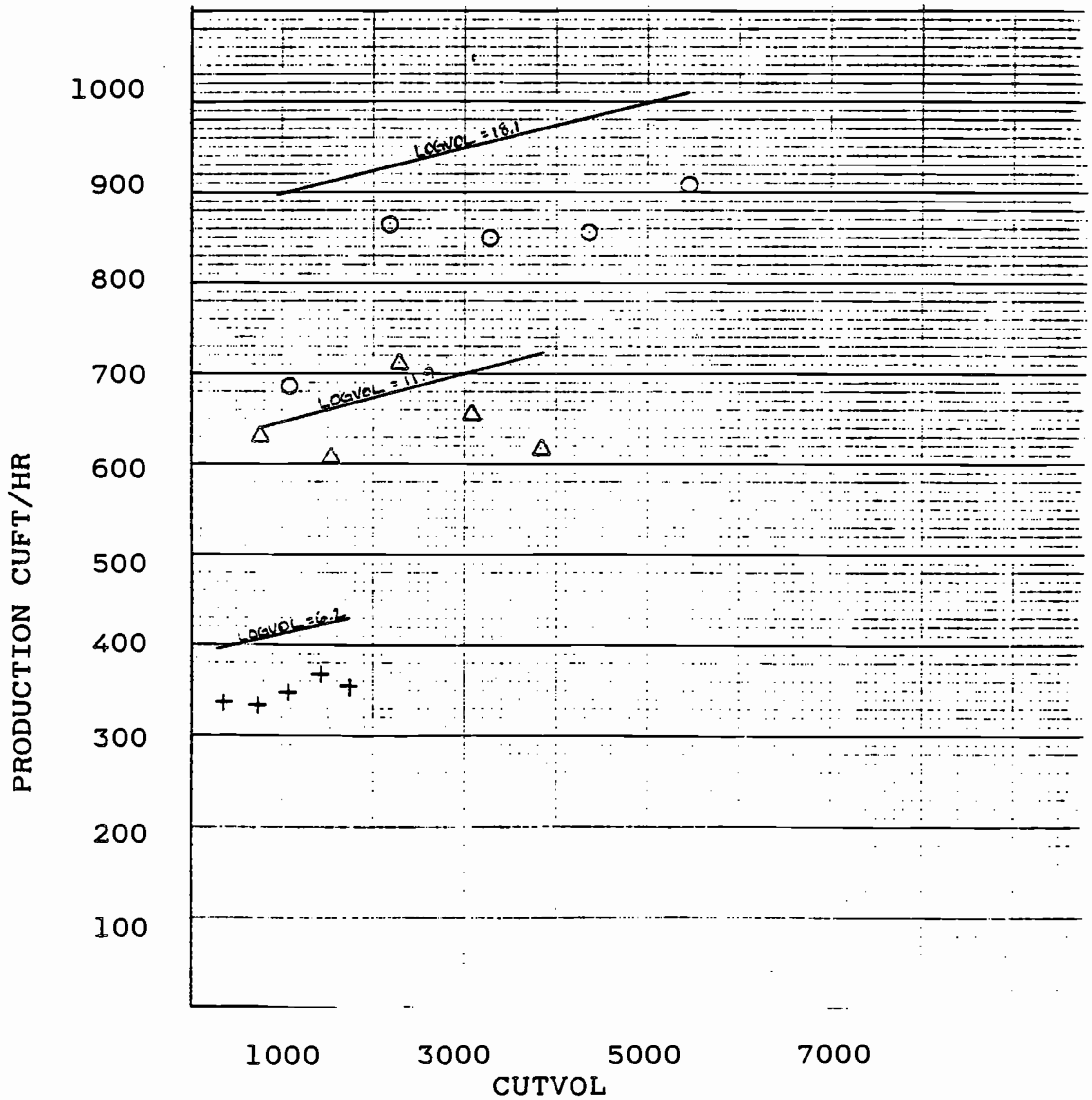


Figure 24. Comparison Between Observed and Predicted Production for the GU-10 Prebunch Configuration when CUTVOL is Varied (ASYD = 450)

