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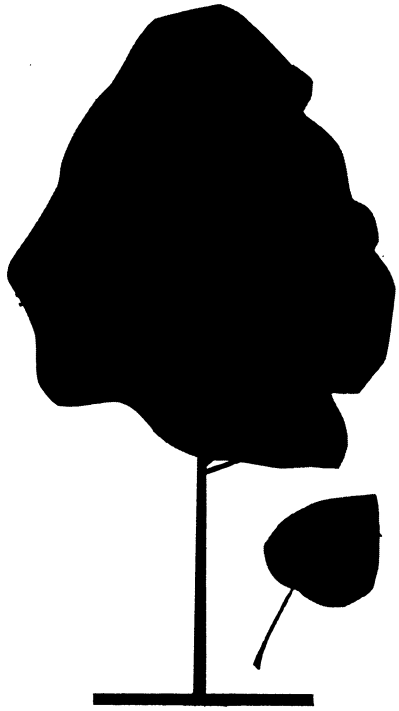

PROJECTING THE ASPEN RESOURCE IN THE LAKE STATES

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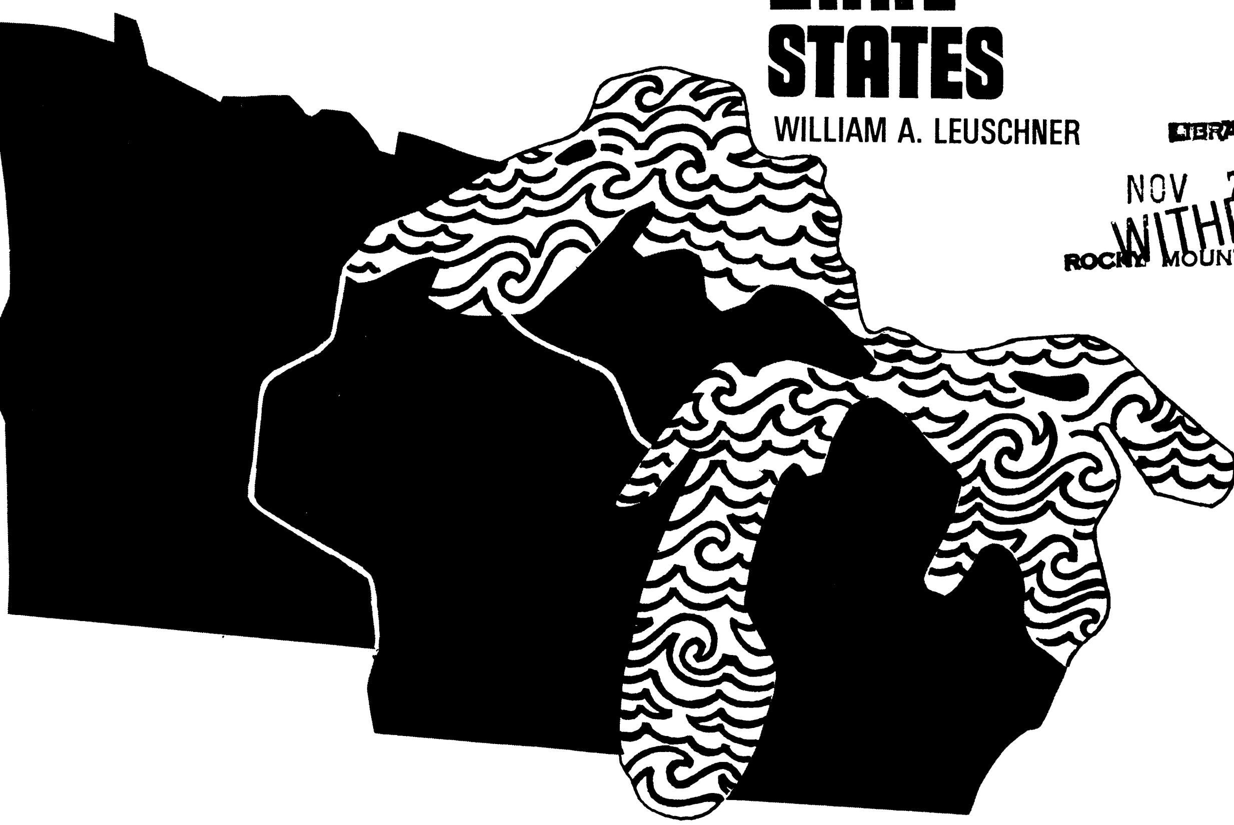

NORTH CENTRAL FOREST EXPERIMENT STATION • FOREST SERVICE • U.S. DEPARTMENT OF AGRICULTURE

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PROJECTING THE ASPEN RESOURCE IN THE LAKE STATES

William A. Leuschner

Aspens *(Populus tremuloides* and *P. grandidentata)* are dominant forest species in the Lake States of Michigan, Minnesota, and Wisconsin. Often looked down upon in the past as little more than a weed, aspen now makes up more than 45 percent of the annual production of pulpwood in the Lake States. Aspen pulpwood harvest increased from 3,000 cords in 1920 (Zasada 1947) to nearly 2 million cords in 1970. And a goodly amount is cut each year for other uses.

Aspen is also important in deer and grouse management. Young aspen and its associated species provide browse and forage for deer. The young sucker stands serve as protective cover against predators for the young and drumming male grouse and the buds of mature male aspen are food for the older birds.

Aspen has several biological characteristics that tend to enhance its appeal and usefulness. First, it is short lived and fast growing so it can be grown in short rotations.

Second, aspen will reproduce itself well by suckering if the old stand is thoroughly clearcut. This means well stocked stands can be established by fairly simple management practices and at a low initial investment.

Finally, the necessity for even-aged management and the moderate size of the trees at the end of the rotation facilitate mechanized harvesting.

These and other characteristics have stimulated research on short-rotation aspen management (Einspahr and Benson 1968). If this research bears fruit, we could see aspen playing an even more important role in the Lake States forest economy.

The future physical supply of aspen will, of course, influence long-term plans for industrial expansion and forest management. In the past, making such projections has been time consuming and expensive because inventory data were gathered State by State, whereas many management decisions, particularly in the industrial sector, required consideration of an entire region. In addition, each State's data were gathered in a different year making an overall comparison of the resource at one point in time even more difficult.

The first objective of this report is to provide a common base of inventory data for aspen in the Lake States. This is done by describing the current status of the growing stock in a base year for all survey units in the region (fig. 1).

The second objective is to give managers and landowners a better idea of what the future will hold by projecting levels of aspen growing stock and cut under several sets of likely conditions. These projections are not intended to predict the exact inventory or cut on a specific future date nor are they intended to cover all possible management alternatives or technological changes. Rather, they seek to define the range of the future physical supply of aspen if certain general policies are followed today. The projections provide an overview of the resource on a regional basis, by survey unit, and should help answer broader questions rather than provide answers for specific forests or sections of land.

The data used in this study are from the forest surveys of Michigan, Minnesota, and Wisconsin made in 1966, 1962, and 1968, respectively. These data were updated to the common base year 1968 using a standard Forest Service technique called TRAS (Larson and Goforth 1970). Thus no new fieldwork was performed for this study. Technical terms, including definitions of cover types, conform with those used by Forest Survey.

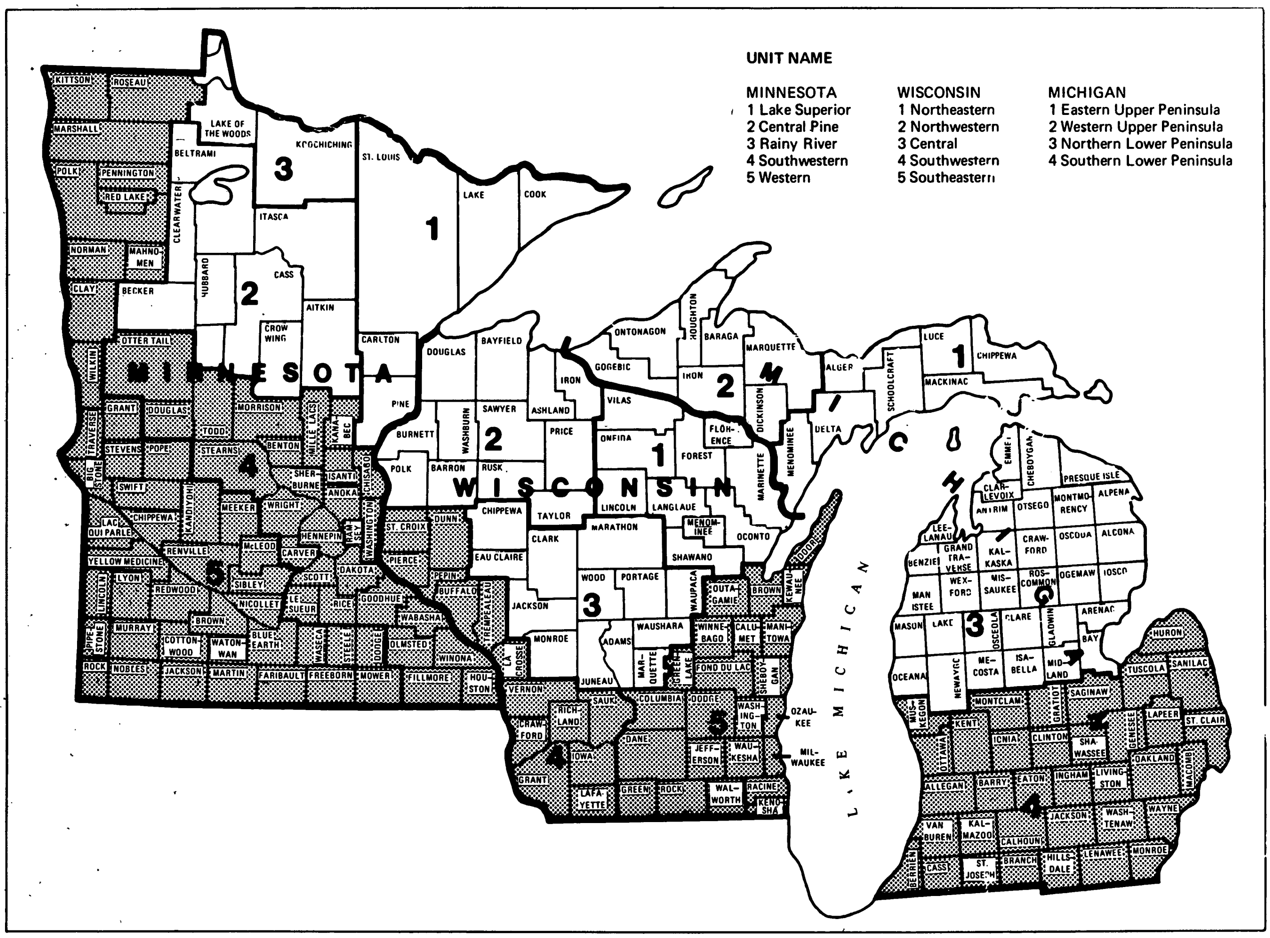

Figure 1.— Forest survey units in the Lake States. Unshaded units are study area.

CURRENT STATUS OF THE RESOURCE

There were an estimated 7.5 billion cubic feet of aspen growing stock in the region in 1968. Most of the aspen volume is in Minnesota, northwestern Wisconsin, and the northern part of Michigan's Lower Peninsula. Most of the volume is in the aspen type and in the smaller diameter classes, regardless of type. Wisconsin, followed by north-central Minnesota and Michigan's northern Lower Peninsula have the better aspen sites.

Further details may be obtained from tables 1-5 which are subdivided by survey unit.[1] Tables 1-4 contain aspen growing stock volumes for aspen in *all cover types* updated to 1968. Tables 1 and 2 show volumes by d.b.h. class and cover type and d.b.h. class and ownership class; tables 3 and 4 contain volume by density (volume of aspen growing stock per acre) and cover type and density and ownership class. Table 5 contains growing stock volumes for the *aspen cover type only* by site index and age classes in the year the survey was made.

THE MODEL AND FUTURE CONDITIONS

It should be understood that these are projections and not predictions. Although they give an exact amount of inventory or cut at a precise point in time, they really indicate only the general level and approximate timing, within the bounds of the assumptions.

[1] *Time and financing restrictions made calculation of the current status and projections on a county basis impossible.*

Different inventory and timing are projected depending on the assumptions used. So anyone using the projections must understand the assumptions.

Sharp changes of direction occurred in the model that would not occur in real life. The model may show an abrupt drop in cut in 1 year whereas in real life cut would drop more slowly and be accompanied by such signs as increased difficulty in finding stumpage and higher prices. The projections, then, must not be interpreted literally. The results are presented as 5-year moving averages to smooth these fluctuations and to remind the user they are not precise predictions.

Although the projections give the resource's response to likely sets of condtions, many of these conditions are under the control of the land manager. He may react to these projections, change the conditions under his control, and thereby cause different results. Indeed, this is desirable and one test of the usefulness of projections.

Finally the projections do not give a final answer. They should be revised every few years to allow for changes in the underlying structure. They should also be revised when new and better data become available or if a major change in technology, such as short rotation management, becomes widely adopted.

