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FOREST CONTROL AND REGULATION...
a comparison of traditional methods and alternatives

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ABSTRACT: Two traditional techniques of forest control and regulation–formulas and area-volume check–are compared to linear programing, as used in a new computerized planning system called Timber Resource Allocation Method (Timber RAM). Inventory data from a National Forest in California illustrate how each technique is used. The traditional methods are simpler to apply and less expensive, but Timber RAM allows a more realistic definition of timber resources and can analyze a wider spectrum of forest management practices.

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An important maxim of forestry is the management of forest lands for a continuous, controlled flow of timber. The key to achieving sustained yield is to establish a regulated forest with the proper distribution of stand age and size classes so that approximately equal periodic harvests of the desired size and quality are produced. Usually the forester is not so fortunate as to start management on a forest with a regular stand distribution. To achieve the desired distribution, he must often liquidate large tracts of old-growth virgin timber, reforest unstocked and understocked lands, and thin or harvest stands of intermediate-age classes. These management operations transform or convert the irregular forest structure to the regulated one.

The period of transition, or conversion period, is usually one rotation or shorter in length. The problem in starting regulation during a conversion period is to determine a cutting schedule which will properly redistribute the age classes and at the same time insure an acceptable flow of harvested timber; that is, when to cut how much of which stand. The cutting priority for a particular stand has usually been determined by applying such rules-of-thumb as "cut the oldest first" or "high risk before vigorous." For the most part, these rules-of-thumb are silviculturally sound. A conflict arises when a manager must decide between several stands of similar characteristics. When to cut a particular stand involves applying the rules-of-thumb or judgment and determining the actual cutting order for all stands. Once the cutting priority has been determined, the second, and perhaps more difficult question must be answered–how much to cut?

Traditionally, the "how much" question has been answered by applying either *volume* or *area* control. *Volume* control implies control of the annual or periodic volume cut during the conversion period, and area control implies control of the annual or periodic area cut. *Area* control will produce a fully regulated forest at the end of one rotation, but its application may produce a wildly fluctuating allowable cut during the conversion period. Volume control, on the other hand, will produce a controlled flow of timber during the conversion period, but may result in not fully regulating the forest. Foresters often must schedule an even flow of timber to maintain mill production as a primary goal and then insure a degree of regulation to provide for sustained yield. Therefore, the ideal answer to the "how much" question is to apply a combination of volume and area control. Until recently, this application has been a tedious, time-consuming process, but the development of computers has made it possible to greatly simplify the process.

Several methods for determining a proposed level of cut are commonly used. Each method differs from the others in precision, sophistication, and convenience of use; requirements in data input and difficulties in formulating the problem generally increase as the reliability and the sophistication of the method increase. This note compares three different methods: formula, area-volume check, and linear programing

FORMULA METHODS

The first of the methods–formula–is the easiest to use, least sophisticated, and least precise. Volume control formulas are based on an adjustment of the present growing stock to some desired level or an estimate for annual or periodic growth or both. For example, the Hanzlik Formula distributes the harvesting of old-growth over one rotation and then adds annual increment to complete the cut estimate. His formula reads:

allowable cut = (Vm/R)+I

in which:

Vm = volume of over rotation-aged timber

R = rotation in years or decades

I = annual or periodic growth.

For the formula to produce a reasonable estimate, there must be a large but not too large proportion of old-growth timber. If there is little old-growth timber present, the formula becomes dependent on increment alone, with the weaknesses apparent in such an approach. If the volume of mature timber is very large, the formula reduces to an area regulation schedule. This change may result in holding old-growth timber longer than silvicultural or economic prudence suggests.[1] To show how formulas would calculate the allowable cut, we drew upon data from a National Forest in California. Rotation age is 120 years, divided into 10-year planning periods. Stand type B has a well-stocked overstory with a developing understory. The allowable cut in the first period varied according to the formula used: 2,972 MMBF (million board feet) in Area Control; 2,272 MMBF in the Hanzlik Formula; and 1,805 MMBF in the Austrian Formula *(table 1; fig. 1).*