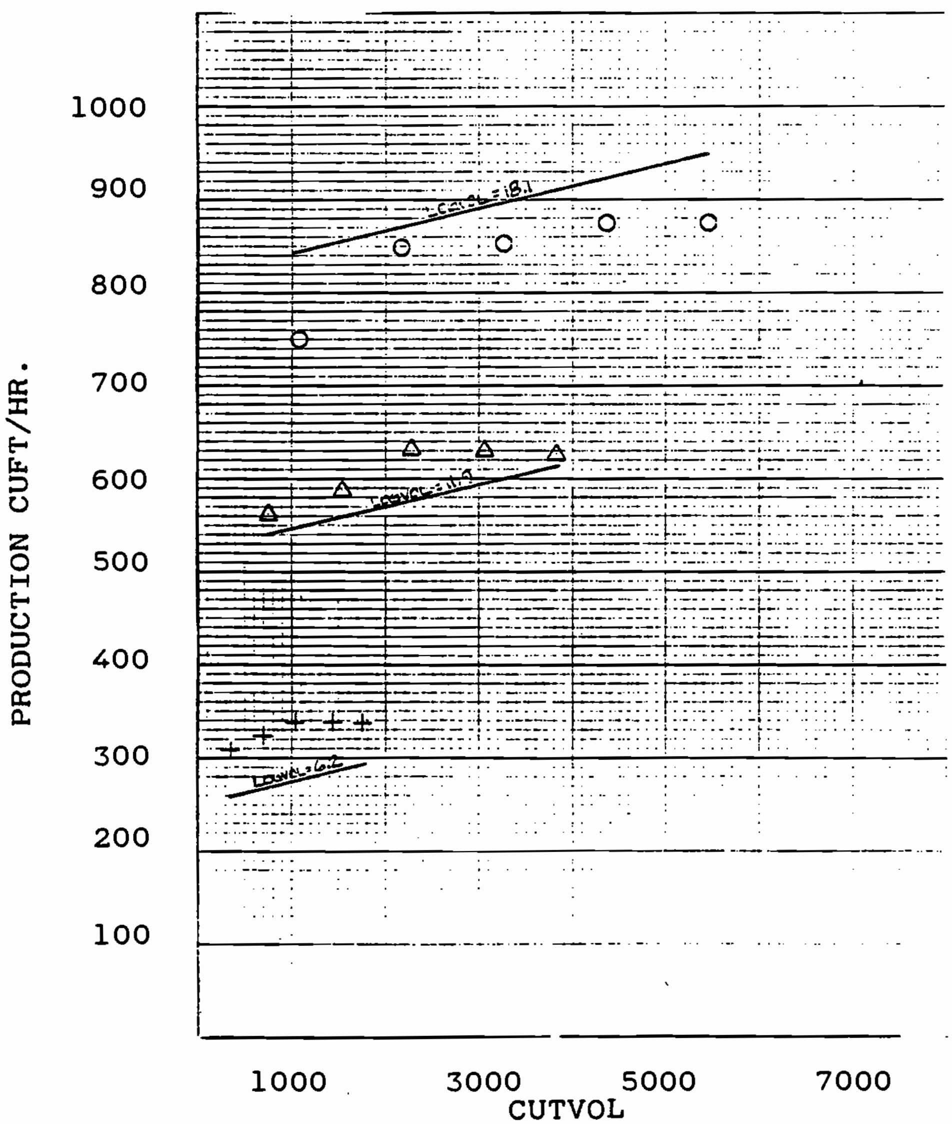


Figure 25. Comparison Between Observed and Predicted Production for the Schield Bantam Swing Configuration when CUTVOL is Varied (ASYD = 450)

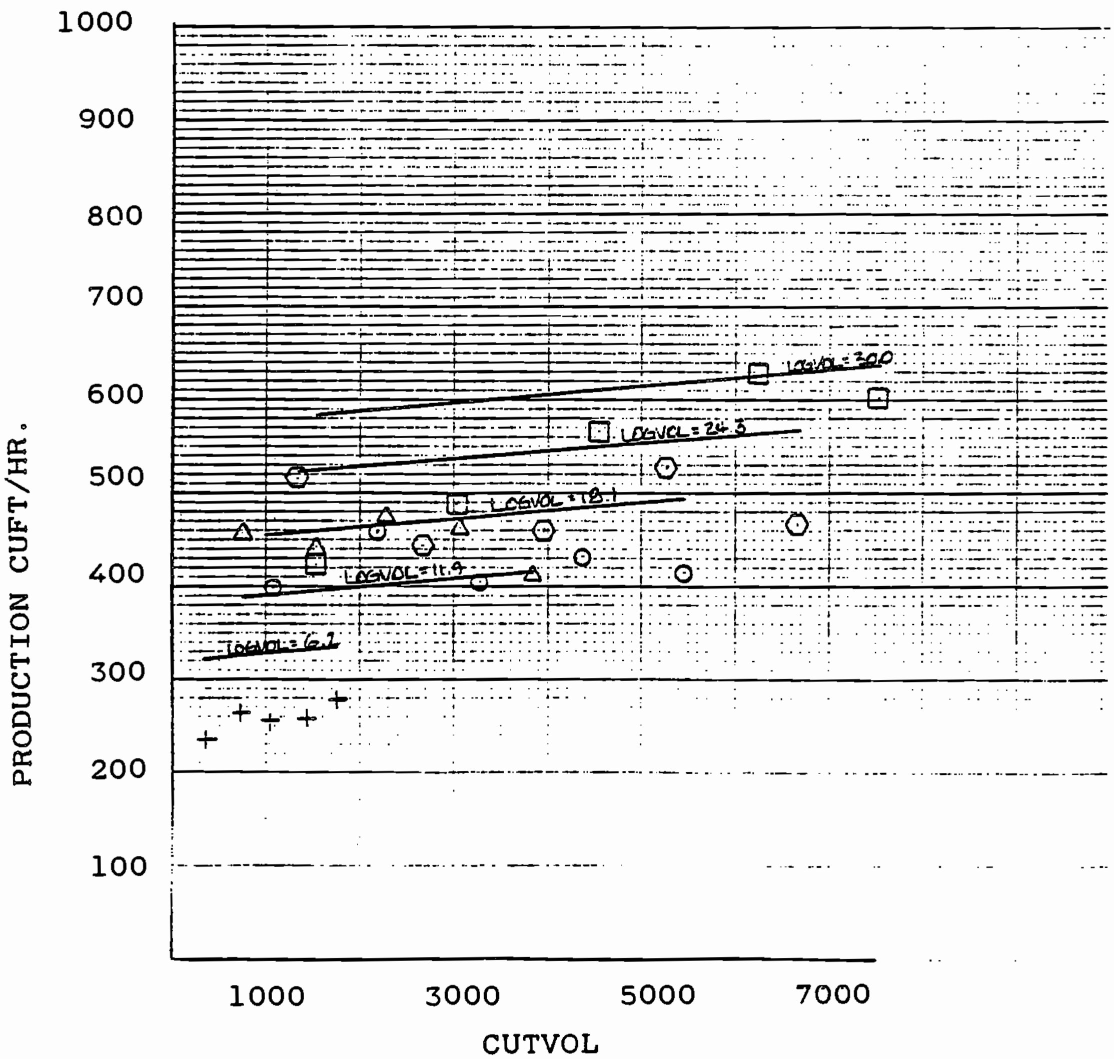


Figure 26. Comparison Between Observed and Predicted Production for the Koller Configuration with Skidder Swing when CUTVOL is Varied (ASYD = 450)