Considering all these qualifications, one may well question the value of the projections. They *are* useful, however, because they define the general situation that will prevail in the future and allow us to assess the options we will have. They facilitate judging whether or how an organization can continue to operate. And if a course of action is recommended to modify the inventory, the projections can be used to indicate the effectiveness of that course of action. Indeed, the results of some possible management practices are projected and their results presented.

The specification of assumptions allows others to judge if all relevant variables have been considered and properly evaluated. Any corrections required can be incorporated and better projections made. Also, although projections must be revised as we progress into the future, the fact that we stop things at one point in time allows us to see ahead more clearly, particularly in the near years. This is analogous to stopping a speeding car to look down the road. You can see the closer terrain in more detail and more clearly than when the car was moving and you can take the time to study more closely that farther down the road. However, you must drive farther down the road and stop again before you can see the distant terrain more clearly.

The Projection Model

The theoretical basis for the projection model is presented in detail elsewhere (Leuschner 1972). Essentially, the model takes the growing stock inventory at the beginning of the year, subtracts cut, adds or subtracts growing stock to account for changes in commercial forest acreage, and adds growth on the cut, on acreage change, and on residual volume. The result is the growing sotck volume at the beginning of the next year. This process is repeated for each succeeding year.

This basic framework is simple. The determination of the variable values and the way they are handled in the actual calculations are what gives the model its uniqueness and validity. These are discussed at greater length in the appendix. The reader who plans to use these projections for major decisions or in-depth work is urged to review them thoroughly.

The program can analyze any number of survey units at one time. In any particular year the program first calculates the new commercial forest acreage for each cover type in each survey unit (fig. 2). The first survey unit then has its cut projected for each 2-inch d.b.h. class and this in turn is allocated by forest type. The total cut is our best estimate of what forest industry will actually buy adjusted for the amount of aspen available. Cut is distributed to survey units and d.b.h. classes according to historical trends.

After cut is allocated, the growing stock volume at the beginning of the next year is calculated for each type and d.b.h. class by means of a growth percent based on historical trends of net annual growth. Thus, mortality is included. Then the cut is checked to see if the resource can support it under the availability assumption. If it can, the program moves on to the next survey unit; if it cannot, the amount of cut that can't be supported is allocated to the remaining survey units.

Table. 1—Aspen growing stock volume, all cover types, by survey unit, d.b.h., and cover type, 1968
(Million cubic feet)

D.b.h. class (inches)	Red, white, and jack pine	Balsam fir-white spruce	Black spruce, tamarack, and cedar	Northern hardwoods	Oak-hickory	Aspen	Birch	Nonstocked and other	Total
				REGIONAL TOTAL					
6	55.7	88.7	20.1	119.2	61.2	1,862.1	52.1	0.4	2,259.5
8	44.8	74.6	18.7	169.3	78.1	1,889.5	51.2	.3	2,326.5
10	33.4	48.3	20.3	181.2	63.5	1,217.2	51.6	--	1,615.5
12	13.7	33.6	11.3	132.8	33.2	515.9	25.4	.2	766.1
14	11.5	15.5	19.2	81.6	12.9	215.9	7.9	--	364.5
16	1.8	7.5	4.1	27.7	2.7	76.9	4.1	--	124.8
18	.4	1.2	4.6	8.8	1.5	11.4	.6	--	28.5
20	.2	1.9	--	2.6	.2	8.7	--	--	13.6
22+	--	--	--	1.8	--	2.6	--	--	4.4
Total	161.5	271.3	98.3	725.0	253.3	5,800.2	192.9	.9	7,503.4
				MICHIGAN - EASTERN UPPER PENINSULA					
6	5.5	12.1	3.8	8.7	--	59.3	1.6	--	91.0
8	1.0	16.4	3.3	13.6	0.5	72.0	.5	--	107.3
10	3.0	2.8	2.3	11.1	--	39.6	2.7	--	61.5
12	.8	6.0	2.0	7.9	--	20.1	.4	--	37.2
14	--	.6	3.2	6.0	--	12.3	--	--	22.1
16	--	.5	.6	2.7	--	4.2	.6	--	8.6
18	--	--	1.2	1.8	--	--	--	--	3.0
20	--	--	--	1.2	--	.4	--	--	1.6
22+	--	--	--	--	--	--	--	--	--
Total	10.3	38.4	16.4	53.0	.5	207.9	5.8	--	332.3
				MICHIGAN - WESTERN UPPER PENINSULA					
6	2.7	15.0	2.1	22.2	3.1	107.4	4.6	--	157.1
8	3.5	17.0	1.2	36.4	3.2	123.3	2.0	--	186.6
10	3.5	11.1	--	35.5	.6	86.1	5.4	--	142.2
12	2.5	13.5	.7	22.2	.6	34.6	3.9	--	78.0
14	.6	6.0	2.7	13.9	.7	26.0	1.1	--	51.0
16	--	1.6	1.0	4.8	--	8.1	--	--	15.5
18	--	.5	--	1.2	--	2.0	--	--	3.7
20	--	--	--	--	--	1.2	--	--	1.2
22+	--	--	--	.7	--	.7	--	--	1.4
Total	12.8	64.7	7.7	136.9	8.2	389.4	17.0	--	636.7
				MICHIGAN - NORTHERN LOWER PENINSULA					
6	5.9	11.4	2.6	23.4	25.1	193.5	7.6	--	269.5
8	3.3	6.7	5.4	34.7	26.6	253.2	10.5	--	340.4
10	2.7	4.5	3.8	31.3	24.9	183.0	4.8	--	255.0
12	2.2	3.9	3.7	32.0	9.6	91.9	2.1	--	145.4
14	.3	1.7	3.4	14.7	3.8	42.9	.9	--	67.7
16	.6	1.6	2.5	5.5	.4	12.4	.7	--	23.7
18	--	--	--	1.2	--	3.5	--	--	4.7
20	--	--	--	.4	--	3.1	--	--	3.5
22+	--	--	--	.4	--	1.5	--	--	1.9
Total	15.0	29.8	21.4	143.6	90.4	785.0	26.6	--	1,111.8
				MINNESOTA - LAKE SUPERIOR					
6	9.5	14.0	0.4	6.9	--	483.6	19.4	--	533.8
8	12.8	13.3	1.3	8.9	1.6	375.1	12.1	--	425.1
10	2.0	5.2	2.8	6.1	--	237.9	12.8	--	266.8
12	.9	2.3	2.2	2.3	.1	123.6	4.4	--	135.8
14	5.1	.7	--	1.0	--	41.3	.7	--	48.8
16	--	2.3	--	--	--	20.1	.7	--	23.1
18	--	--	--	--	--	2.1	--	--	2.1
20	--	--	--	.4	--	--	--	--	.4
22+	--	--	--	--	--	--	--	--	--
Total	30.3	37.8	6.7	25.6	1.7	1,283.7	50.1	--	1,435.9

(Continued on next page)

After all survey units are completed, the process is repeated for as many years as the analyst cares to project.

Future Resource Conditions

Because the future is always uncertain, there are many possible directions the resource can take and consequently many sets of assumptions. To avoid confusing the results with too many answers, projections were limited to three sets of conditions that were judged generally indicative of what could happen to the resource. The sets of conditions, or assumptions, were called *recent trends, breakup,* and *positive practices* and were used to project cut and growing stock in each survey unit.

Table 1 continued

D.b.h. class (inches)	Red, white, and jack pine	Balsam fir–white spruce	Black spruce, tamarack, and cedar	Northern hardwoods	Oak–hickory	Aspen	Birch	Nonstocked and other	Total
				MINNESOTA - CENTRAL PINE					
6	18.6	9.0	0.8	9.9	6.5	473.5	7.4	--	525.7
8	10.9	3.5	.9	7.9	11.0	502.1	9.4	--	545.7
10	7.3	3.5	7.8	11.6	9.2	281.8	11.0	--	332.2
12	1.4	.3	--	8.7	2.1	91.5	3.4	--	107.4
14	1.7	.5	9.2	15.8	.5	39.5	1.4	--	68.6
16	--	--	--	.7	.2	10.4	1.2	--	12.5
18	--	.2	3.4	.4	--	1.4	--	--	5.4
20	--	1.0	--	--	--	.3	--	--	1.3
22+	--	--	--	--	--	--	--	--	--
Total	39.9	18.0	22.1	55.0	29.5	1,400.5	33.8	--	1,598.8
				MINNESOTA - RAINY RIVER					
6	2.1	14.3	5.9	4.7	0.1	138.5	0.3	--	165.9
8	.8	4.9	2.0	2.1	.1	100.1	.7	--	110.7
10	--	6.9	1.1	10.4	.1	75.0	.6	--	94.1
12	--	1.1	.4	9.2	--	11.0	.4	--	22.1
14	--	2.6	.3	4.0	--	6.8	.2	--	13.9
16	--	--	--	.7	--	8.1	.2	--	9.0
18	--	.3	--	--	.1	--	--	--	.4
20	--	.9	--	--	--	2.5	--	--	3.4
22+	--	--	--	--	--	--	--	--	--
Total	2.9	31.0	9.7	31.1	.4	342.0	2.4	--	419.5
				WISCONSIN - NORTHEASTERN					
6	4.1	7.5	3.3	16.8	4.2	131.4	4.8	--	172.1
8	5.3	7.5	2.8	26.6	6.7	165.7	6.9	--	221.5
10	7.1	7.4	1.5	29.1	3.7	111.7	5.4	--	165.9
12	3.1	3.2	.8	16.1	2.9	47.6	4.1	--	77.8
14	2.4	1.4	.4	6.5	2.1	15.9	2.2	--	30.9
16	.5	.4	--	4.2	.5	4.2	.3	--	10.1
18	.2	--	--	2.1	.4	1.5	.4	--	4.6
20	--	--	--	.3	--	.7	--	--	1.0
22+	--	--	--	.6	--	.4	--	--	1.0
Total	22.7	27.4	8.8	102.3	20.5	479.1	24.1	--	684.9
				WISCONSIN - NORTHWESTERN					
6	5.0	5.3	0.8	19.0	8.8	190.3	5.9	--	235.1
8	5.6	4.9	1.1	32.6	15.1	230.2	7.9	0.3	297.7
10	7.7	6.5	.9	35.3	15.3	164.5	8.0	--	238.2
12	2.2	3.4	.6	30.1	10.7	79.3	5.9	.2	132.4
14	1.2	2.1	--	16.5	3.2	28.0	1.2	--	52.2
16	.7	1.1	--	8.3	.8	7.8	.5	--	19.2
18	.2	.2	--	2.1	.4	.5	.2	--	3.6
20	.2	--	--	.4	--	.3	--	--	.9
22+	--	--	--	.2	--	--	--	--	.2
Total	22.8	23.5	3.4	144.5	54.3	700.9	29.6	.5	979.5
				WISCONSIN - CENTRAL					
6	2.3	0.1	0.4	7.5	13.3	84.7	0.7	0.3	109.3
8	1.7	.3	.6	6.6	13.3	67.8	1.1	--	91.4
10	.2	.3	.3	10.9	9.6	37.6	.7	--	59.6
12	.5	--	.9	4.3	7.2	16.3	.8	--	30.0
14	.2	--	--	3.0	2.8	3.0	.1	--	9.1
16	--	--	--	.7	.7	1.7	--	--	3.1
18	--	--	--	--	.7	.4	--	--	1.1
20	--	--	--	--	.2	.2	--	--	.4
22+	--	--	--	--	--	--	--	--	--
Total	4.9	.7	2.2	33.0	47.8	211.7	3.4	.3	304.0

Recent Trends

The assumptions for these conditions are derived from the difference between the last two forest surveys for a particular survey unit and, for variables that are not included in forest survey data, from the recent historical trends. The *recent trends* projections show what the cut and growing stock would be if the trends that prevailed in the last decade or so continued into

Table 2.—Aspen growing stock volume, all cover types, by survey unit, d.b.h., and ownership class, 1968
(Million cubic feet)