All formula techniques are static–they only estimate an allowable cut for a given point in time. Increment, growing stock, and other forest factors are not constant with time. Therefore, estimates based on time-independent formulas are of doubtful reliability and should be used only as first approximations in short-range planning or as starting points for more realistic methods. The formula methods can only crudely solve one of the problems posed in timber management–how much to cut? They do not provide the manager with guidelines on where to cut, which stand to cut, or how to cut. Formula methods, therefore, cannot guarantee that the cut estimate will move the forest toward regulation, nor can they evaluate the consequences of alternative management practices, such as intermediate cuttings, precommercial thinnings, and introduction of genetically improved stock. Clearly the movement toward intensive management practices and the ever increasing demand for forest products demonstrate the need for more powerful tools.

AREA-VOLUME CHECK METHOD

The area-volume check method starts where the formula method leaves the manager–with an initial allowable cut estimate. Commercial timber stands are first stratified into classes by age or other significant silvicultural characteristics. These classes are then ordered into a cutting sequence. Starting with the manager's estimate of initial allowable cut, the area-volume check technique "harvests" every acre of the first class before entering the next class. Each acre is harvested only once during the conversion period and the uncut timber classes are continuously updated to account for growth. The initial allowable cut generally results in one of two situations: all the classes are clearcut before the end of the specified conversion period (i.e., the initial cut estimate was set too high) or by the end of the conversion period some of the timber stands are still uncut (the initial cut was set too low). The next step is to adjust the initial cut estimate in the appropriate direction and again clearcut all the stands, setting harvests equal to the new cut estimate. This procedure is repeated until the time required to cut all the managed land with the current allowable cut is close enough to the

Table 1–*Sample problem data drawn from a National Forest in California; rotation age is 120, divided into 10-year planning periods*

Existing stand structure		Yield table		
Age	Area	Age	Yield/acre	Growth/decade
Decades	*Thousand acres*	*Decades*	*M bd. ft.*	*M bd. ft.*
		STAND TYPE A		
2	88.715	2	0.0	0.0
		3	.0	6.3
4	39.489	4	6.3	5.4
		5	11.7	5.1
6	42.894	6	16.8	4.8
		7	21.6	4.3
8	57.308	8	25.9	4.0
		9	29.9	3.6
10	35.513	10	33.5	3.2
		11	36.7	2.9
12	14.271	12	39.6	2.5
		13	42.1	2.1
14	18.730	14	44.2	1.8
		15	46.0	1.3
16	36.420	16	47.3	.7
		17	48.0	.9
18	72.465	18	48.9	.3
		19	49.2	-.1
20	64.237	20	49.1	-.5
		21	48.6	
		STAND TYPE B		
35	92.483	35	63.4	1.8
Total	562.525	36	65.2	

length of the conversion period to be acceptable to the manager.

The area-volume check technique allows the manager to evaluate at least partially some of the consequences of a given cutting schedule and level. The final annual or periodic cut could theoretically be maintained for the full conversion period, but the forest would not be regulated since area control is not really considered. This problem is overcome by repeating the calculation for each planning period, assuming that the schedule for the preceding period was followed.[2] If this procedure is followed indefinitely, the annual or the periodic allowable cut will asymptotically approach the sustained yield level. However, it may take much longer than one rotation to reach it.

The area-volume check method shares some of the shortcomings of the formula method. It still lacks versatility in that, except for clearcutting, it cannot realistically simulate management practices. Partial cuts and the effects of fertilization or genetically improved stock must be "fudged in" after the calculation is complete.

Although area-volume check does specify when a timber stand is entered, its specification is merely a reflection of the cutting priority selected by the manager. The area-volume check method cannot be used to determine the schedule which will yield the most timber nor the largest revenue.

LINEAR PROGRAMING METHOD

Linear programing offers an alternative to the traditional techniques of formulas and area-volume check. Besides providing for control of periodic harvests to insure their even flow and regulation, it can determine the cutting schedule which will yield the highest volume of timber or which will maximize economic objectives such as net or gross revenue. Professional foresters without formal training in linear programing can use this technique without difficulty with the computerized system: Timber Resources Allocation Method (Timber RAM).[3] In this note, the use of linear programing is discussed in the context of Timber RAM.