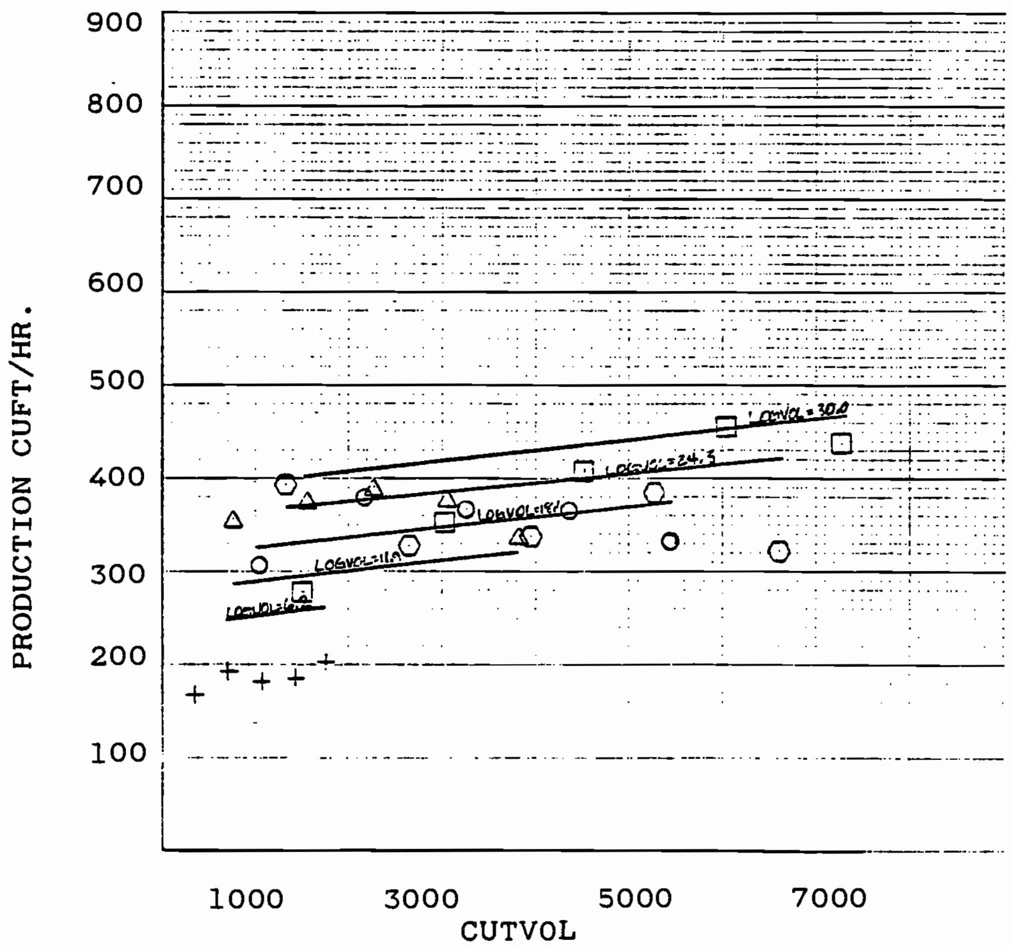


Figure 27. Comparison Between Observed and Predicted Production for the Mini Alp Configuration when CUTVOL is Varied (ASYD = 450)

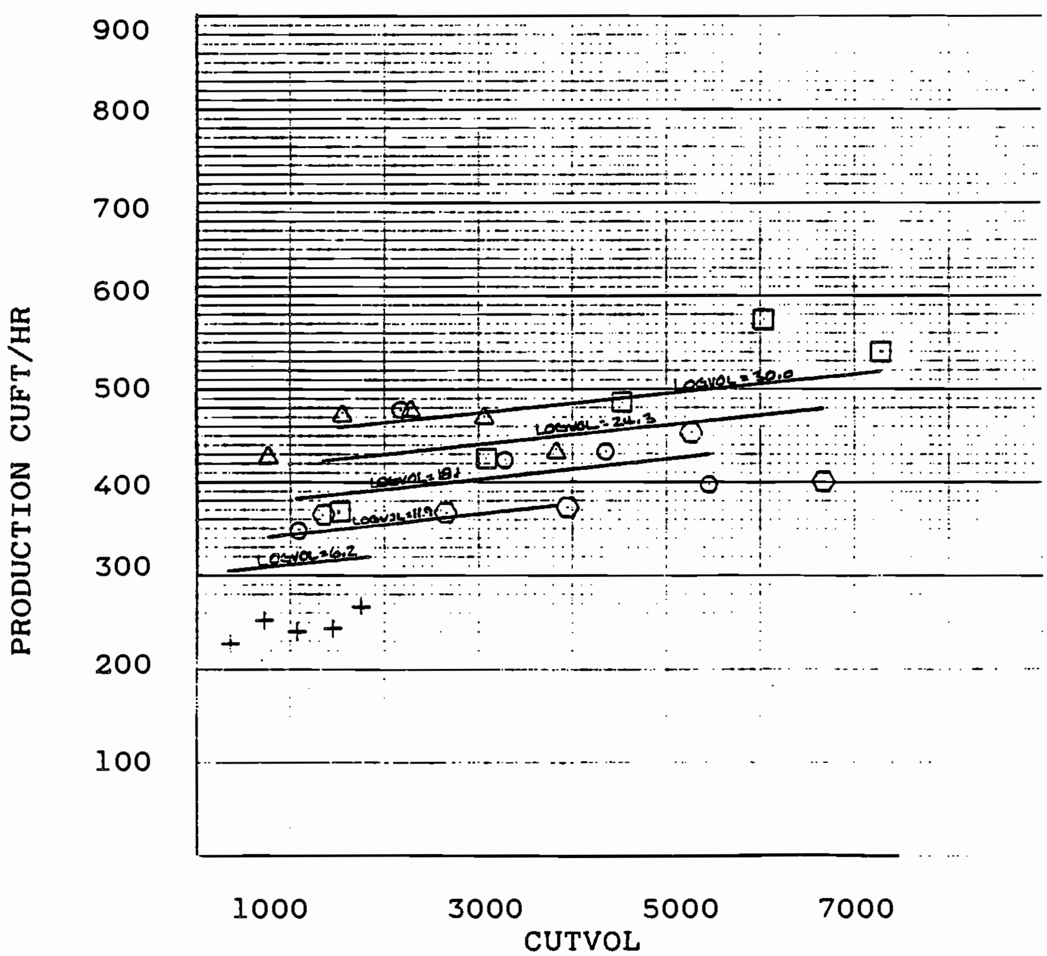


Figure 28. Comparison Between Observed and Predicted Production for the SJ-2 Configuration When CUTVOL is Varied (ASYD = 450)