REGIONAL TOTAL

D.b.h. class (inches)	National Forest	Indian	Other federal	State	County & municipal	Forest industry[2]	Farmer	Misc. private	Total
6	351.1	54.0	19.1	256.2	490.1	143.5	206.3	739.2	2,259.5
8	338.7	68.0	19.2	205.0	429.9	176.7	271.3	817.7	2,326.5
10	191.5	39.9	13.9	167.4	281.6	146.3	213.4	561.5	1,615.5
12	91.2	19.3	2.5	62.1	106.2	88.2	141.4	255.2	766.1
14	44.5	5.0	.9	38.3	56.4	41.8	56.0	121.6	364.5
16	15.6	1.6	.7	10.0	13.8	15.9	27.0	40.2	124.8
18	4.4	--	--	3.0	3.7	3.7	4.7	9.1	28.5
20	2.5	--	.1	.4	1.2	3.2	1.1	5.0	13.6
22+	.7	--	--	.1	--	.7	.5	2.4	4.4
Total	1,040.2	187.8	56.4	742.5	1,382.9	620.0	921.7	2,551.9	7,503.4
				MICHIGAN - EASTERN UPPER PENINSULA					
6	18.0	--	2.9	3.9	--	25.6	9.7	30.9	91.0
8	13.0	--	.8	9.5	--	28.4	15.8	39.8	107.3
10	9.6	--	2.3	5.9	0.3	12.2	9.4	21.8	61.5
12	7.4	--	--	2.9	--	5.1	8.7	13.1	37.2
14	4.0	--	--	3.5	--	5.1	1.5	8.0	22.1
16	.6	--	--	.6	--	1.6	3.0	2.8	8.6
18	1.1	--	--	.8	--	--	.1	1.0	3.0
20	.7	--	--	--	--	--	--	.9	1.6
22+	--	--	--	--	--	--	--	--	--
Total	54.2	--	6.0	27.1	.3	78.0	48.4	118.3	332.3
				MICHIGAN - WESTERN UPPER PENINSULA					
6	25.7	--	--	20.6	5.0	27.2	17.4	61.2	157.1
8	30.5	--	0.4	22.2	4.6	34.8	23.4	70.7	186.6
10	23.4	--	.9	18.4	3.7	31.7	11.9	52.2	142.2
12	12.8	--	--	9.7	1.9	25.4	6.1	22.1	78.0
14	8.4	--	--	6.6	.4	13.1	4.1	18.4	51.0
16	2.6	--	--	1.9	--	5.3	.8	4.9	15.5
18	.6	--	--	.5	--	1.7	--	.9	3.7
20	.2	--	--	.1	--	--	--	.9	1.2
22+	.3	--	--	.1	--	.5	--	.5	1.4
Total	104.5[1]	--	1.3	80.1[1]	15.6	139.7	63.7	231.8	636.7
				MICHIGAN - NORTHERN LOWER PENINSULA					
6	6.4	--	1.1	9.1	3.9	3.9	37.6	207.5	269.5
8	15.5	--	1.6	7.7	4.7	3.2	45.5	262.2	340.4
10	9.8	--	--	10.1	3.7	2.7	30.8	197.9	255.0
12	6.2	--	.4	8.5	1.7	2.0	26.6	100.0	145.4
14	1.8	--	--	2.8	1.1	.7	17.0	44.3	67.7
16	.7	--	--	--	.4	--	6.9	15.7	23.7
18	.3	--	--	--	--	--	1.1	3.3	4.7
20	1.2	--	--	--	--	--	--	2.3	3.5
22+	--	--	--	--	--	--	--	1.9	1.9
Total	41.9	--	3.1	38.2	15.5	12.5	165.5	835.1	1,111.8
				MINNESOTA - LAKE SUPERIOR					
6	162.4	26.7	--	64.7	121.7	9.8	18.5	130.0	533.8
8	135.7	12.7	--	47.3	88.8	20.7	25.2	94.7	425.1
10	84.6	.7	--	32.2	61.4	22.3	15.5	50.1	266.8
12	42.0	.6	--	13.9	28.3	23.9	4.7	22.4	135.8
14	15.8	--	--	4.9	9.2	6.9	1.6	10.4	48.8
16	8.5	--	--	2.1	3.9	.9	2.5	5.2	23.1
18	.2	--	--	.7	1.2	--	--	--	2.1
20	--	--	--	.1	.3	--	--	--	.4
22+	--	--	--	--	--	--	--	--	--
Total	449.2	40.7	--	165.9	314.8	84.5	68.0	312.8	1,435.9

(Continued on next page)

the future. These projections can serve as a standard for comparison and may indicate whether or not we should change our current practices.

The specific assumptions are discussed in detail in the appendix. The major ones will be discussed in general here under three categories: growth, cut, and acreage.

It is assumed that the growth variables remain constant throughout the projection period: specifically, the growth percent calculated by d.b.h. class and survey unit remains constant, the ingrowth into the 6-inch d.b.h. class (the first d.b.h. class in the computer program) by survey unit remains constant, and the outgrowth from one d.b.h. class into the next d.b.h. class remains constant.

D.b.h. class (inches)	National Forest	Indian	Other federal	State	County & municipal	Forest industry 2/	Farmer	Misc. private	Total
				MINNESOTA - CENTRAL PINE					
6	89.4	10.3	4.3	83.5	161.7	25.5	36.6	114.4	525.7
8	90.6	35.7	9.2	57.9	156.4	24.5	43.8	127.6	545.7
10	16.4	17.2	5.7	50.7	95.8	13.8	54.1	78.5	332.2
12	1.7	5.5	1.0	10.8	18.6	4.5	47.9	17.4	107.4
14	6.5	--	--	12.1	25.7	1.4	12.9	10.0	68.6
16	.1	--	.5	.9	.9	.2	6.0	3.9	12.5
18	2.2	--	--	.5	1.1	--	1.3	.3	5.4
20	.5	--	--	.1	.3	--	--	.4	1.3
22+	--	--	--	--	--	--	--	--	--
Total	207.4	68.7	20.7	216.5	460.5	69.9	202.6	352.5	1,598.8
				MINNESOTA - RAINY RIVER					
6	0.2	4.9	6.4	55.0	56.0	11.6	1.7	30.1	165.9
8	.2	2.3	4.4	35.2	30.6	17.4	2.4	18.2	110.7
10	.1	2.7	3.6	31.7	19.9	23.3	5.2	7.6	94.1
12	--	.4	.9	5.6	3.9	6.8	1.6	2.9	22.1
14	--	--	.5	4.6	.8	4.9	.5	2.6	13.9
16	--	--	.2	2.9	.5	4.7	--	.7	9.0
18	--	--	--	.1	.1	.2	--	--	.4
20	--	--	.1	.1	.1	3.1	--	--	3.4
22+	--	--	--	--	--	--	--	--	--
Total	.5	10.3	16.1	135.2	111.9	72.0	11.4	62.1	419.5
				WISCONSIN - NORTHEASTERN					
6	17.5	0.7	0.5	6.8	42.0	22.2	10.9	71.5	172.1
8	28.2	3.3	.5	9.9	44.8	23.2	18.5	93.1	221.5
10	31.4	2.9	.2	8.6	22.1	23.5	12.7	64.5	165.9
12	11.3	2.8	--	6.2	10.1	11.3	5.0	31.1	77.8
14	5.1	.6	.4	2.5	4.2	5.7	2.6	9.8	30.9
16	.7	.1	--	.5	1.7	1.8	1.7	3.6	10.1
18	--	--	--	--	.2	1.2	1.0	2.2	4.6
20	--	--	--	--	.1	.2	.5	.2	1.0
22+	.5	--	--	--	--	--	.5	--	1.0
Total	94.7	10.4	1.6	34.5	125.2	89.1	53.4	276.0	684.9
				WISCONSIN - NORTHWESTERN					
6	31.5	10.4	--	5.9	59.7	16.7	47.9	63.0	235.1
8	25.0	13.6	--	10.1	73.8	21.5	71.0	82.7	297.7
10	16.0	16.4	0.2	8.4	63.9	14.9	47.4	71.0	238.2
12	9.7	9.9	.1	4.3	36.9	8.9	26.8	35.6	132.4
14	3.0	4.4	--	1.2	13.8	3.4	11.1	15.3	52.2
16	2.5	1.4	--	1.1	6.5	1.4	3.3	3.0	19.2
18	--	--	--	.4	1.1	.6	.4	1.1	3.6
20	--	--	--	--	.3	--	.2	.4	.9
22+	--	--	--	--	--	.2	--	--	.2
Total	87.9	56.2	.3	31.4	255.9	67.6	208.1	272.1	979.5
				WISCONSIN - CENTRAL					
6	--	1.0	3.9	6.6	40.0	1.2	25.9	30.7	109.3
8	--	.5	2.3	5.2	26.2	2.9	25.7	28.6	91.4
10	--	--	1.1	1.4	10.8	1.9	26.5	17.9	59.6
12	--	--	.1	.1	4.9	.4	13.9	10.6	30.0
14	--	--	--	--	1.3	.4	4.6	2.8	9.1
16	--	--	--	--	--	--	2.7	.4	3.1
18	--	--	--	--	--	--	.9	.2	1.1
20	--	--	--	--	--	--	.4	--	.4
22+	--	--	--	--	--	--	--	--	--
Total	--	1.5	7.4	13.3	83.2	6.8	100.6	91.2	304.0

1/ Due to Forest Survey data collection procedures direct estimates of National Forest and State volumes were unavailable by d.b.h. but the sum of the total row of the two was known. This volume was allocated to National Forest and State in the same proportion as it was present in 1966. These totals were then allocated to d.b.h. in the same proportion as volume was present in other d.b.h. classes.

2/ Includes leased land.

Cut is determined as a function of mill pulping capacity.[2] It is assumed that pulping capacity continues to increase at its historical rate during the projection period and that pulpwood remains a constant percent of total aspen cut. Further, it is assumed that cut is at least initially distributed to survey unit and d.b.h. class in its historical proportion and to cover

[2] *Leuschner, William A. An econometric model of the Wisconsin aspen pulpwood market. (Unpublished manuscript.)*

Table 3.—Aspen growing stock volume, all cover types, by survey unit, volume per acre, and cover type, 1968
(Million cubic feet)

REGIONAL TOTAL

Volume per acre (cubic feet)	Red, white, and jack pine	Balsam fir-white spruce	Black spruce, tamarack, and cedar	Northern hardwoods	Oak-hickory	Aspen	Birch	Other	Total
0 - 199	62.9	61.9	35.9	181.8	75.7	487.8	48.4	0.9	955.3
200 - 399	47.1	81.4	34.9	226.9	86.0	703.9	70.1	--	1,250.3
400 - 599	29.7	61.8	6.3	140.7	48.5	879.8	41.6	--	1,208.4
600 - 799	10.3	61.5	9.7	100.0	30.1	878.5	20.0	--	1,110.1
800 - 999	5.3	3.7	1.8	45.2	10.2	860.9	6.5	--	933.6
1,000 - 1,199	1.7	--	4.9	10.8	2.8	652.9	--	--	673.1
1,200 - 1,599	4.5	1.0	4.8	6.3	--	938.8	6.3	--	961.7
1,600 - 1,999	--	--	--	1.3	--	234.1	--	--	235.4
2,000+	--	--	--	12.0	--	163.5	--	--	175.5
Total	161.5	271.3	98.3	725.0	253.3	5,800.2	192.9	.9	7,503.4
MICHIGAN - EASTERN UPPER PENINSULA									
0 - 199	8.0	11.5	6.1	16.3	0.5	24.4	0.8	--	67.6
200 - 399	2.3	3.1	7.8	18.0	--	31.1	5.0	--	67.3
400 - 599	--	4.2	2.5	9.4	--	49.7	--	--	65.8
600 - 799	--	19.6	--	9.3	--	43.6	--	--	72.5
800 - 999	--	--	--	--	--	25.4	--	--	25.4
1,000 - 1,199	--	--	--	--	--	24.8	--	--	24.8
1,200 - 1,599	--	--	--	--	--	8.9	--	--	8.9
1,600 - 1,999	--	--	--	--	--	--	--	--	--
2,000+	--	--	--	--	--	--	--	--	--
Total	10.3	38.4	16.4	53.0	.5	207.9	5.8	--	332.3
MICHIGAN - WESTERN UPPER PENINSULA									
0 - 199	7.3	12.3	4.8	28.9	1.9	30.1	5.7	--	91.0
200 - 399	2.0	24.1	2.9	35.9	1.9	55.8	7.3	--	129.9
400 - 599	3.5	24.1	--	28.2	4.4	80.9	4.0	--	145.1
600 - 799	--	4.2	--	16.2	--	50.0	--	--	70.4
800 - 999	--	--	--	27.7	--	62.2	--	--	89.9
1,000 - 1,199	--	--	--	--	--	69.8	--	--	69.8
1,200 - 1,599	--	--	--	--	--	40.6	--	--	40.6
1,600 - 1,999	--	--	--	--	--	--	--	--	--
2,000+	--	--	--	--	--	--	--	--	--
Total	12.8	64.7	7.7	136.9	8.2	389.4	17.0	--	636.7
MICHIGAN - NORTHERN LOWER PENINSULA									
0 - 199	8.9	7.8	6.7	42.5	24.8	42.7	3.5	--	136.9
200 - 399	1.0	15.0	2.1	54.5	34.0	107.2	13.6	--	227.4
400 - 599	5.1	7.0	2.9	17.1	16.0	141.2	9.5	--	198.8
600 - 799	--	--	9.7	24.0	11.3	159.6	--	--	204.6
800 - 999	--	--	--	--	4.3	108.2	--	--	112.5
1,000 - 1,199	--	--	--	5.5	--	49.7	--	--	55.2
1,200 - 1,599	--	--	--	--	--	98.8	--	--	98.8
1,600 - 1,999	--	--	--	--	--	48.9	--	--	48.9
2,000+	--	--	--	--	--	28.7	--	--	28.7
Total	15.0	29.8	21.4	143.6	90.4	785.0	26.6	--	1,111.8
MINNESOTA - LAKE SUPERIOR									
0 - 199	9.6	8.3	3.2	4.1	0.6	43.8	15.0	--	84.6
200 - 399	12.6	10.8	3.5	8.6	1.1	124.1	13.3	--	174.0
400 - 599	8.0	13.6	--	6.5	--	228.9	4.1	--	261.1
600 - 799	--	1.4	--	2.4	--	172.2	11.5	--	187.5
800 - 999	--	3.7	--	2.1	--	217.8	2.3	--	225.9
1,000 - 1,199	--	--	--	--	--	171.3	--	--	171.3
1,200 - 1,599	--	--	--	2.0		288.3	3.9	--	294.2
1,600 - 1,999	--	--	--	--	--	--	--	--	--
2,000+	--	--	--	--	--	37.3	--	--	37.3
Total	30.2	37.8	6.7	25.6	1.7	1,283.7	50.1	--	1,435.9

(Continued on next page)

type in proportion to the aspen growing stock in that type.