Other techniques determine an allowable cut corresponding to a predetermined timber class cutting sequence. The total volume harvested under the

Area Control

1. Calculate the area to be cut per decade:

$$\frac{\text{Total area}}{\text{Decades in rotation}} = \frac{562.525 \text{ M-acres}}{12 \text{ Decades}}$$

$= 46.877$ thousand-acres/decade

2. Assume a cutting schedule determined by the "cut the oldest first" rule of thumb. For the first decade, the only yield coefficient needed in this sample problem is that of the oldest class (35 decades) since the area of the 35-decade class is greater than the area to be cut during the first decade.

3. Calculate the first decade harvest volume:

46.877 M-acres x 63.4 MBF/A = 2,972 MMBF

Hanzlik Formula

$$\text{First-decade harvest volume} = \frac{V_m}{R} + I$$

where V_m = volume of mature merchantable timber above rotation age,
R = number of decades per rotation,
and I = first decade increment.

1. Calculate V_m:

Class Area (M-acres)		Vol/Acre (MBF)		Total Volume (MMBF)
92.483	x	63.4	=	5863.42
64.237	x	49.1	=	3154.04
72.465	x	48.9	=	3543.54
36.420	x	47.3	=	1722.67
18.730	x	44.2	=	827.86
				15,111.53 MMBF

2. Calculate I:

Class Area (M-acres)		Growth/Acre (MBF)		Total Increment (MMBF)
92.483	x	1.8	=	166.47
64.237	x	-0.5	=	-32.12
72.465	x	0.3	=	21.74
36.420	x	0.7	=	25.49
18.730	x	1.8	=	33.72
14.271	x	2.5	=	35.68
35.513	x	3.2	=	113.64
57.308	x	4.0	=	229.23
42.894	x	4.8	=	205.89
39.486	x	5.4	=	213.24
				1,012.98 MMBF

3. Calculate first decade harvest:

$$\frac{V_m}{R} + I = \frac{15,112}{12} + 1,013 = 2,272 \text{ MMBF}$$

Austrian Formula

$$\text{First decade harvest volume} = I + \frac{G_a - G_r}{a},$$

where I = first decade increment,
G_a = present growing stock,
G_r = desired growing stock, and
a = an arbitrary number of decades in which to make the growing stock adjustment (the full rotation of 12 decades is allowed in the case of this sample problem).

1. Calculate I:
(see Hanzlik calculation)

2. Calculate G_a:

Class Area (M-acres)		Vol/Acre (MBF)		Total Volume (MMBF)
92.483	x	63.4	=	5863.42
64.237	x	49.1	=	3154.04
72.465	x	48.9	=	3543.54
36.420	x	47.3	=	1722.67
18.730	x	44.2	=	827.86
14.271	x	39.6	=	565.13
35.513	x	33.5	=	1189.69
57.308	x	25.9	=	1484.28
42.894	x	16.8	=	720.62
39.489	x	6.3	=	1567.32
				20,638.57 MMBF

3. Calculate G_r:

Assume desired growing stock is sustained yield potential under perfect regulation; yield at rotation age is seen to be 39.6 MBF/A. The "average" yield is then 19.8 MBF/A, and desired growing stock is:

total area x "average" yield, or

562.525 (M-acres) x 19.8 (MBF/A) = 11,138 MMBF

4. Calculate the first decade harvest:

$$I + \frac{G_a - G_r}{a} = 1,013 + \frac{20,639 - 11,138}{12}$$

$$= 1,805 \text{ MMBF}$$

Figure 1—*Differences in initial allowable cut resulted from using three formula approaches. Data were drawn from an inventory on a National Forest in California.*

area-volume check schedule, for example, will generally vary for different cutting sequences. To find the sequence which will yield the highest timber harvest, the manager would have to try all promising permutations of timber classes—a tedious and expensive procedure even when there are only a few classes. In many actual situations, the highest timber harvest obtainable could be realized only by eliminating the basic area-volume check requirement: that a class be completely liquidated before the next one is harvested.