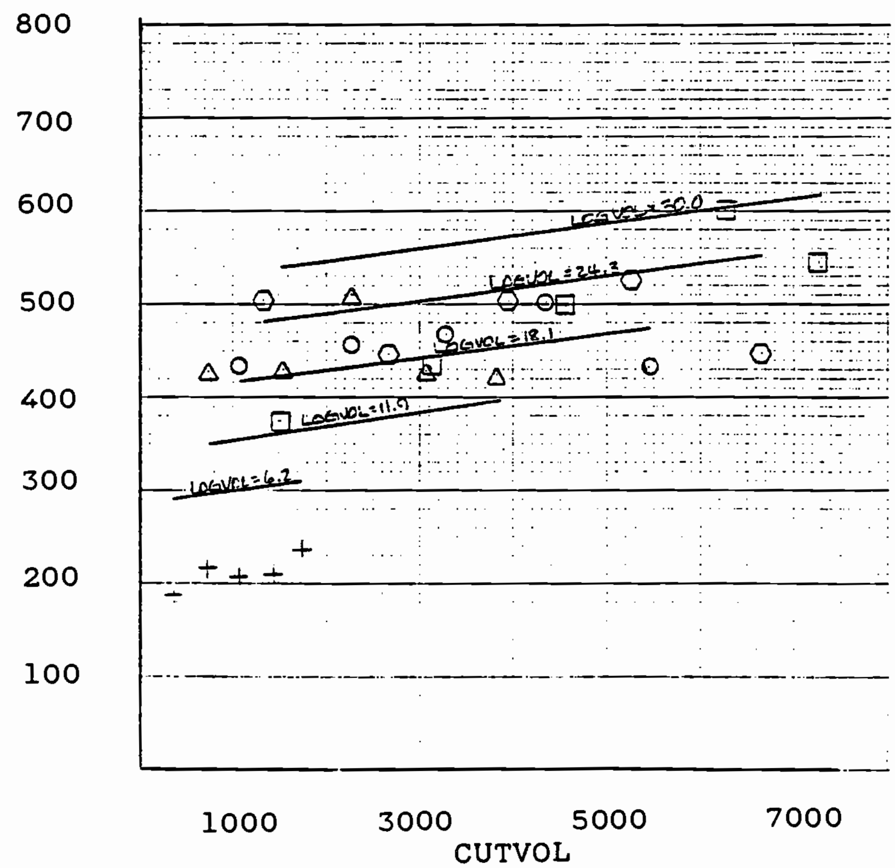
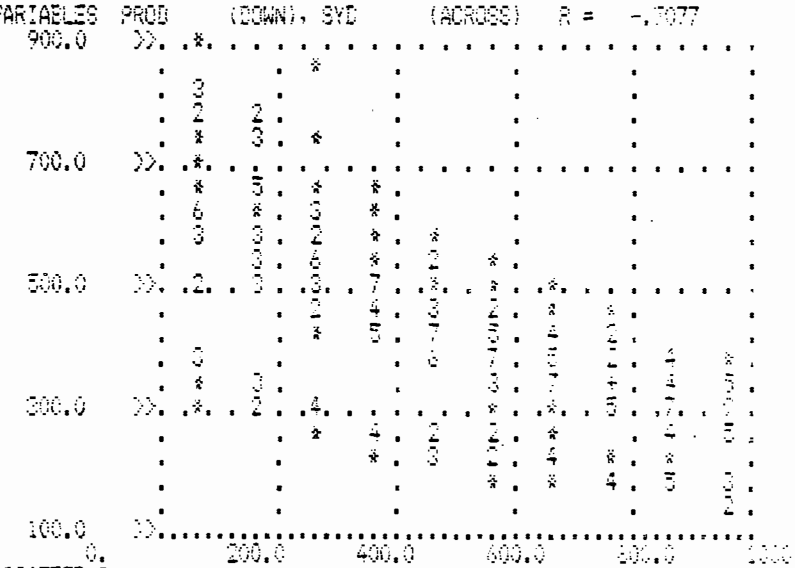


Figure 29. Comparison Between Observed and Predicted Production for the Peewee Configuration without the Skidder Swing (ASYD = 450)

Scattergrams

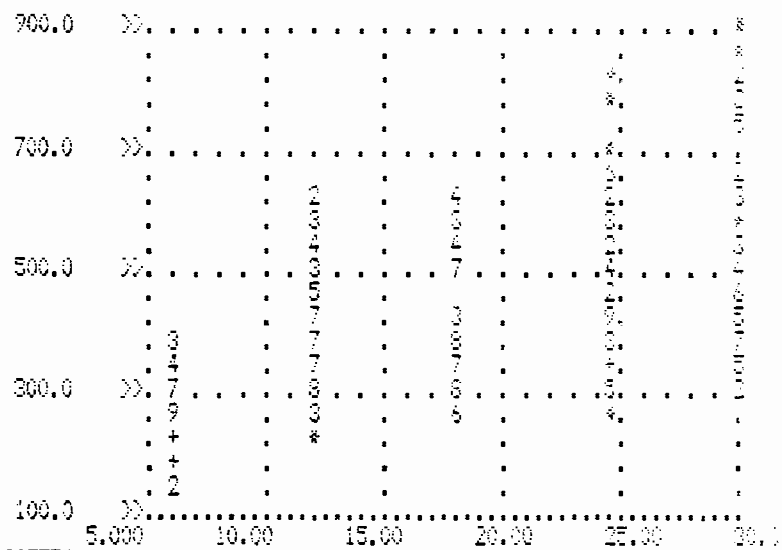
```
? SCATTER,2,1
 LOWER BOUND OF X=     50.0000        UPPER BOUND OF X=     [illegible]
 LOWER BOUND OF Y=     129.000        UPPER BOUND OF Y=     [illegible]
```

```
VARIABLES  PROD     (DOWN), SYD      (ACROSS)   R =   -.7077
```




```
? SCATTER,3,1
 LOWER BOUND OF X=     6.20000        UPPER BOUND OF X=     [illegible]
 LOWER BOUND OF Y=     129.000        UPPER BOUND OF Y=     [illegible]
```

```
VARIABLES  PROD     (DOWN), LOGVOL   (ACROSS)   R =    .5691
```




```
? SCATTER,4,1
 LOWER BOUND OF X=     355.000        UPPER BOUND OF X=     [illegible]
 LOWER BOUND OF Y=     129.000        UPPER BOUND OF Y=     [illegible]
```

Figure 30. Scattergrams of ASYD and LOGVOL Versus Production for the Koller Configuration Without the Skidder Swing