Commercial forest acreage in all types is changed at the same rate as the aspen type acreage changed between forest surveys. This has two effects. First, the trend of the breakup (see below) occurring between surveys is automatically included in the projection, and second, the absolute amount of acreage change levels off as we proceed through time. It is also assumed, throughout the projection period, that 1 acre is added for every 2 acres subtracted when there is a net decrease in commercial forest area. The opposite is assumed for net additions. Finally, it was assumed that the volume lost from the system due to acreage losses is the average volume per acre in that cover type and that acreage coming into the system has no measurable aspen volume on it for 25 years.

Table 3 continued

Volume per acre (cubic feet)	Red, white, and jack pine	Balsam fir-white spruce	Black spruce, tamarack, and cedar	Northern hardwoods	Oak-hickory	Aspen	Birch	Other	Total
				MINNESOTA - CENTRAL PINE					
0 - 199	8.9	3.4	7.9	13.8	9.9	259.3	9.8	--	312.5
200 - 399	12.3	6.7	14.7	15.3	9.0	175.2	9.0	--	242.2
400 - 599	1.5	2.0	--	11.3	3.0	124.1	5.2	--	147.1
600 - 799	7.1	5.9	--	11.7	5.9	148.5	5.6	--	184.7
800 - 999	5.3	--	--	--	1.7	157.4	4.2	--	168.6
1,000 - 1,199	1.7	--	--	2.9	--	138.7	--	--	143.3
1,200 - 1,599	3.1	--	--	--	--	235.5	--	--	238.6
1,600 - 1,999	--	--	--	--	--	95.4	--	--	95.4
2,000+	--	--	--	--	--	66.4	--	--	66.4
Total	39.9	18.0	22.1	55.0	29.5	1,400.5	33.8	--	1,598.8
				MINNESOTA - RAINY RIVER					
0 - 199	1.5	3.7	--	2.9	0.2	7.4	--	--	15.7
200 - 399	--	3.8	--	3.9	.2	28.8	--	--	36.7
400 - 599	--	1.3	--	3.8	--	14.8	--	--	19.9
600 - 799	--	21.2	--	2.9	--	60.4	--	--	84.5
800 - 999	--	--	--	--	--	39.3	--	--	39.3
1,000 - 1,199	--	--	4.9	--	--	49.3	--	--	54.2
1,200 - 1,599	1.4	1.0	4.8	4.3	--	108.0	2.4	--	121.9
1,600 - 1,999	--	--	--	1.3	--	33.6	--	--	34.9
2,000+	--	--	--	12.0	--	.4	--	--	12.4
Total	2.9	31.0	9.7	31.1	.4	342.0	2.4	--	419.5
				WISCONSIN - NORTHEASTERN					
0 - 199	9.1	7.0	5.0	26.9	6.4	25.4	5.0	--	84.8
200 - 399	8.2	9.1	2.9	38.1	7.5	62.8	10.6	--	139.2
400 - 599	5.4	3.4	.9	22.3	5.0	79.7	5.6	--	122.3
600 - 799	--	7.9	--	12.8	1.6	78.7	2.9	--	103.9
800 - 999	--	--	--	2.2	--	82.8	--	--	85.0
1,000 - 1,199	--	--	--	--	--	62.9	--	--	62.9
1,200 - 1,599	--	--	--	--	--	70.2	--	--	70.2
1,600 - 1,999	--	--	--	--	--	11.0	--	--	11.0
2,000+	--	--	--	--	--	5.6	--	--	5.6
Total	22.7	27.4	8.8	102.3	20.5	479.1	24.1	--	684.9
				WISCONSIN - NORTHWESTERN					
0 - 199	6.1	7.2	2.4	37.3	12.7	36.8	6.5	0.5	109.5
200 - 399	7.3	8.8	1.0	39.9	18.5	78.7	9.9	--	164.1
400 - 599	6.2	6.2	--	33.8	11.2	109.2	13.2	--	179.8
600 - 799	3.2	1.3	--	17.9	4.9	133.1	--	--	160.4
800 - 999	--	--	--	13.2	4.2	131.8	--	--	149.2
1,000 - 1,199	--	--	--	2.4	2.8	67.0	--	--	72.2
1,200 - 1,599	--	--	--	--	--	73.9	--	--	73.9
1,600 - 1,999	--	--	--	--	--	45.2	--	--	45.2
2,000+	--	--	--	--	--	25.2	--	--	25.2
Total	22.8	23.5	3.4	144.5	54.3	700.9	29.6	.5	979.5
				WISCONSIN - CENTRAL					
0 - 199	3.5	0.7	0.4	9.2	18.6	17.6	2.0	0.3	52.3
200 - 399	1.4	--	--	12.7	13.9	40.2	1.4	--	69.6
400 - 599	--	--	--	8.3	8.9	51.4	41.6	--	68.6
600 - 799	--	--	--	2.8	6.4	32.5	--	--	41.7
800 - 999	--	--	1.8	--	--	35.9	--	--	37.7
1,000 - 1,199	--	--	--	--	--	19.5	--	--	19.5
1,200 - 1,599	--	--	--	--	--	14.6	--	--	14.6
1,600 - 1,999	--	--	--	--	--	--	--	--	--
2,000+	--	--	--	--	--	--	--	--	--
Total	4.9	.7	2.2	33.0	47.8	211.7	3.4	.3	304.0

Breakup

Aspen stands begin to deteriorate rapidly after the trees pass maturity, a process commonly called "breakup." Overmature trees are increasingly susceptible to their traditional disease and insect enemies; Graham reports a stand can be reduced to a worthless condition in 5 to 10 years (Graham *et al.* 1963, p. 44). As the aspens die they are replaced by more tolerant tree and brush species that usually are present as an understory. The weak aspen suckers cannot compete with this vegetation and most of them die unless a fire or other major disturbance occurs. The two predominant features of stand breakup are

Table 4.—Aspen growing stock volume, all cover types, by survey unit, ownership class, and volume per acre, 1968
(Million cubic feet)

Volume per acre (cubic feet)	National Forest	Indian	Other federal	State	County & municipal	Forest industry	Farmer	Misc. private	Total
REGIONAL TOTAL									
0 - 199	146.2	74.6	11.7	89.4	95.1	74.4	171.7	292.2	955.3
200 - 399	169.7	13.6	9.5	100.7	194.9	97.4	233.5	431.0	1,250.3
400 - 599	161.0	17.8	7.7	94.2	221.1	125.3	133.6	447.7	1,208.4
600 - 799	139.0	19.1	6.1	106.7	239.6	69.7	128.8	401.1	1,110.1
800 - 999	143.9	17.5	4.7	85.2	219.1	63.0	92.4	307.8	933.6
1,000 - 1,199	107.2	12.6	2.1	75.5	154.4	60.4	38.0	222.9	673.1
1,200 - 1,599	146.9	19.1	12.8	133.6	221.8	96.3	49.7	281.5	961.7
1,600 - 1,999	13.2	4.4	1.3	32.8	22.8	2.4	47.0	111.5	235.4
2,000+	13.1	9.1	.5	24.4	14.1	31.1	27.0	56.2	175.5
Total	1,040.2	187.8	56.4	742.5	1,382.9	620.0	921.7	2,551.9	7,503.4
MICHIGAN - EASTERN UPPER PENINSULA									
0 - 199	19.0	--	2.0	3.2	0.3	6.2	15.9	21.0	67.6
200 - 399	15.0	--	4.0	2.6	--	10.3	9.3	26.1	67.3
400 - 599	9.9	--	--	3.8	--	22.1	14.9	15.1	65.8
600 - 799	4.3	--	--	--	--	20.5	8.3	39.4	72.5
800 - 999	6.0	--	--	--	--	12.5	--	6.9	25.4
1,000 - 1,199	--	--	--	8.6	--	6.4	--	9.8	24.8
1,200 - 1,599	--	--	--	8.9	--	--	--	--	8.9
1,600 - 1,999	--	--	--	--	--	--	--	--	--
2,000+	--	--	--	--	--	--	--	--	--
Total	54.2	--	6.0	27.1	.3	78.0	48.4	118.3	332.3
MICHIGAN - WESTERN UPPER PENINSULA									
0 - 199	14.8	--	--	11.3	2.6	18.7	10.0	33.6	91.0
200 - 399	21.4	--	1.3	16.8	2.6	28.1	12.8	46.9	129.9
400 - 599	23.8	--	--	19.9	2.3	36.0	9.7	53.4	145.1
600 - 799	11.5	--	--	8.4	--	20.1	7.5	22.9	70.4
800 - 999	14.8	--	--	10.6	--	14.0	10.4	40.1	89.9
1,000 - 1,199	11.5	--	--	8.3	8.1	15.6	6.0	20.3	69.8
1,200 - 1,599	6.7	--	--	4.8	--	7.2	7.3	14.6	40.6
1,600 - 1,999	--	--	--	--	--	--	--	--	--
2,000+	--	--	--	--	--	--	--	--	--
Total	104.5[1/]	--	1.3	80.1[1/]	15.6	139.7	63.7	231.8	636.7
MICHIGAN - NORTHERN LOWER PENINSULA									
0 - 199	12.4	--	--	3.6	1.8	0.6	23.7	94.8	136.9
200 - 399	16.5	--	--	9.1	1.2	2.9	52.1	145.6	227.4
400 - 599	3.8	--	3.1	8.5	--	9.0	24.2	150.2	198.8
600 - 799	9.2	--	--	2.8	4.1	--	34.2	154.3	204.6
800 - 999	--	--	--	--	--	--	31.3	81.2	112.5
1,000 - 1,199	--	--	--	--	--	--	--	55.2	55.2
1,200 - 1,599	--	--	--	--	8.4	--	--	90.4	98.8
1,600 - 1,999	--	--	--	--	--	--	--	48.9	48.9
2,000+	--	--	--	14.2	--	--	--	14.5	28.7
Total	41.9	--	3.1	38.2	15.5	12.5	165.5	835.1	1,111.8
MINNESOTA - LAKE SUPERIOR									
0 - 199	27.6	2.2	--	9.2	17.3	3.1	5.8	19.4	84.6
200 - 399	54.7	5.1	--	20.7	38.8	7.4	14.5	32.8	174.0
400 - 599	90.6	6.3	--	25.6	48.2	9.0	15.8	65.6	261.1
600 - 799	52.7	6.6	--	26.7	50.2	2.2	10.8	38.3	187.5
800 - 999	72.5	7.0	--	28.8	57.2	9.6	4.1	46.7	225.9
1,000 - 1,199	59.5	4.4	--	17.9	33.7	--	7.9	47.9	171.3
1,200 - 1,599	84.4	9.1	--	37.0	69.4	23.1	9.1	62.1	294.2
1,600 - 1,999	--	--	--	--	--	--	--	--	--
2,000+	7.2	--	--	--	--	30.1	--	--	37.3
Total	449.2	40.7	--	165.9	314.8	84.5	68.0	312.8	1,435.9

(Continued on next page)

that the mortality increases rapidly and that the stands do not reproduce to aspen.

Another cause of incomplete aspen reproduction is the partial harvesting of pure aspen stands. Here the residual stand prevents the reproduction of aspen but not the reproduction of more tolerant species and so the site is converted to some nonaspen type. Although this is not strictly breakup (because part of the stand has been harvested) the net effect, on reproduction at least, is the same.