Linear programing, as used in Timber RAM, can determine an "optimum" cutting schedule while controlling the area or volume harvested for each decade during two periods: (a) the conversion period; and (b) the post-conversion period. Harvests are controlled during the conversion period to insure an acceptable flow of timber yield or an acceptable decade to decade variation in the area harvested. Conversion period control insures short-run even flow (the specific options available—conventional, sequential, and arbitrary—will be considered later). Harvests are controlled during the post-conversion period to insure a specified degree of forest regulation, since controlling harvest levels during the conversion period only will often generate a poorly regulated forest.

Planning the regulation of a forest requires making assumptions about future management practices. The Timber RAM system assumes that when an acre of any stand is first clearcut during the conversion period, it is immediately reforested to again be clearcut at its specified rotation age. Thus a cutting sequence, which may include partial cuts as well as clearcuts, is determined for every acre at the time of its first clearcut and repeated for each succeeding rotation. In the simplest case with the same rotation age for all stands, the post-conversion period need only be one rotation in length.[4] Hence, each acre is clearcut only once during the post-conversion period. The Timber RAM system achieves regulation by restricting the level of the harvested area or volume for each decade during the post-conversion period around the "average" post-conversion harvest. The degree of regulation is controlled by specifying the percent allowable variation of the harvests around their average. A different tolerance can be specified for each decade of the post-conversion period.

In Timber RAM harvest control can be imposed on the basis of: (1) area control, (2) volume control, or (3) area-volume control.

With area control, it is the number of acres harvested in each decade of the conversion and the post-conversion period which is restricted. Partial cuts may be included in the calculation and can be given any weight from 0 (control clearcut area only) to 1 (control total area harvested). Area control in Timber RAM makes no provision for distinguishing variations of site quality or productivity in harvest scheduling. The user is cautioned that since there is no volume control during the conversion period, wide decade to decade fluctuations in allowable cut are possible if area control is applied to a forest with an irregular stand structure.

If even flow of stumpage during the conversion period is a primary goal, but the forester still wishes to apply some degree of regulation to his existing stand structure, the Timber RAM volume control option may be the answer. With volume control, it is the volume harvested in each conversion and post-conversion decade which is restricted. No attempt is made to distinguish the type of cuts being made in each decade. Also, since area is not considered, the resulting age class structure may be far from a regulated state. Volume control does, however, guarantee that a forest structure will be established which will yield controllable harvests on a decade to decade sustained yield basis—our first requirement for regulation.

In many actual problems, either simple area or volume control will produce satisfactory results. However, area control does not guarantee even flow during conversion, and volume control does not necessarily produce a regulated stand structure. With area-volume control, both even flow during conversion and a regulated stand structure can be approximated. In this method, volume control is applied to the conversion period to insure even flow. Volume control is also applied to the post-conversion decades except that only clearcuts are included in the calculation of the harvest by "screening out" all partial cuts[5] (i.e., only clearcut volumes are controlled around their average). Since each acre is clearcut only once during a rotation and since the clearcut volume per acre reflects site quality, Timber RAM area-volume control approximates traditional area control in which each acre is weighted by its relative productivity. If all stands are managed at a uniform level of intensity and are maintained in a well-stocked condition, area-volume control can guarantee even flow and insure regulation both as to harvest levels and age class distribution. If these conditions are not met, the volume harvested during the post-conversion period may fluctuate more from one period to the next than under simple volume regulation.

By way of summation, the Timber RAM system has basically three options for controlling harvests.

Each option is subject to its own inherent limitations. The user, however, by the judicious and clever use of these options and careful problem formulation, can handle a wide range of regulation problems including multiple rotation ages, the introduction of genetically improved stock, and mixed management intensities. The actual "how to do it" discussion is beyond the scope of this paper. The main point is—the Timber RAM system is sufficiently versatile to allow the forester a great deal of freedom to formulate the type and degree of regulation to be used within the context of his particular problem and management objectives.