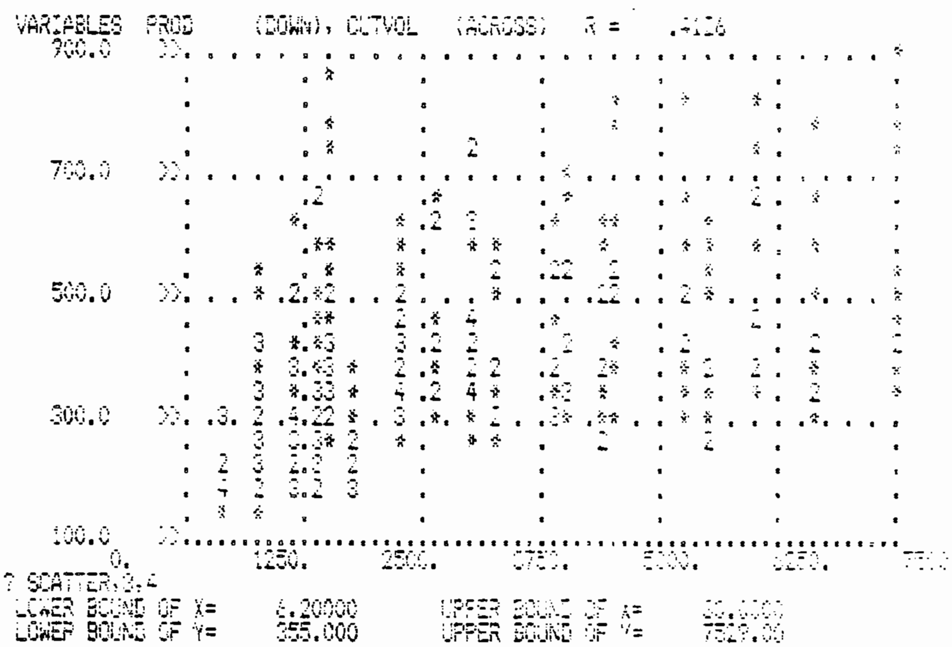
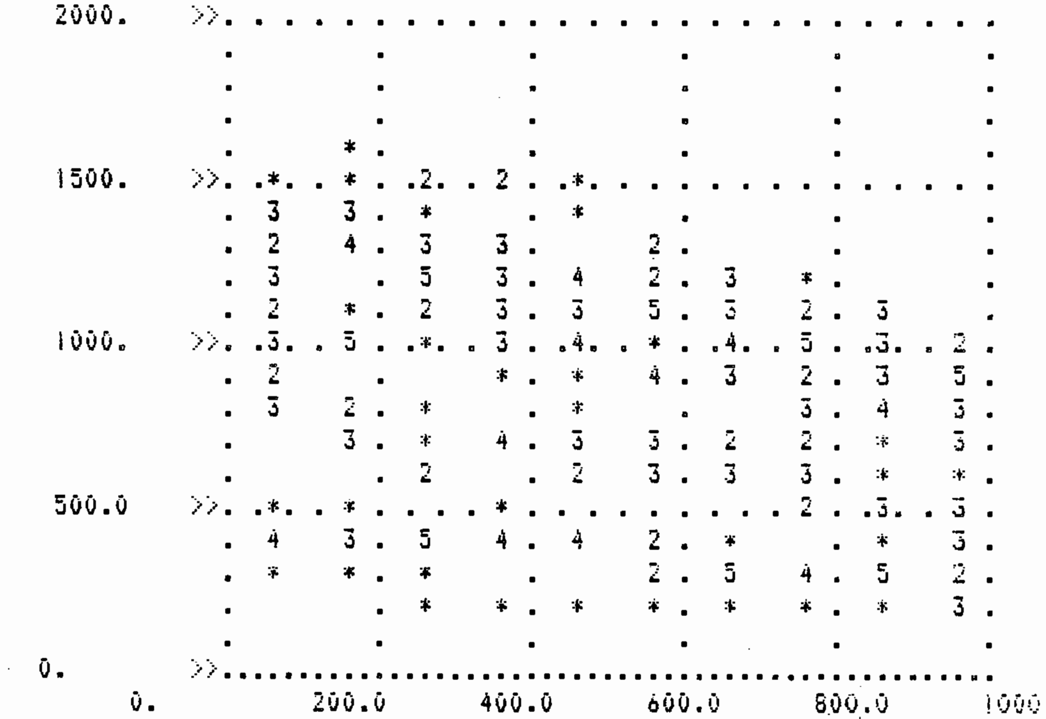


Figure 31. Scattergram of CUTVOL Versus Production for the Koller Configuration Without the Skidder Swing