Foresters are also concerned about the loss of aspen volume in mixed stands where aspen is not the predominant species. Here the existing aspen trees may be cut or die and the remaining species success-

Table 4 continued

Volume per acre (cubic feet)	National Forest	Indian	Other federal	State	County & municipal	Forest industry	Farmer	Misc. private	Total
MINNESOTA - CENTRAL PINE									
0 - 199	42.3	68.7	7.1	44.1	18.6	16.7	61.3	53.7	312.5
200 - 399	27.4	--	--	28.6	51.6	12.7	70.0	51.9	242.2
400 - 599	14.8	--	--	15.5	67.6	9.6	4.1	35.5	147.1
600 - 799	24.4	--	2.8	25.4	67.8	8.2	16.4	39.7	184.7
800 - 999	20.5	--	3.2	21.3	74.3	7.7	--	41.6	168.6
1,000 - 1,199	18.3	--	--	19.1	62.6	5.4	--	37.9	143.3
1,200 - 1,599	40.4	--	7.6	42.2	97.2	6.3	--	44.9	238.6
1,600 - 1,999	13.2	--	--	13.8	11.4	2.4	32.4	22.2	95.4
2,000+	6.1	--	--	6.5	9.4	.9	18.4	25.1	66.4
Total	207.4	68.7	20.7	216.5	460.5	69.9	202.6	352.5	1,598.8
MINNESOTA - RAINY RIVER									
0 - 199	--	0.9	0.5	5.4	2.0	3.5	--	3.4	15.7
200 - 399	--	1.7	1.2	12.0	10.0	2.1	1.1	8.6	36.7
400 - 599	--	1.1	.5	7.4	4.8	1.2	1.7	3.2	19.9
600 - 799	0.1	1.7	3.3	29.8	27.0	1.0	1.7	19.9	84.5
800 - 999	.1	1.1	1.5	12.6	14.7	5.5	--	3.8	39.3
1,000 - 1,199	.1	1.5	2.1	17.0	12.6	16.3	3.6	1.0	54.2
1,200 - 1,599	.2	1.7	5.2	35.6	28.6	42.4	--	8.2	121.9
1,600 - 1,999	--	.4	1.3	11.7	7.5	--	--	14.0	34.9
2,000+	--	.2	.5	3.7	4.7	--	3.3	--	12.4
Total	.5	10.3	16.1	135.2	111.9	72.0	11.4	62.1	419.5
WISCONSIN - NORTHEASTERN									
0 - 199	10.1	0.7	0.1	4.7	17.0	13.8	11.2	27.2	84.8
200 - 399	16.1	1.3	.6	5.0	29.0	19.6	12.3	55.3	139.2
400 - 599	11.7	1.9	.9	4.8	24.8	16.3	8.1	53.8	122.3
600 - 799	12.9	1.5	--	4.7	25.3	8.5	10.1	40.9	103.9
800 - 999	11.0	--	--	7.9	18.7	6.0	9.4	32.0	85.0
1,000 - 1,199	17.7	2.2	--	4.6	7.5	7.6	2.3	21.0	62.9
1,200 - 1,599	15.2	2.8	--	2.8	2.9	17.3	--	29.2	70.2
1,600 - 1,999	--	--	--	--	--	--	--	11.0	11.0
2,000+	--	--	--	--	--	--	--	5.6	5.6
Total	94.7	10.4	1.6	34.5	125.2	89.1	53.4	276.0	684.9
WISCONSIN - NORTHWESTERN									
0 - 199	19.9	2.0	0.3	3.5	24.7	10.7	22.2	26.2	109.5
200 - 399	18.8	5.5	--	3.1	42.2	12.5	35.1	46.9	164.1
400 - 599	6.3	8.6	--	6.6	48.2	22.2	33.3	54.6	179.8
600 - 799	23.9	7.9	--	4.5	52.5	7.6	28.7	35.3	160.4
800 - 999	19.0	9.4	--	4.0	46.9	5.5	27.9	36.5	149.2
1,000 - 1,199	--	4.5	--	--	25.2	9.1	13.5	19.9	72.2
1,200 - 1,599	--	5.4	--	2.4	12.2	--	27.6	26.3	73.9
1,600 - 1,999	--	4.0	--	7.3	4.0	--	14.5	15.4	45.2
2,000+	--	8.9	--	--	--	--	5.3	11.0	25.2
Total	87.9	56.2	.3	31.4	255.9	67.6	208.1	272.1	979.5
WISCONSIN - CENTRAL									
0 - 199	--	--	1.6	4.3	10.8	1.2	21.6	12.8	52.3
200 - 399	--	--	2.4	2.8	19.4	1.8	26.3	16.9	69.6
400 - 599	--	--	3.4	1.9	25.1	--	21.9	16.3	68.6
600 - 799	--	1.5	--	4.3	12.7	1.6	11.1	10.5	41.7
800 - 999	--	--	--	--	7.3	2.2	9.2	19.0	37.7
1,000 - 1,199	--	--	--	--	4.8	--	4.8	9.9	19.5
1,200 - 1,599	--	--	--	--	3.1	--	5.7	5.8	14.6
1,600 - 1,999	--	--	--	--	--	--	--	--	--
2,000+	--	--	--	--	--	--	--	--	--
Total	--	1.5	7.4	13.3	83.2	6.8	100.6	91.2	304.0

1/ Due to Forest Survey data collection procedures direct estimates of National Forest and State volumes were unavailable by volume per acre but the sum of the total row of the two was known. This volume was allocated to National Forest and State in the same proportion as it was presented in 1966. These totals were then allocated to volume per acre in the same proportion as volume was present in other volume per acre classes.

fully compete and stop aspen reproduction. Again we have the same two predominant features, rapid decrease in aspen volume and no aspen reproduction.

Most foresters agree these processes are occurring, although there is a difference of opinion about the actual amount and the rate of spread. Unfortun-

Table 5.—Aspen growing stock volume, aspen type only, by survey unit, age class, and site index, 1966
(Million cubic feet)[1]

Age (years)	Site 0 - 39	40 - 49	50 - 59	60 - 69	70 - 79	80 - 89	90+	Total
MICHIGAN - EASTERN UPPER PENINSULA								
0 - 9	--	2.3	2.0	--	0.6	--	--	4.9
10 - 19	--	4.7	.6	0.4	--	--	--	5.7
20 - 29	6.7	1.4	15.6	4.7	--	--	--	28.4
30 - 39	3.3	12.9	40.1	4.4	--	--	--	60.7
40 - 49	6.4	14.0	33.2	4.3	--	--	--	57.9
50+	5.4	28.4	16.7	6.7	--	--	--	57.2
Total	21.8	63.7	108.2	20.5	.6	--	--	214.8
MICHIGAN - WESTERN UPPER PENINSULA								
0 - 9	--	2.8	4.0	4.1	--	--	--	10.9
10 - 19	--	2.0	7.7	8.6	--	--	--	18.3
20 - 29	2.6	15.9	12.8	15.3	2.9	--	--	49.5
30 - 39	20.6	31.9	43.6	51.8	20.5	--	--	168.4
40 - 49	1.8	28.5	30.1	5.2	11.4	--	--	77.0
50+	1.0	25.7	34.2	5.2	1.7	--	--	67.8
Total	26.0	106.8	132.4	90.2	36.5	--	--	391.9
MICHIGAN - NORTHERN LOWER PENINSULA								
0 - 9	6.5	8.3	16.7	6.5	0.6	--	--	38.6
10 - 19	.2	3.5	4.5	.9	4.2	--	--	13.3
20 - 29	1.8	5.3	15.5	44.4	36.2	2.7	--	105.9
30 - 39	4.5	30.5	72.1	125.5	52.5	10.2	--	295.3
40 - 49	5.2	30.2	48.4	69.9	40.9	--	--	194.6
50+	--	47.4	43.8	48.7	6.1	1.6	--	147.6
Total	18.2	125.2	201.0	295.9	140.5	14.5	--	795.3
MINNESOTA - LAKE SUPERIOR								
0 - 9	0.1	1.7	0.2	2.5	--	--	--	4.5
10 - 19	2.0	8.2	21.7	21.5	14.5	--	--	67.9
20 - 29	6.5	82.6	114.6	78.5	36.2	--	--	318.4
30 - 39	12.8	71.1	168.9	66.1	1.0	--	--	319.9
40 - 49	8.3	19.2	85.1	18.0	20.6	--	--	151.2
50+	1.4	19.7	47.3	3.7	--	--	--	72.1
Total	31.1	202.5	437.8	190.3	72.3	--	--	934.0
MINNESOTA - CENTRAL PINE								
0 - 9	0.5	2.6	3.4	1.3	--	1.2	--	9.0
10 - 19	3.5	10.8	14.7	40.7	17.2	.2	--	87.1
20 - 29	4.0	50.3	165.3	189.1	82.1	4.3	--	495.1
30 - 39	3.3	47.8	170.7	111.8	36.1	--	--	369.7
40 - 49	--	24.3	33.4	84.7	4.3	--	--	146.7
50+	1.0	2.5	1.5	15.7	--	--	--	20.7
Total	12.3	138.3	389.0	443.3	139.7	5.7	--	1,128.3
MINNESOTA - RAINY RIVER								
0 - 9	--	3.6	2.4	2.6	--	1.5	--	10.1
10 - 19	2.5	1.5	2.7	12.5	2.1	.3	--	21.6
20 - 29	.5	3.9	41.0	22.6	34.9	--	--	102.9
30 - 39	--	2.5	57.5	19.8	--	31.5	--	111.3
40 - 49	.2	--	2.2	--	--	--	--	2.4
50+	--	--	14.4	7.2	--	--	--	21.6
Total	3.2	11.5	120.2	64.7	37.0	33.3	--	269.9

(Continued on next page)

ately, field data to answer these questions are not readily available. The *breakup* assumption simulates widespread breakup occurring immediately and projects a minimum or worst likely condition.

The *breakup* computer program is exactly the same as the *recent trends* program with two exceptions. First, all uncut volume in the 12-inch and larger d.b.h. classes is moved into the next larger d.b.h. class at each repetition of the program. Because each repetition of the program represents 1 year in this analysis and because there are six d.b.h. classes 12 inches and larger, the volume in the 12-inch class in a particular year that is not cut in the next 6 years will be removed from ("grown" out of) the growing stock projections. Similarly, in a particular year the volume in the 14-inch class has 5 years to be cut before it is grown through the remaining d.b.h. classes and removed, that in the 16-inch class has 4 years, and so on.

The second exception is that the ingrowth into the 6-inch d.b.h. class is set at zero beginning in the 25th year of the projections. This is done to account for the

Table 5 continued

Age (years)	Site 0 - 39	40 - 49	50 - 59	60 - 69	70 - 79	80 - 89	90+	Total
				WISCONSIN - NORTHEASTERN				
0 - 9	3.5	0.3	3.9	5.4	2.8	0.9	--	16.8
10 - 19	.3	2.0	4.1	6.1	10.1	2.8	--	25.4
20 - 29	7.9	1.7	4.6	11.8	10.8	10.8	--	47.6
30 - 39	44.8	2.5	18.9	45.6	49.2	15.8	3.4	180.2
40 - 49	7.0	10.2	26.6	59.8	53.0	7.1	--	163.7
50+	.3	2.2	8.2	16.0	18.7	--	--	45.4
Total	63.8	18.9	66.3	144.7	144.6	37.4	3.4	479.1
				WISCONSIN - NORTHWESTERN				
0 - 9	0.2	3.2	8.2	10.2	5.6	2.0	0.3	29.7
10 - 19	.8	3.6	5.9	9.3	11.3	2.9	1.3	35.1
20 - 29	--	1.3	1.7	14.3	29.6	12.4	9.5	68.8
30 - 39	--	6.0	33.8	101.6	118.8	44.9	4.6	309.7
40 - 49	--	2.0	29.7	79.4	74.9	10.2	--	196.2
50+	--	1.6	14.0	32.5	11.7	--	--	59.8
Total	1.0	17.7	93.3	247.3	251.9	72.4	15.7	699.3
				WISCONSIN - CENTRAL				
0 - 9	--	0.7	1.9	1.6	2.1	1.2	--	7.5
10 - 19	--	1.4	3.4	7.5	4.3	2.1	0.3	19.0
20 - 29	0.2	1.0	6.0	9.8	5.6	4.0	5.3	31.9
30 - 39	--	4.8	23.7	30.8	30.7	15.3	--	105.3
40 - 49	--	1.4	6.4	14.5	15.6	4.4	--	42.3
50+	--	3.6	1.3	.8	--	--	--	5.7
Total	.2	12.9	42.7	65.0	58.3	27.0	5.6	211.7

1/ Volume by age and site could not be updated because of the manner in which the data was stored. The volumes in this table are as of the survey year in each state and it is impossible to add them to a regional total.

lack of aspen reproduction. The 25th year was chosen because it seemed a fair average of the length of time it takes aspen reproduction to reach 6 inches d.b.h. Reproduction was not set equal to zero immediately because the conditions in force 25 years ago determine it and these are reflected, in part, in the *recent trends* projection.

Positive Practices

It was mentioned earlier that land managers can affect future inventory and cut. Actions we can take today can positively affect the aspen growing stock of tomorrow. The *positive practices* assumptions indicate what these practices could accomplish if they were instituted today—they are NOT a prescription for what should be done to increase the volume of the aspen resource in the Lake States.

Two problems in current practices are readily identifiable. First, some areas are being heavily cut for aspen, chiefly because of their proximity to pulpmills, which means low transportation costs. If the positive effects were thought worthwhile, cut could be shifted to other areas where greater volumes of aspen growing stock exist.

The second problem is that many stands do not reproduce to aspen. This may be due to breakup, partial cut of pure aspen stands, or the reduction of aspen volume in nonaspen cover types. One cultural practice to increase reproduction might be to remove all trees when cutting.

The *positive practices* assumptions simulate what would happen if such practices were begun immediately. The assumptions are the same as for the *recent trends* with two exceptions. First, cut is now allocated to a particular type, d.b.h. class, and survey unit in proportion to the amount of *aspen* growing stock in that category. For example, if the 6-inch d.b.h. class of the white, red, and jack pine types in the Northeast Survey Unit has 0.15 percent of the total aspen growing stock in the five survey units, it is allocated 0.15 percent of the total cut.