Conversion Harvest Control Options

The Timber RAM system offers the user a choice of three alternative methods for controlling harvests during the conversion period: (1) conventional, (2) sequential, and (3) arbitrary control. Either the volume or the area is controlled depending upon the type of harvest control chosen. For the following discussion and illustrations, volume control is assumed.

Conventional Control

Conventional control calculates an average allowable cut for the conversion period, and then constrains periodic harvests[6] during the conversion period to any desired percentage variation around this average. This is essentially a modification of traditional volume regulation with two important differences: (a) periodic cuts need not be equal, and (b) Timber RAM will determine the optimal cutting schedule for the standing timber. *Figure 2* illustrates the use of conventional control with the same data used in *figure 1* to illustrate the formula techniques.

The range of acceptable variation in periodic harvests during and after the conversion period can be set at any level desired by the manager. In addition, he can vary this level for each individual periodic harvest. Thus the manager can specify the degree of even flow and regulation. Varying the allowable tolerances will produce different "optimum" cutting schedules. In general, the tighter the manager makes the tolerances, the lower the total timber harvest will be.[7] The drop in harvested volume occurs because the more constraining tolerance levels will give the program less freedom in scheduling timber harvests. In *figure 2* periodic harvests were allowed to range within five percent of their average during the conversion period and within ten percent of their average during the post-conversion period.

Sequential Control

When the average periodic yield during the conversion differs by more than 5 or 10 percent from either the present allowable cut or the post-conversion

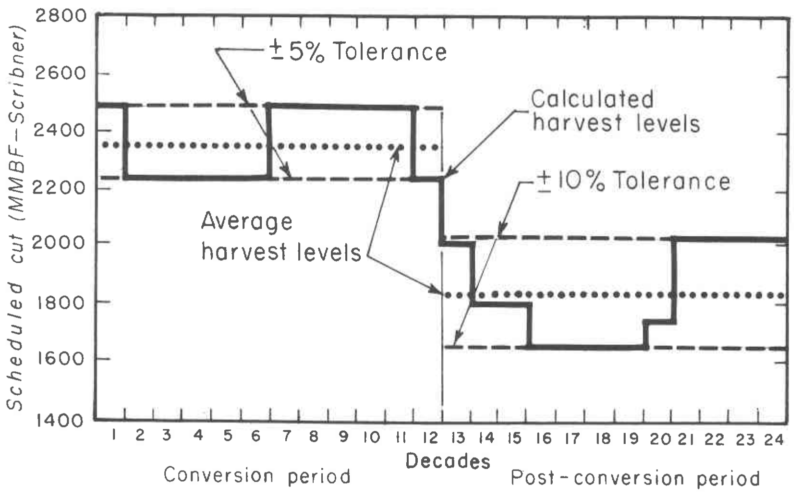

Figure 2—*Timber RAM Conventional Control. The user constrains periodic harvest levels to a percentage variation around their average during the conversion period. In the problem illustrated, the user chose ± 5 percent as the allowable variation. To insure regulation, he specified that post-conversion periodic harvests be within ± 10 percent of their average. Thus, the user controls the degree of evenflow and regulation simply by setting the tolerances for each decade.*

periodic average, the use of conventional control may result in a sharp increase—or drop—in harvest levels at the beginning or end of the conversion period. These fluctuations can be avoided by using the sequential control option of Timber RAM. This option approximates best the Forest Service policy of providing a smooth transition from the present cut to the average post-conversion harvest level. Each periodic harvest during the conversion period is constrained to the previous periodic harvest level plus or minus a percentage selected by the manager. The first periodic harvest is also "linked" in this manner to the present cut, and the last harvest of the conversion period is "linked" to the average post-conversion harvest level. Post-conversion periodic harvests are allowed to fluctuate around their average level to insure the desired level of regulation in the same manner as under conventional control. Different percentage variations can be specified for each of the "links" and for each periodic harvest during the conversion and post-conversion periods *(fig. 3)*.

Arbitrary Control

In special circumstances, the timber manager may want to raise or lower some of the periodic harvests during conversion to specified levels. With the arbitrary control option he can find a cutting schedule which meets this special requirement and also moves the forest toward regulation.