LOWER BOUND OF X= 50.0000 UPPER BOUND OF X= 950.000
LOWER BOUND OF Y= 169.000 UPPER BOUND OF Y= 1575.00

VARIABLES PROD (DOWN), SYD (ACROSS) R = -.3135



SCATTER.I.I
LOWER BOUND OF X= 6.20000 UPPER BOUND OF X= 30.0000
LOWER BOUND OF Y= 169.000 UPPER BOUND OF Y= 1575.00

VARIABLES PROD (DOWN), LOGVOL (ACROSS) R = .8762

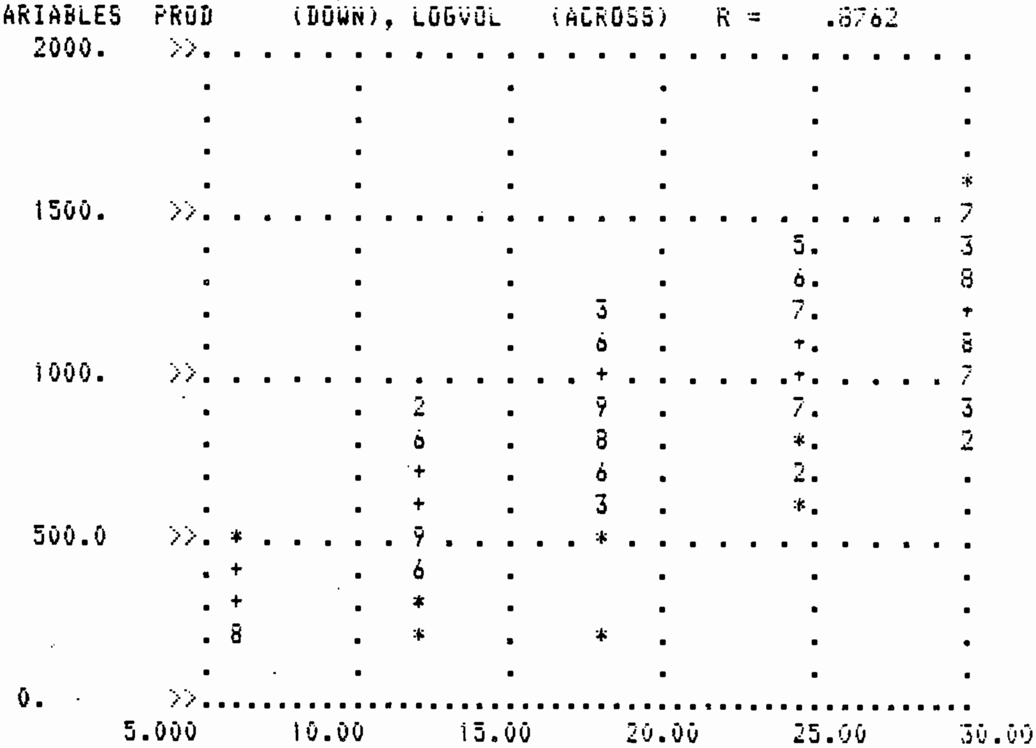


Figure 32. Scattergrams of ASYD and LOGVOL Versus Production for the West Coast Tower Configuration with 4 Chokers

```
? SCATTER,4,1
 LOWER BOUND OF X=     355.000        UPPER BOUND OF X=      7529.00
 LOWER BOUND OF Y=     169.000        UPPER BOUND OF Y=      1575.00
```

```
VARIABLES  PROD     (DOWN), CUTVOL   (ACROSS)   R =     .6735
```

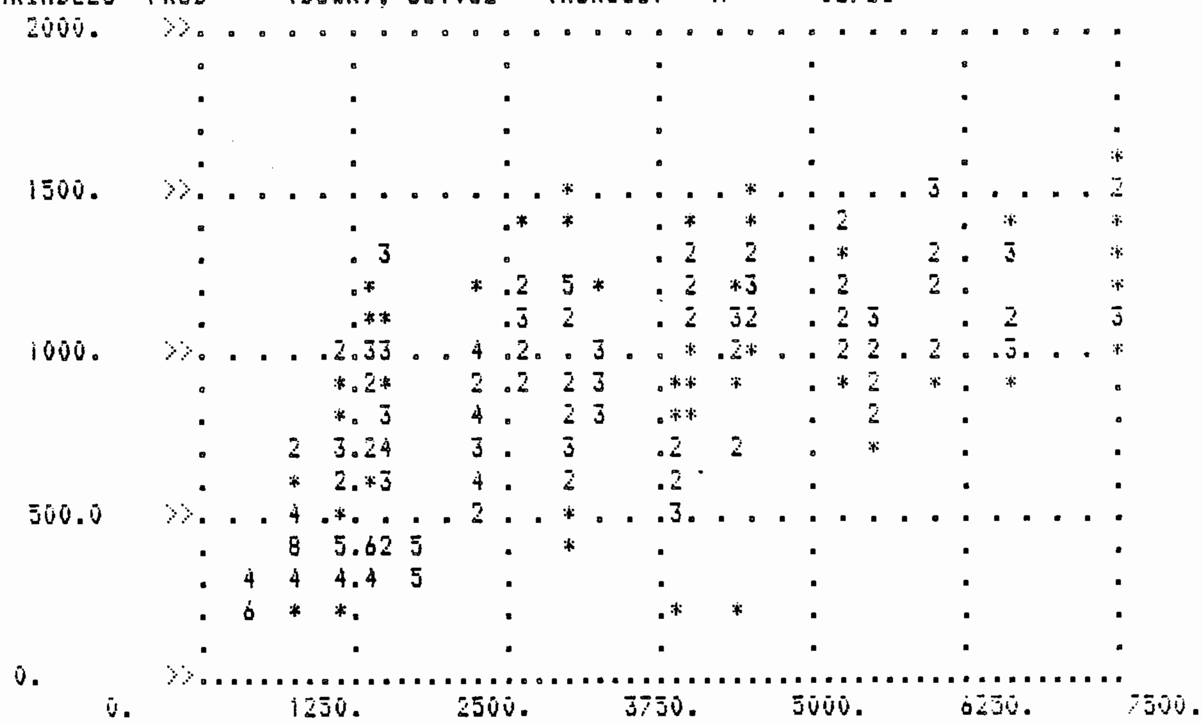


Figure 33. Scattergram of CUTVOL Versus Production for the West Coast Tower Configuration with 4 chokers