The second assumption is that ingrowth into the 6-inch d.b.h. class will be double that in *recent trends* beginning in the 25th year of the projection. The logic

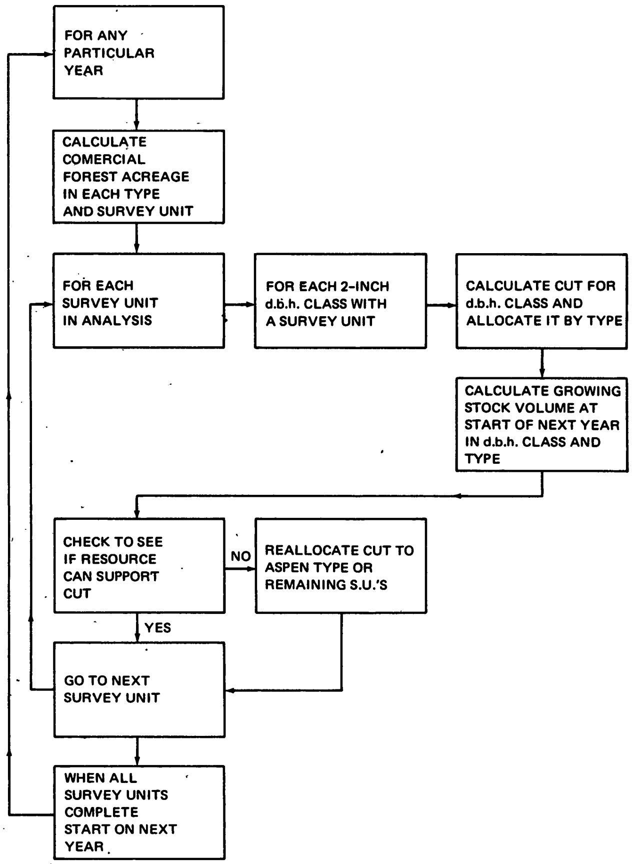

Figure 2.— Outline of computer program for projecting aspen cut and inventory.

for choosing the 25th year is the same as in the *breakup* conditions. The actual amount of reproduction would depend in part on how large a cost we were willing to incur. Although there is no way to predict this, doubling ingrowth did not seem unreasonable.

REGIONAL PROJECTIONS

Goods and services, including harvested aspen, flow within and sometimes between economic regions. These regions are not precisely defined nor are there firm rules for doing so. In the case of harvested aspen, past history and the existing transportation network help define regions. Data availability and the range within which the species grow give a further, pragmatic, definition to the regions.

The Wisconsin-Upper Peninsula region includes the northern three survey units in Wisconsin and the two units in Michigan's Upper Peninsula (U.P.) (fig. 1). Only a small amount of the aspen pulpwood cut in Wisconsin is exported but a large proportion of the aspen cut in the U.P. is shipped into Wisconsin. Further, the large proportion of the U.P. aspen cut in the Eastern Survey Unit makes it likely that the supply in that Unit affects demand in the Western Unit.

The second region includes only one survey unit, Michigan's Northern Lower Peninsula. Roughly half of the aspen pulpwood cut in Michigan is cut on the Lower Peninsula and virtually all of that in the Northern Unit. Bridge tolls have kept significant amounts of aspen from crossing the Straits of Mackinac in the past and make it unlikely that much will in the future under present conditions.

The Minnesota region is made up of the three northernmost survey units. Over 90 percent of the aspen pulpwood harvested in Minnesota the last several years has been used within the State. Further, the aspen stands are distant—usually a multiline rail haul—from the nearest mills in Wisconsin. There were also data considerations, discussed below, that made it logical to analyze Minnesota separately.

These three regions were projected separately. This meant that the survey units within any one region could have unsupported cut allocated to each other but not to survey units in other regions (see discussion of the Projection Model). The results of the projections will be discussed by these regions (tables 6 and 7).

Wisconsin-Upper Peninsula

Five survey units were allowed to *interact* for this set of projections (fig. 3).

Recent Trends

The *recent trends* projections show that in about 15 to 20 years the Northeast Survey Unit will not be able to support its historical trend of cut and that 8 to 10 years after that the two U.P. units will not be able to support the cut allocated to them. This cut consists of their historical trends plus the additional cut allo-

Table 6.— Projected aspen cut and growing stock, all cover types, by survey unit, year, and assumption, 5-year average

Survey unit and year	Recent Trends		Breakup		Positive Practices	
	Cut	Growing stock	Cut	Growing stock	Cut	Growing stock
	Million cubic feet	Billion cubic feet	Million cubic feet	Billion cubic feet	Million cubic feet	Billion cubic feet
MICHIGAN:						
Eastern Upper Peninsula						
1970	15.2	0.35	15.2	0.34	12.8	0.35
1975	17.4	.37	17.4	.33	15.3	.38
1980	19.5	.38	19.5	.33	17.4	.39
1985	21.6	.37	22.6	.33	19.0	.38
1990	26.9	.34	31.7	.28	20.1	.35
1995	29.5	.27	28.1	.22	20.7	.32
2000	24.6	.24	28.6	.19	20.5	.30
Western Upper Peninsula						
1970	22.9	.63	22.9	.62	22.7	.62
1975	26.1	.59	26.1	.46	23.6	.59
1980	29.3	.53	29.3	.38	24.3	.55
1985	32.5	.46	33.8	.29	24.6	.49
1990	40.3	.35	35.9	.16	24.7	.43
1995	41.5	.26	23.5	.11	24.3	.37
2000	27.7	.14	16.8	.10	23.4	.34
Northern Lower Peninsula						
1970	38.1	1.08	38.1	1.08	38.1	1.08
1975	43.4	1.00	43.4	.80	43.4	.99
1980	48.8	.88	48.8	.65	48.8	.86
1985	54.1	.73	54.1	.49	54.1	.69
1990	59.5	.55	59.5	.29	59.5	.49
1995	64.8	.33	26.6	.14	64.8	.27
2000	57.3	.20	17.7	.12	26.5	.09
MINNESOTA:						
Lake Superior						
1970	23.8	1.52	23.8	1.51	28.3	1.51
1975	28.5	1.74	28.5	1.51	34.0	1.70
1980	33.1	1.97	33.1	1.59	39.7	1.88
1985	37.7	2.22	37.7	1.67	45.4	2.05
1990	42.3	2.47	42.3	1.72	51.1	2.21
1995	47.0	2.74	47.0	1.73	56.6	2.35
2000	51.6	3.00	51.6	1.68	60.9	2.51
Central Pine						
1970	30.6	1.67	30.6	1.67	31.4	1.67
1975	36.6	1.86	36.6	1.67	37.0	1.85
1980	42.5	2.04	42.5	1.70	42.4	2.01
1985	48.5	2.19	48.5	1.71	47.5	2.14
1990	54.4	2.33	54.4	1.66	52.1	2.25
1995	60.4	2.42	60.4	1.56	55.9	2.33
2000	66.3	2.47	66.3	1.41	57.7	2.38
Rainy River						
1970	13.6	.43	13.6	.43	8.4	.45
1975	16.3	.47	16.3	.43	10.3	.51
1980	18.9	.51	18.9	.45	12.4	.59
1985	21.6	.56	21.6	.48	14.9	.67
1990	24.2	.63	24.2	.53	17.7	.76
1995	26.8	.71	26.8	.56	21.7	.90
2000	29.5	.85	29.5	.53	28.8	1.19
WISCONSIN:						
Northeastern						
1970	41.4	.67	41.4	.67	25.5	.70
1975	48.5	.61	48.5	.51	29.0	.73
1980	55.7	.50	55.7	.38	32.6	.73
1985	62.8	.34	58.6	.23	35.8	.72
1990	55.5	.26	44.4	.22	38.7	.68
1995	52.2	.28	63.7	.24	40.9	.63
2000	66.5	.32	66.1	.24	41.6	.61
Northwestern						
1970	25.2	1.03	25.2	1.02	36.7	1.01
1975	29.5	1.15	29.5	.97	42.4	1.06
1980	33.9	1.26	33.9	1.03	48.1	1.08
1985	38.2	1.36	39.9	1.10	53.5	1.07
1990	48.1	1.41	56.9	1.16	58.7	1.02
1995	59.6	1.47	63.3	1.08	63.8	.99
2000	68.9	1.45	76.0	.86	68.7	1.00
Central						
1970	5.4	.35	5.4	.35	12.4	.34
1975	6.3	.50	6.3	.45	17.4	.43
1980	7.3	.68	7.3	.60	23.3	.52
1985	8.2	.90	8.5	.80	30.5	.61
1990	10.3	1.13	12.2	1.03	38.9	.68
1995	12.8	1.53	13.6	1.25	49.3	.76
2000	14.8	1.97	16.3	1.40	62.5	.91

cated to them to make up for the diminished cut in the Northeast Unit.

The projections also show that nearly all the cut coming from these three survey units after the cut is diminished will be from the 6- and 8-inch d.b.h. classes. By 1998 about 30 percent of the cut in the Northwest and Central Units and nearly all the cut in the remaining units will be from the 6- and 8-inch classes. If the forest industry will take this small diameter

Table 7.—Recent trends *projections of aspen growing stock, by survey unit, year, d.b.h., and cover type*
(Million cubic feet)[1]

MICHIGAN - EASTERN UPPER PENINSULA

Year and d.b.h. class	Red, white, and jack pine	Balsam fir-white spruce	Black spruce tamarack, and cedar	Northern hardwoods	Oak-hickory	Aspen	Birch, nonstocked and other	Total
1978								
6	17.1	18.4	27.6	50.0	0.6	120.5	4.9	239.1
8	4.8	9.1	7.6	15.5	.2	49.4	1.5	88.1
10	1.1	3.0	1.9	4.3	.1	15.6	.5	26.5
12	.5	1.2	.9	1.8	--	2.8	.2	7.5
14	.2	.8	.8	1.9	--	4.4	.1	8.2
16+	.1	.5	1.7	2.7	--	3.0	.2	8.2
Total	23.8	33.1	40.4	76.2	.9	195.7	7.4	377.5
1988								
6	20.7	19.7	35.8	64.0	.8	110.3	6.0	257.4
8	7.0	7.7	11.9	21.6	.3	7.0	2.2	57.7
10	2.9	3.7	5.0	8.5	.1	--	.9	21.2
12	1.1	1.7	2.1	3.3	--	--	.4	8.7
14	.4	.8	.9	1.4	--	--	.2	3.7
16+	.2	.6	1.4	1.7	--	--	.2	4.1
Total	32.4	34.1	57.2	100.6	1.3	117.4	9.8	352.8
1998								
6	19.5	17.6	34.6	61.6	.8	29.0	5.8	169.0
8	4.8	4.4	10.6	14.9	.2	2.5	1.9	39.3
10	3.2	2.7	5.7	9.8	.1	.1	1.1	22.9
12	1.9	1.9	3.4	5.8	.1	--	.6	13.8
14	1.0	1.0	1.8	2.9	--	--	.3	7.1
16+	.6	1.0	1.8	2.5	--	--	.3	6.2
Total	31.1	28.7	57.9	97.6	1.2	31.6	10.1	258.2
MICHIGAN - WESTERN UPPER PENINSULA								
1978								
6	2.7	14.0	2.4	22.6	2.9	115.0	4.3	163.7
8	2.4	12.2	1.4	22.7	2.4	90.4	2.5	134.1
10	2.0	8.6	.5	20.4	1.3	63.0	2.3	98.2
12	1.6	7.0	.3	16.0	.6	38.2	2.2	66.0
14	1.3	6.9	1.1	14.6	.5	28.6	2.0	54.8
16+	.7	5.4	1.6	12.1	.4	20.8	1.1	42.2
Total	10.7	54.0	7.3	108.3	8.1	356.1	14.5	559.1
1988								
6	2.6	12.7	2.6	22.3	2.6	117.7	4.0	164.4
8	1.7	8.3	1.3	14.7	1.7	67.8	2.2	97.7
10	.7	3.6	.6	7.0	.7	27.2	.9	40.7
12	.5	1.8	.3	3.8	.3	11.7	.5	18.8
14	.8	3.6	.4	7.9	.3	18.3	1.1	32.5
16+	1.1	6.0	1.4	13.1	.5	25.6	1.7	49.4
Total	7.4	36.0	6.5	68.8	6.1	268.2	10.4	403.5
1998								
6	2.3	10.3	2.4	19.7	2.1	19.0	3.3	59.2
8	1.2	5.6	1.4	10.2	1.1	.9	1.7	22.2
10	1.0	4.1	.9	7.5	.8	--	1.2	15.5
12	.8	2.9	.6	5.6	.5	--	.8	11.2
14	.5	2.1	.4	4.3	.3	--	.6	8.2
16+	.9	2.9	1.0	6.2	.3	--	.9	12.2
Total	6.6	28.0	6.7	53.6	5.2	20.0	8.5	128.6
MICHIGAN - NORTHERN LOWER PENINSULA								
1978								
6	6.5	9.7	2.8	22.7	23.0	191.8	6.7	263.4
8	3.8	6.8	3.2	22.5	19.8	172.8	6.9	235.6
10	2.1	3.9	2.5	18.6	15.2	125.9	4.5	172.8
12	1.4	2.6	2.1	17.2	10.3	84.9	2.6	121.3
14	.9	1.8	2.1	14.1	6.0	52.7	1.4	79.0
16+	.7	2.0	2.8	12.7	3.3	35.6	1.2	58.2
Total	15.4	26.8	15.5	107.8	77.6	663.7	23.3	930.3
1988								
6	6.6	8.0	2.9	21.1	20.2	183.4	6.1	248.2
8	3.5	5.2	2.0	14.6	13.7	118.3	4.4	161.7
10	1.2	2.0	.9	6.8	6.0	50.5	2.0	69.5
12	.6	1.0	.6	4.7	3.6	29.1	1.1	40.6
14	.5	1.0	.8	5.9	3.4	28.4	.9	40.9
16+	.9	2.0	2.1	11.9	4.6	41.2	1.2	63.9
Total	13.3	19.2	9.3	65.0	51.5	450.8	15.7	624.8
1998								
6	6.2	6.0	2.7	18.2	16.5	46.7	5.1	101.4
8	2.9	3.4	.5	9.6	8.9	2.7	3.0	31.1
10	1.7	2.8	.6	6.8	6.3	.1	2.1	20.2
12	.9	1.9	.3	4.6	4.1	--	1.3	13.2
14	.5	1.1	.2	3.1	2.3	--	.7	7.9
16+	.4	1.6	.7	7.0	3.2	--	.9	13.8
Total	12.7	16.9	4.9	49.3	41.3	49.5	13.1	187.6