Let us assume that a wood products firm expects its timber supply to decline drastically during the third, fourth, and fifth planning decades because of a disastrous fire on some of its lands. The firm may consider filling this gap by purchasing additional timber land and planning its management with the arbitrary control option of Timber RAM. Minimum harvest levels for these three decades would be specified on the newly purchased land, and the remaining periodic harvests of the conversion period would be allowed to vary somewhat more than under normal circumstances. Regulation of the newly purchased land could still be achieved by specifying a maximum variation in post-conversion periodic harvests around their average. Assuming the purchase to be identical to the simulated forest in our previous examples, the periodic harvests for the three decades could be set as high as 3,100 MMBF while post-conversion periodic harvests are maintained within 10 percent of the average post-conversion harvest *(fig. 4)*.

The basic data required for using the Timber RAM system include the following:

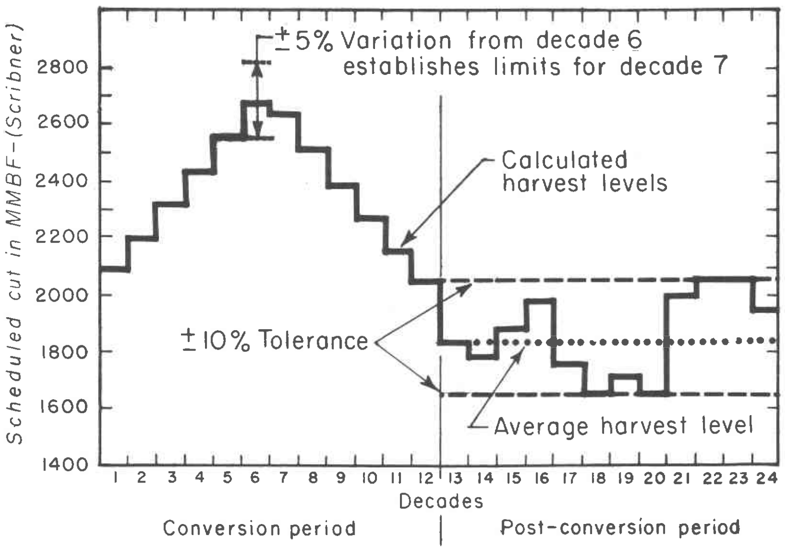

Figure 3—*Timber RAM Sequential Control. The user constrains the level of each periodic harvest during the conversion period to an allowable percentage variation around the level calculated for the preceding decade. In the problem illustrated, the user chose ± 5 percent as the allowable variation between decades. Forest regulation was insured by also allowing only a ± 10 percent variation for post-conversion harvests around their average. The user can set the allowable tolerance for each decade independently.*