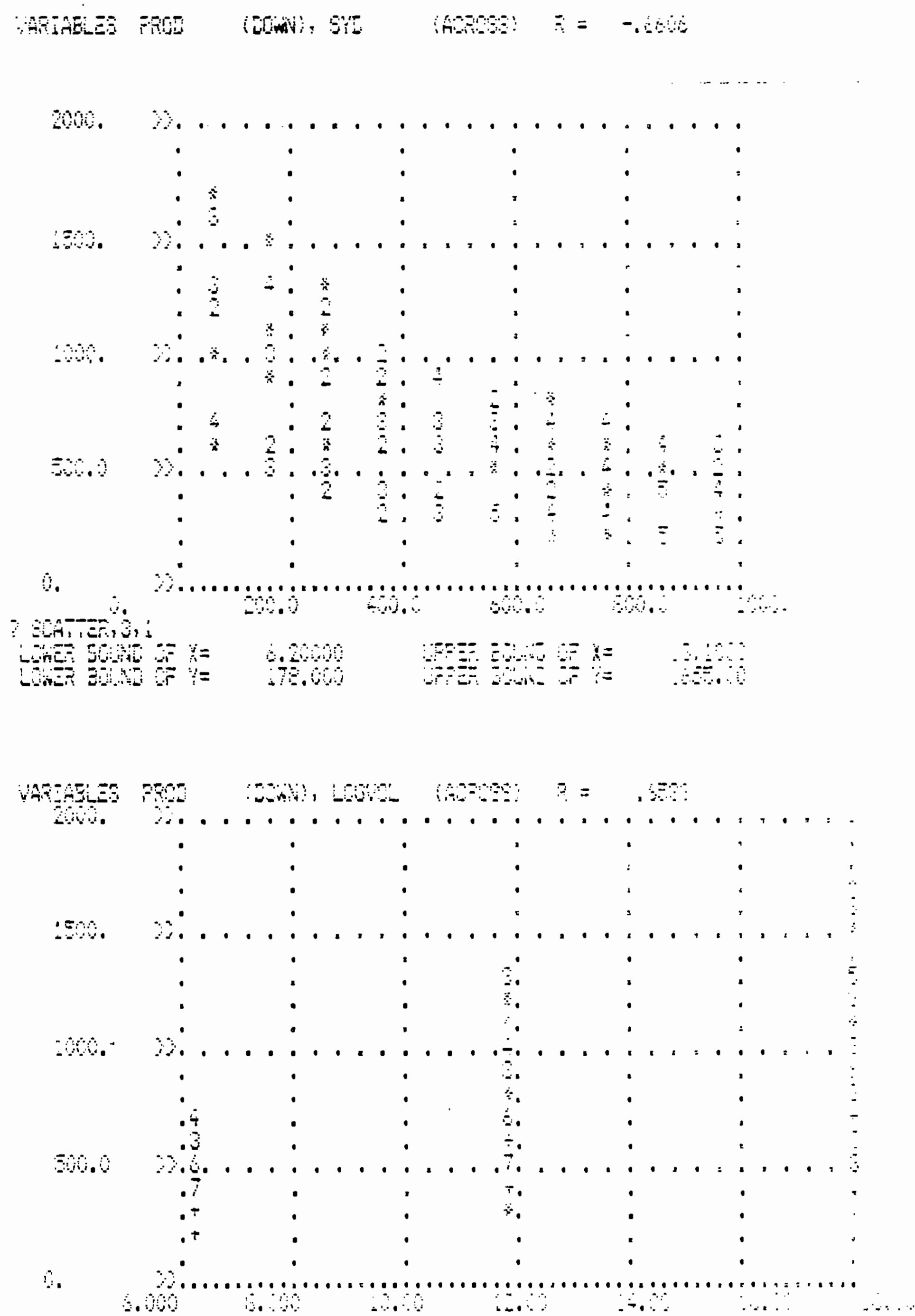
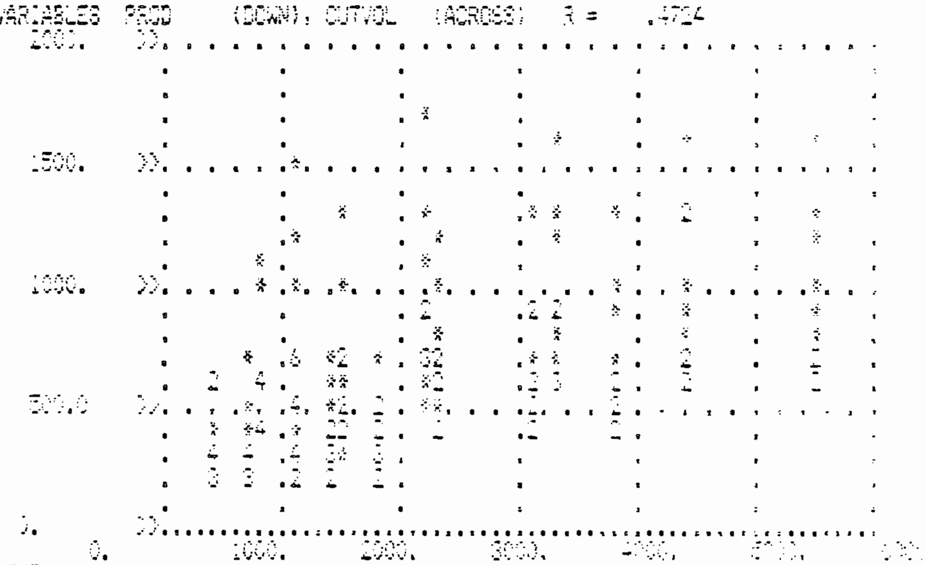


Figure 34. Scattergrams of ASYD and LOGVOL Versus Production for the Skagit GU-10 Prebunching Configuration

```
? SCATTER,4,1
LOWER BOUND OF X=     353.000        UPPER BOUND OF X=     [illegible]
LOWER BOUND OF Y=     176.000        UPPER BOUND OF Y=     [illegible]

VARIABLES  PROD     (DOWN), CUTVOL   (ACROSS)   R =    .4724
```



```
? END
 ** LEAVING REGRESS **
? EXIT
```

Figure 35. Scattergram of CUTVOL Versus Production for the Skagit GU-10 Prebunching Configuration

Log Volume Histograms

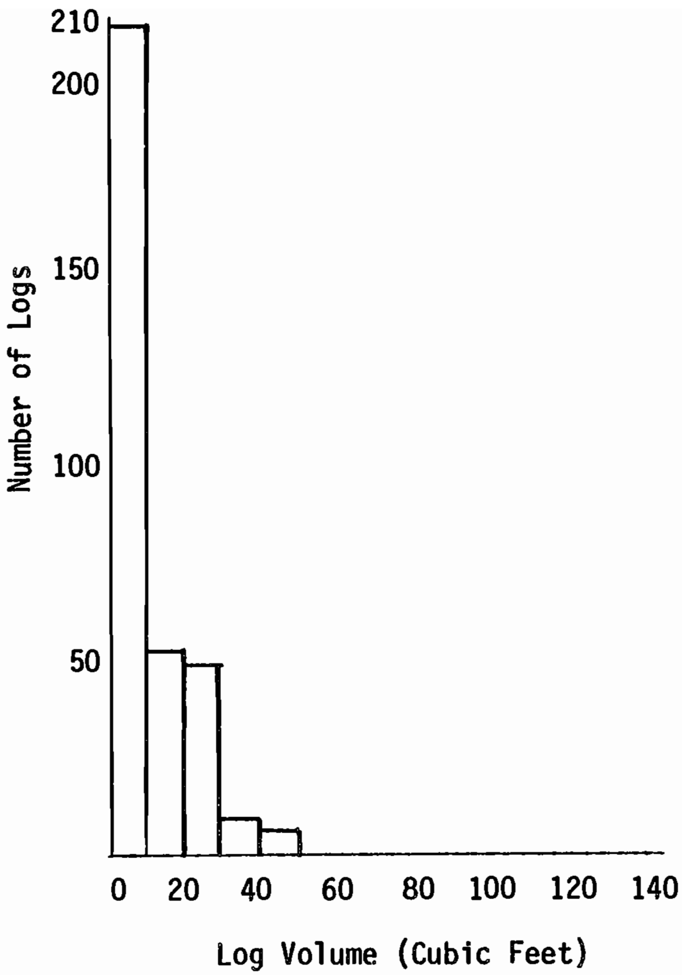


Figure 36. Log Volume Histogram of a 60 Year Old Douglas-fir Stand Thinned at 50 Percent Intensity