(Continued on next page)

Table 7 continued

Year and d.b.h. class	Red, white, and jack pine	Balsam fir-white spruce	Black spruce tamarack, and cedar	Northern hardwoods	Oak-hickory	Aspen	Birch, nonstocked and other	Total
MINNESOTA - LAKE SUPERIOR								
1978								
6	14.0	20.3	2.7	10.7	0.1	418.7	28.4	494.8
8	13.8	16.8	1.6	9.9	1.0	458.9	19.4	521.4
10	8.3	10.8	2.1	8.1	.7	349.8	14.9	394.7
12	3.6	5.8	2.2	5.1	.3	222.1	9.8	248.8
14	3.3	2.7	1.4	2.8	.1	124.3	4.9	139.6
16+	3.0	2.6	.6	1.3	--	69.8	2.2	79.6
Total	46.0	59.0	10.6	37.9	2.2	1,643.6	79.6	1,878.9
1988								
6	19.6	28.2	5.6	15.3	.1	361.0	39.6	469.3
8	16.7	22.2	3.1	12.4	.7	471.1	28.7	554.7
10	12.4	16.0	2.2	10.0	.8	427.1	20.5	489.0
12	7.6	10.5	2.2	7.5	.6	327.1	14.5	370.1
14	5.2	6.5	2.1	5.4	.3	234.0	9.9	263.4
16+	5.7	5.3	1.9	4.3	.2	199.4	7.9	224.8
Total	67.2	88.7	17.1	54.9	2.7	2,019.7	121.1	2,371.3
1998								
6	26.4	37.7	9.2	20.8	.2	310.4	53.4	458.1
8	21.0	29.0	5.4	16.1	.5	439.8	39.8	551.6
10	16.1	21.5	3.4	12.5	.7	449.8	28.6	532.5
12	11.9	15.7	2.6	9.9	.7	403.9	21.0	465.6
14	8.9	11.5	2.5	8.2	.6	349.7	16.1	397.4
16+	10.8	12.6	3.6	9.7	.5	434.3	18.4	490.3
Total	95.1	128.0	26.7	77.2	3.2	2,387.9	177.3	2,895.5
MINNESOTA - CENTRAL PINE								
1978								
6	19.0	9.2	2.1	11.8	7.0	362.2	9.2	420.5
8	16.7	6.9	1.4	10.7	10.5	534.9	10.4	591.5
10	11.8	4.9	4.5	11.1	10.8	443.2	11.2	497.5
12	5.7	2.3	3.1	8.7	6.2	231.3	7.0	264.3
14	2.6	1.0	4.3	10.0	2.7	105.6	3.6	129.9
16+	1.2	.4	4.7	7.9	1.0	45.8	2.0	63.3
Total	56.9	24.8	20.2	60.3	38.2	1,723.1	43.4	1,967.0
1988								
6	18.7	9.1	3.3	13.1	7.2	274.4	10.6	336.4
8	19.7	8.8	2.2	12.9	10.0	487.1	11.5	552.3
10	16.3	7.0	3.3	12.3	11.2	512.8	11.9	574.8
12	10.0	4.2	3.2	9.6	8.3	353.0	8.9	397.2
14	5.6	2.3	3.5	9.0	5.4	214.1	6.1	245.9
16+	3.6	1.3	5.6	11.3	3.7	142.1	4.7	172.7
Total	74.0	32.7	21.1	68.2	45.8	1,983.7	53.8	2,279.3
1998								
6	17.5	8.5	4.2	13.7	7.0	204.6	11.7	267.2
8	20.0	9.3	3.1	13.8	9.2	392.8	12.5	460.6
10	18.8	8.4	3.0	13.3	10.6	485.7	12.6	552.5
12	13.5	5.8	2.8	10.5	9.0	404.9	10.1	456.7
14	9.3	3.9	3.1	9.4	7.3	311.7	8.1	352.8
16+	8.6	3.5	6.4	15.7	7.8	317.8	9.2	369.0
Total	87.8	39.4	22.7	76.4	51.0	2,117.5	64.1	2,458.8
MINNESOTA - RAINY RIVER								
1978								
6	4.4	29.5	14.5	10.2	0.4	114.4	1.8	175.2
8	1.9	12.6	5.7	4.5	.2	113.2	.9	139.0
10	.7	6.9	2.3	5.5	.1	82.4	.6	98.4
12	.2	3.3	.9	5.2	--	39.4	.4	49.3
14	--	2.0	.4	4.4	--	16.4	.2	23.5
16+	--	1.0	.2	2.7	.1	7.3	.2	11.8
Total	7.3	55.3	23.9	32.6	.7	373.2	4.1	497.2
1988								
6	9.0	59.4	31.5	21.2	.7	94.1	4.9	220.8
8	4.0	26.5	13.3	9.4	.3	105.9	2.1	161.5
10	1.6	11.4	5.2	5.0	.1	77.7	1.0	102.0
12	.6	4.9	1.9	3.5	.1	45.3	.4	56.7
14	.2	2.8	.8	3.6	--	28.2	.3	36.0
16+	.1	1.7	.6	2.8	--	14.4	.4	19.9
Total	15.5	106.7	53.2	45.5	1.3	365.6	9.1	597.0
1998								
6	18.3	119.8	65.7	43.3	1.4	78.7	11.5	338.8
8	8.2	53.5	28.5	19.2	.6	92.6	5.3	208.0
10	3.2	21.2	10.8	7.8	.3	65.3	2.4	111.0
12	1.1	7.9	3.8	3.3	.1	37.4	1.0	54.7
14	.5	4.2	1.8	2.8	.1	30.3	.5	40.2
16+	.3	2.8	1.1	3.1	--	23.2	.4	30.9
Total	31.6	209.4	111.7	79.6	2.5	327.6	21.1	783.6

(Continued on next page)

Table 7 continued

Year and d.b.h. class	Red, white, and jack pine	Balsam fir-white spruce	Black spruce tamarack, and cedar	Northern hardwoods	Oak-hickory	Aspen	Birch, nonstocked and other	Total
				WISCONSIN - NORTHEASTERN				
1978								
6	7.8	10.6	7.7	33.6	6.4	178.2	6.9	251.3
8	4.1	6.0	3.2	19.0	4.3	111.4	4.6	152.7
10	2.5	3.3	1.2	11.4	2.2	55.6	2.6	78.8
12	1.2	1.4	.7	5.5	1.0	20.8	1.2	31.9
14	1.1	1.0	.3	4.7	.9	13.6	1.1	22.8
16+	1.2	.6	.3	4.6	.8	2.5	.9	11.0
Total	18.0	23.0	13.5	78.7	15.7	382.2	17.4	548.5
1988								
6	10.2	12.6	10.8	45.3	7.9	33.0	8.5	128.4
8	4.7	4.7	5.1	16.0	3.0	1.8	3.5	38.8
10	2.8	3.0	2.7	10.0	2.1	--	2.4	23.0
12	2.0	2.2	1.5	6.6	1.5	--	1.8	15.5
14	1.2	1.3	.8	4.0	.9	--	1.1	9.4
16+	1.8	1.3	.7	6.6	1.3	--	1.5	13.2
Total	22.7	25.1	21.6	88.6	16.7	34.8	18.8	228.3
1998								
6	10.2	11.8	11.0	45.5	7.6	61.8	8.5	156.3
8	7.6	4.0	8.3	13.3	5.5	5.5	6.1	50.2
10	5.0	3.9	5.2	13.1	3.5	.4	4.0	35.2
12	3.3	3.2	3.1	10.4	2.4	--	2.6	25.1
14	2.1	2.3	1.8	7.2	1.6	--	1.8	16.8
16+	3.0	2.7	1.7	10.3	2.1	--	2.8	22.3
Total	31.2	27.8	31.1	99.8	22.7	67.6	25.8	306.0
				WISCONSIN - NORTHWESTERN				
1978								
6	15.7	12.4	7.0	61.1	19.5	325.5	14.9	456.1
8	7.1	6.0	2.3	32.0	12.6	212.2	8.2	280.4
10	5.1	4.4	1.0	24.7	10.7	147.2	6.1	199.2
12	3.5	3.4	.6	21.7	8.9	95.6	4.9	138.5
14	2.1	2.5	.3	18.5	6.3	57.3	3.3	90.4
16+	1.5	1.9	.1	15.1	3.6	30.0	1.8	54.1
Total	34.9	30.7	11.3	173.1	61.6	867.9	39.3	1,218.7
1988								
6	25.9	19.3	12.8	101.3	29.8	391.2	23.6	604.0
8	11.9	9.3	5.3	48.2	15.7	240.0	12.0	342.3
10	5.4	4.4	1.9	23.2	8.6	131.9	6.1	181.4
12	2.9	2.5	.7	14.4	5.8	78.4	3.7	108.4
14	2.2	2.3	.4	14.2	5.5	61.3	3.1	89.0
16+	2.3	2.4	.4	17.0	5.6	53.5	3.0	84.1
Total	50.6	40.1	21.5	218.4	71.0	956.2	51.5	1,409.3
1998								
6	35.4	25.7	18.2	138.6	39.3	413.1	32.0	702.4
8	17.3	12.9	8.5	68.3	20.3	256.8	16.9	401.1
10	6.5	5.0	3.0	26.0	8.2	113.8	7.5	170.0
12	2.0	1.6	1.0	8.5	2.9	41.5	3.0	60.7
14	1.5	1.3	.5	7.7	2.9	37.6	2.2	53.8
16+	2.0	2.0	.4	12.8	4.7	49.1	2.9	73.9
Total	64.8	48.4	31.6	262.1	78.4	911.9	64.6	1,461.8
				WISCONSIN - CENTRAL				
1978								
6	13.7	0.5	2.3	27.4	42.9	179.0	7.2	273.1
8	4.8	.3	1.0	12.0	20.8	103.5	2.6	145.0
10	1.6	.3	.5	9.3	12.8	60.8	1.2	86.5
12	.7	.2	.5	7.0	8.9	33.7	.8	51.7
14	.4	--	.4	4.8	5.9	16.4	.5	28.4
16+	.2	--	.2	3.0	3.6	7.2	.3	14.5
Total	21.4	1.4	4.9	63.5	94.9	400.5	12.6	599.2
1988								
6	32.6	1.3	5.5	60.2	91.5	256.2	17.6	464.8
8	13.9	.6	2.4	28.0	44.3	167.9	7.6	264.8
10	5.6	.4	1.1	14.8	23.1	101.8	3.3	150.2
12	2.3	.2	.7	9.4	13.6	60.1	1.6	87.8
14	1.0	.2	.5	7.1	9.4	36.0	.9	55.0
16+	.6	.1	.5	6.9	8.4	25.4	.7	42.7
Total	56.1	2.8	10.8	126.3	190.3	647.5	31.7	1,065.4
1998								
6	63.1	2.4	10.6	112.8	169.3	321.5	34.4	714.1
8	31.2	1.3	5.3	58.1	88.8	241.7	17.3	443.7
10	14.9	.7	2.6	30.4	47.1	162.0	8.6	266.4
12	6.8	.4	1.4	16.9	25.9	102.7	4.2	158.3
14	3.2	.3	.8	11.2	16.2	67.1	2.2	100.9
16+	2.0	.3	1.0	13.1	17.3	63.1	1.8	98.6
Total	121.3	5.3	21.7	242.4	364.6	958.2	68.5	1,782.0

1/ The program was written to print volume estimates by d.b.h. class only every ten years consequently these estimates are for years ending in "8" instead of "0." Table may not add to totals due to rounding.

stock, the region as a whole can support the projected cut until about 1995. At that time, the east half of the U.P. will suffer a reduction in cut that is not likely to be offset by available growing stock in the Northwest and Central Units.