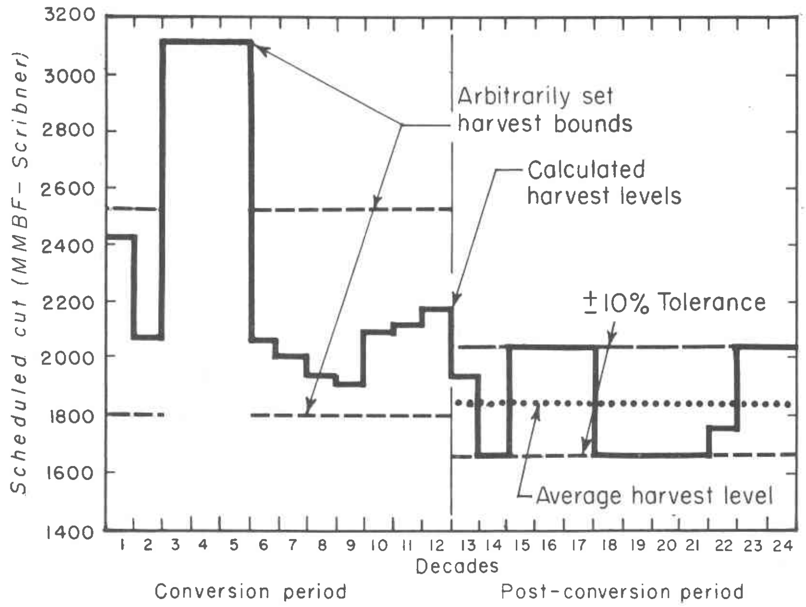

Figure 4—*Timber RAM Arbitrary Control. The user specifies the exact volume ranges within which he wants to maintain periodic harvest levels during the conversion period. In the problem illustrated, the user set the lower bound at 1,800 MMBF and the upper bound at 2,500 MMBF, except for decades 3-5 where he set the minimum harvest level at 3,100 MMBF. Regulation was insured by specifying an allowable tolerance of ± 10 percent around the post-conversion average. The user can set the bounds and allowable percentage variations differently for each decade.*

- Age and acreage of each timber class[8]
- Intermediate and harvest volumes for each timber class for every age at which Timber RAM is allowed to schedule a cut
- Tolerance levels for variation in periodic harvests during the conversion and post-conversion periods (if arbitrary control is used, an acceptable range of harvest levels must be specified for each periodic harvest during the conversion period)
- Rotation age(s)
- Length of the conversion period—this can be shorter than the rotation age when adequate young growth stands are already established
- Period in which each timber class can be first harvested, and the period by which it must be completely clearcut.[9]

A COMPARISON OF METHODS

The three approaches to forest control—formula, area-volume check, linear programing—attempt to control timber production by computing one or more allowable cut levels. Differences in computation of harvest volume under each method are shown in this summary:

	Harvest Volume		
	Decade 1	*Decades 1-12*	*Annual Average*
		MMBF	
Method:			
Present cut level	1,998	(1)	199.8
Area Control	2,972	27,430	228.5
Hanzlik Formula	2,272	(1)	227.2
Austrian Formula	1,805	(1)	180.5
Area Volume Check	2,296	25,113	209.3
Timber RAM:			
Conventional	2,490	28,463	237.2
Sequential	2,100	28,293	235.8
Arbitrary	2,420	28,067	233.9

[1]These methods provide estimates for the first decade only.

When judging the value of each method, an obvious question to ask is: "How do the allowable cut levels reflect changes in management practices?" If the manager wishes to evaluate the worth of alternative policies, he needs a tool which will accurately predict the long-range effects of his decision. Unfortunately, the traditional methods of calculation are not well suited to this type of simulation.

A few examples will demonstrate this point:

• In area-volume check, a more intensive cutting schedule that would include intermediate cuts could be represented only by increasing the clearcut yield. In reality, however, the increased yield occurs anywhere from 10 to 60 or more years before the harvest. Thus the area-volume check will predict less yield before clearcuts and more yield at clearcuts than is actually realized, and any decisions based on this method must be adjusted accordingly.

• A manager wishes to investigate a recreational development and would like to increase his timber harvest over the first few planning periods to help offset the increased cost. Since neither area-volume check nor formulas allow the flexibility to constrain individual harvest levels, neither method will be useful to the forester in deciding how much more of which stands to cut in order to raise the additional capital and still insure regulation.

In Timber RAM, however, most management practices, including both of the situations just described, can be realistically simulated. All partial or clearcuts are accounted for when they occur, and the manager can force periodic harvests to any levels which are feasible. Moreover, for each plan which the manager is considering, Timber RAM will calculate the optimal harvest schedule, thus giving the manager information he needs to judge the merits of each alternative policy. In fact, owing to the versatility of linear programing, Timber RAM can simulate virtually any conceivable management practice. Listed below are some of the features of Timber RAM which make this possible.

• The user can specify any number of timber stands or classes, each with different silvicultural or economic properties.

• The intensity of cutting is not pre-determined. For each timber class, any number of management alternatives reflecting any desired combination or sequence of cuts can be defined. Timber RAM will pick the most productive alternative or combination of alternatives for each timber class. Thus a Timber RAM cutting schedule does not have to be restricted to one type of management, but can reflect several different practices on each timber class. Area-volume check and formula methods assume clearcutting only. Intensive management practices must be "fudged in" after completing the calculations.