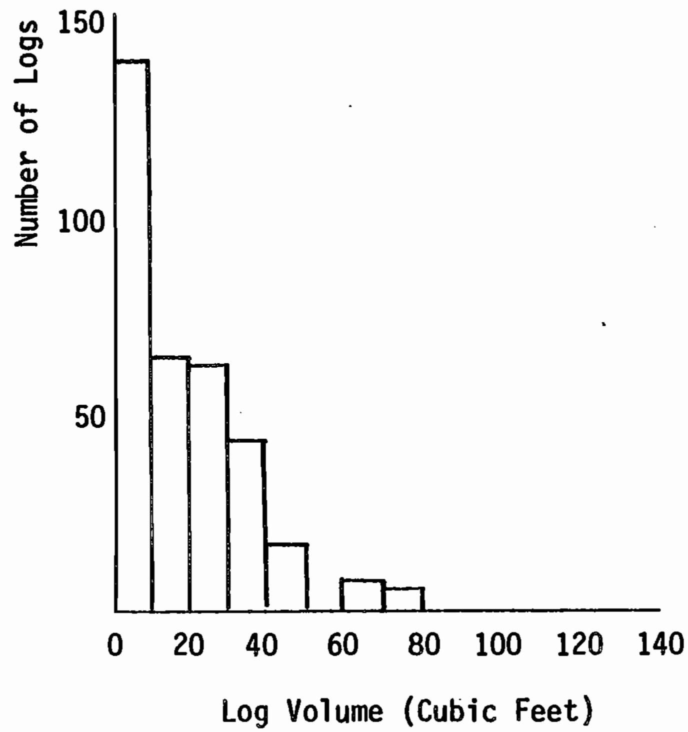


Figure 37. Log Volume Histogram of an 80 Year Old Douglas-fir Stand Thinned at 50 Percent Intensity

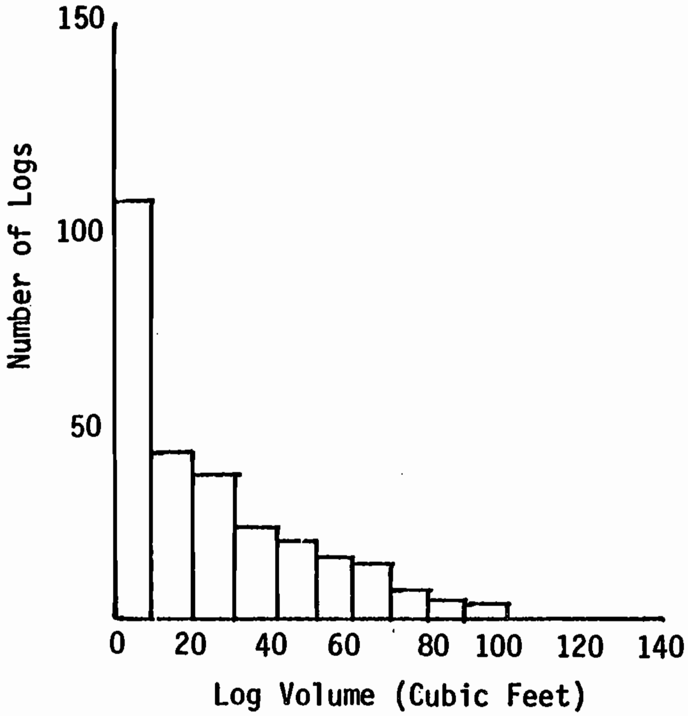


Figure 38. Log Volume Histogram of a 100 Year Old Douglas-fir Stand Thinning at 50 Percent Intenstiy

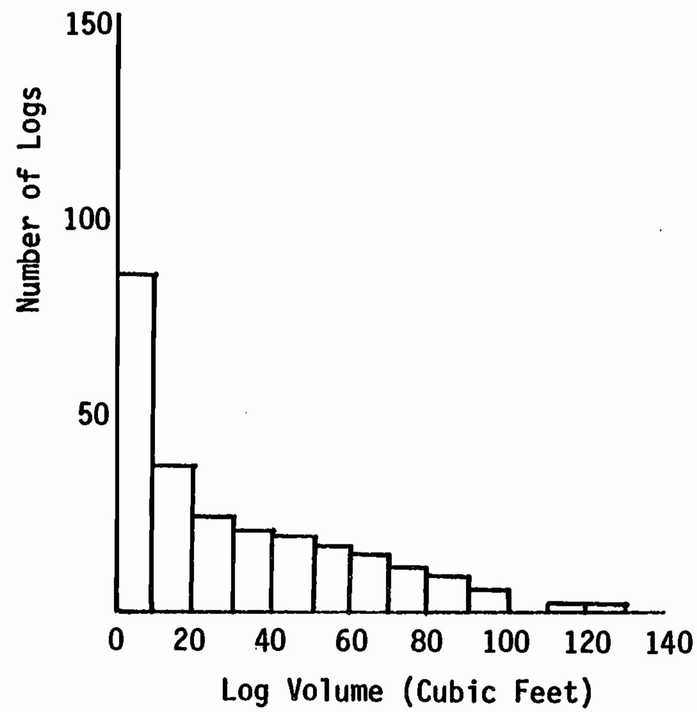


Figure 39. Log Volume Histogram at a 120 Year Old Douglas-fir Stand Thinning at 50 Percent Intensity