• For any management alternative on any given timber class, the manager can specify a range of periods during which a first cut can be made and a range of periods during which the stand can be clearcut. Timber RAM will then determine the "optimal" sequence or sequences of cuts for each timber class. We know of no other system having this versatility.

• To account for the present and anticipated state of roading, each timber class can be made partially or totally inaccessible for up to 50 years. As the road system is built, the timber classes can become more accessible, thus allowing the investigation of various roading plans. Accessibility introduces extremely tedious computations with formulas or area-volume check.

• If the manager anticipates increased yields in the future (a result, for example, of genetically improved stock or a fertilization program), he may specify improved sustained yield figures, the period of time when the program will be ready for implementation, and the amount of stock available for use (if the amount is restricted).

• Timber volume harvested in any period can be forced to any level consistent with the degree of forest regulation specified.

• With Timber RAM, the economic as well as the silvicultural implications of management practices can be assessed. The manager can predict, constrain, or optimize discounted dollar values as well as timber volume. None of the other methods discussed can consider economic values in determining allowable cut.

Linear programing is a more powerful planning tool than either formulas or area-volume check techniques. The area-volume check technique is more complex to use than formulas; but it provides more accurate projections of future yields. Linear programing is still more complex; but it permits the exploration of a wide spectrum of alternative silvicultural practices and harvest control policies. With a system such as Timber RAM, the versatility of the linear programing technique is brought within easy reach of professional foresters who have had little or no training in mathematical programing or operations research.

NOTES

[1]For a more detailed discussion see: Davis, K. P. *Forest management.* Ed. 2. New York: McGraw-Hill Book Co. p. 137-138. 1966.

[2]The area-volume check method has been computer-simulated in the programs ARVOL and SORAC. These programs were used in the example. For details on their use, see: Chappelle, D. E. *A computer program for calculating allowable cut using the area-volume check method.* U.S.D.A. Forest Serv. Res. Note PNW-44, Pacific NW. Forest & Range Exp. Sta., Portland, Ore. 4 p. 1966; Chappelle, D. E. and R. W. Sassaman. *User's manual for ARVOL computer program.*

Pacific NW. Forest & Range Exp. Sta., Portland, Ore. 30 p. (n.d.); Sassaman, R. W., D. E. Chappelle, and K. Fritchman. *User's manual for the SORAC computer program.* Pacific NW. Forest & Range Exp. Sta., Portland, Ore. 80 p. 1969.

[3]Timber RAM is a subsystem of the Resources Allocation Method (RAM), a system designed to assist planners in the multiple-use management of wildlands. RAM is being developed by the Pacific Southwest Forest and Range Experiment Station in cooperation with the Forest Service's California Region. Timber RAM is designed for the planning of commercial timber lands under multiple-use guidelines. In this Note, only the harvest control options of Timber RAM are discussed in details. A full description of Timber RAM and a user's manual will be published in forthcoming reports.

[4]Timber RAM can also handle multiple and alternative rotations for timber classes. When more than one rotation age is specified, the cycle of recurring harvests will be equal in length to the lowest common multiple of the rotation ages. If rotations of 8 and 10 decades were mixed, for example, the cycle would be 40 decades. However, controlling the post-conversion harvests for only 10 decades (the longest rotation) will in most cases provide an acceptable degree of regulation.

[5]The partial cuts are included in other portions of the system so that the true post-conversion periodic volume levels can be estimated.

[6]Since the planning period in Timber RAM is one decade in length, the term "periodic" will be used in the discussion. The reader should not confuse this usage with the conversion or post-conversion "periods," which denote much longer spans of time.

[7]If the allowable variations in harvests specified by the manager for either the conversion or post-conversion periods are very small, no feasible cutting schedule may exist. Timber RAM will then print "infeasible solution" and the manager will have to increase the acceptable variations in harvests.

[8]To reduce data processing costs, stands with similar ecological and economic characteristics are grouped into the same "timber class."

[9]Hence Timber RAM can be forced to wait until the timber reaches a minimum age before scheduling it for cutting. Timber RAM can also be forced to liquidate high risk classes within any specified time span if it is consistent with the forest regulation requirements.

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