The growing stock projections explain why cut will be diminished. The rapid and steady decrease in the Northeast and U.P. Units in the early years will result in a resource base incapable of supporting the cut. The inventory will finally level as cut is reduced and then will begin a slow climb upward.[3]

The growing stock in the Northwest Unit will increase at a decreasing rate as it is allocated more cut. The Central Unit's increase in growing stock will be rapid and occurs in the projections because the aspen type increased in the *recent trends* and because historically the Unit supplied only 7 percent of the Wisconsin cut. Actually, one would expect cut to shift into the Central Unit as the supply diminished in other units resulting in less growing stock.

The proportion of volume in 10-inch and smaller d.b.h. classes is about the same in 1998 as in 1968 in the Northeast and west half of the U.P. Units; about 10 percent higher in the Northwest and east half of the U.P. Units; and about 5 percent lower in the Central Unit.

Breakup

Under the *breakup* assumptions the cut will be reduced 3 to 5 years sooner in those units that previously had a reduced cut, will drop more sharply, and usually will reach a lower level.[4] Once again the region as a whole supports the total cut until the cut in both units in the U.P. has diminished and then virtually all the cut comes from the 6- and 8-inch d.b.h. classes. The pattern in 1998 is also similar to *recent trends* except now almost all of the Northwest Unit's cut is in the 6-, 8-, and 10-inch d.b.h. classes.[5]

The growing stock volume will follow the same general pattern as that in *recent trends* but will be lower. One exception is the Northwest Unit which dropped sharply during the last 10 years. On the average, 95 percent of the growing stock volume is in trees 10 inches d.b.h. and smaller in 1998.

Positive Practices

Under the *positive practices* assumptions each unit will be able to support its allocated cut. Essentially, the cut will be further reduced in those units where cut had already been diminished and increased in the Northwest and Central Units. In 1998, 65 percent of the cut will come from the 6- and 8-inch d.b.h. classes; individual units will range between 47 and 79 percent—an improved distribution.

The growing stock picture is heartening but not good. In units where cuts had previously been diminished, the inventory level will be higher than under either of the previous sets of assumptions but still will show a downward trend. A lower level and a downward trend will prevail in the Northwest Unit as it sustains much more of the cut than before, and the inventory in the Central Unit will increase at an increasing rate but will reach more realistic levels. The amount of growing stock volume in the 6-, 8-, and 10-inch d.b.h. classes in 1998 will decrease in the Northeast and west half of the U.P. Units, remain about constant in the Northwest and the Central Units, and increase in the east half of the U.P. Unit.

In summary, a diminished cut is likely in the Northeast Unit in 15 to 20 years and in the two U.P. Units in 20 to 25 years. The cut in these units, both immediately preceding and continuing after cut has been reduced, will be almost all in the 6- and 8-inch

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[3] *The inventory increases after a diminished cut because cut is limited by growing stock; e.g., cut must be less than 80 percent of the growing stock. This means that a larger absolute amount of growing stock must be available each year before it can be cut again when, as in these projections, the amount of cut keeps increasing.*

[4] *In some cases, such as the Northeast Unit, the* breakup *cut recovers sooner than the* recent trends *cut. This happens because cut is diminished sooner allowing the growing stock to recover sooner and support the cut.*

[5] *The Northwest and Central Units show a higher cut under the* breakup *than under the* recent trends *assumptions. This is caused by the greater diminished cut in the Northeast and west half of the U.P. Units being allocated to these units and their growing stock levels being high enough to support the increased cut.*

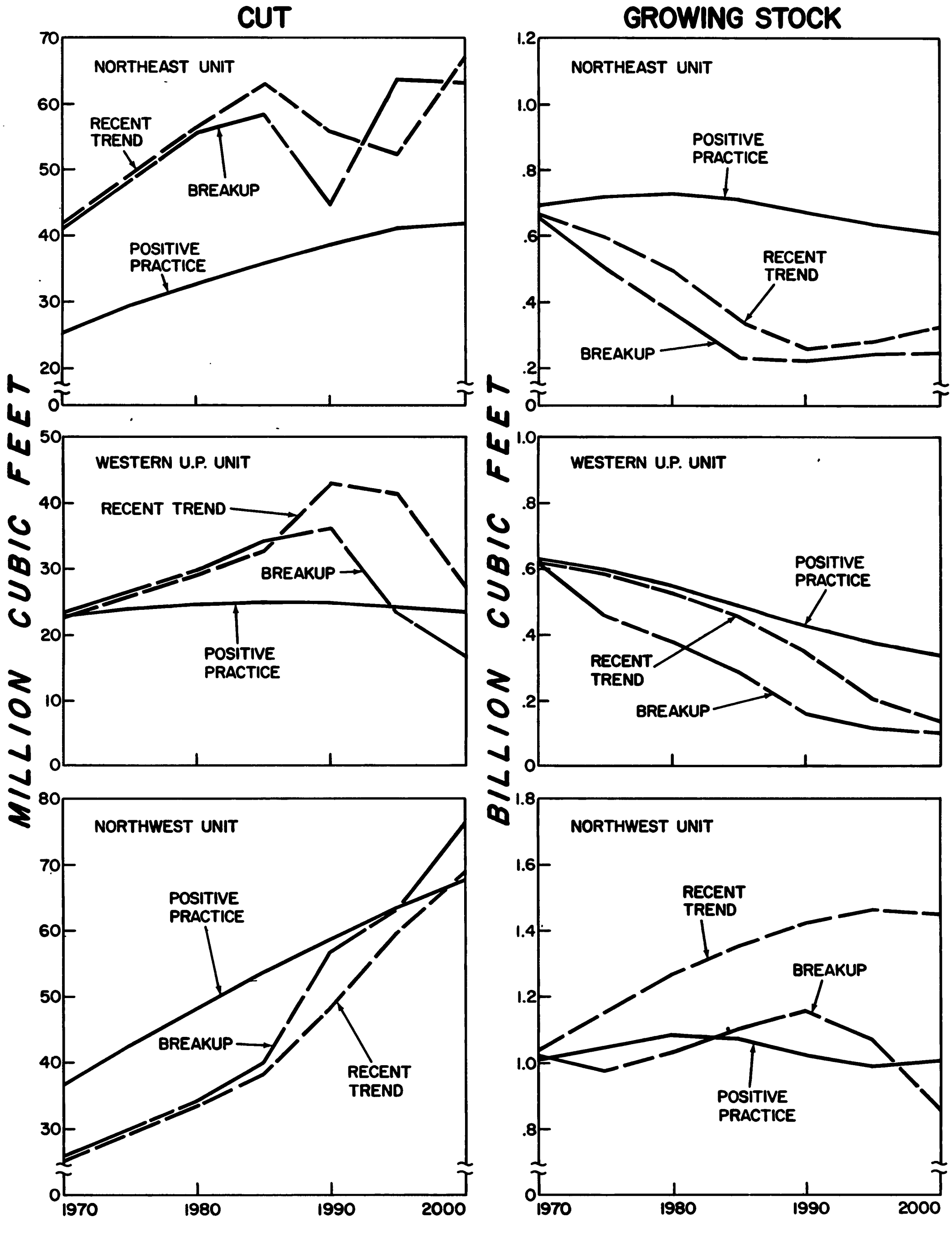

Figure 3.— Projections for Wisconsin—U.P. region, 5-year average every 5 years.

d.b.h. classes. The region as a whole can compensate for the diminished cut in the Northeast Unit but, by assumption, not in the east half of the U.P. Unit. Inventory will continue to decrease except under the *recent trends* projections in the Northwest Unit and all projections in the Central Unit. This is true even in the *positive practices* assumptions where ingro is doubled after the 25th year of projections.

Implications

Several implications can be drawn from these sults. First, wood-using industries will have to s

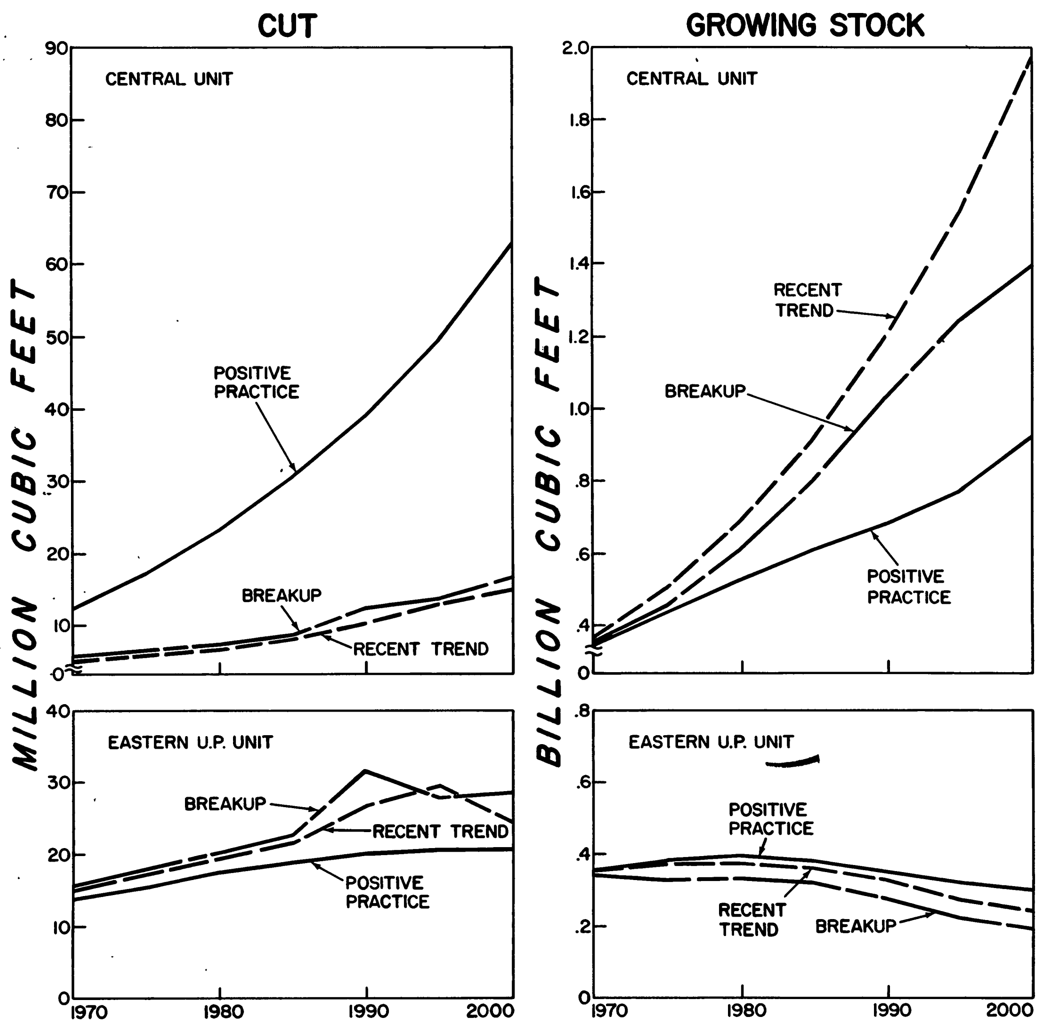

Figure 3 continued

their wood procurement areas or plan on using less aspen. In the early years of the projections this means a substantial shift to the Northwest and Central Units. This shift would certainly increase costs, probably mostly in transportation and in developing or shifting the producer-procurement organization. Determining the amount of these costs is beyond the scope of this study and whether they will be worthwhile or not must be assessed by the individuals incurring them. However, prices of aspen in those units would be expected to increase in future years as the supply is decreased, so costs should increase regardless of whether procurement is shifted or not.

One response to decreased aspen availability would be to substitute more abundant species for aspen. Whether there will be sufficient volumes of other species at acceptable prices is also beyond the scope of this study. Another alternative would be to increase capacity only in regions where aspen or a suitable substitute is available.

A second implication is that mills should avoid installing new capital equipment or processes that can only use aspen. This would give them greater flexibility if they found it necessary to substitute other species for aspen.

The third implication stems from the projected small diameters cut in the *recent trends* and *breakup* projections. The dependency of materials handling systems on lineal rates of flow means that handling costs may increase as the diameter of the stock cut decreases. New harvesting and processing systems will probably have to be developed if costs are to be held at a reasonable level.

Fourth, the projected decreased diameter of aspen cut and growing stock should make it increasingly difficult and expensive for nonpulping industries, such as sawtimber and veneer, to obtain their raw materials.

A fifth implication flows from the *positive practices* assumptions. These demonstrate there are steps we can take to improve the future resource. The long time it takes our actions to be reflected in increased inventory and a more smoothly flowing cut means there is little time to lose. The actions we take today will not be reflected in merchantable timber for 20 to 25 years.

Northern Lower Peninsula

In this region, consisting of only one survey unit, cut will be maintained under both the *recent trends* and *positive practices* assumptions until the final years of the projections (fig. 4). The *breakup* assumptions will reduce the cut again, about 5 years *earlier* than the *recent trends* projections. Almost all the cut will be in the 6- and 8-inch d.b.h. classes by the time it is diminished (a trend common by now) except under *positive practices* where only 70 percent will be in these classes.

In all projections the growing stock shows a sharp downward trend and the volume in trees smaller than 12 inches d.b.h. ranges from 90 percent for *breakup* to 73 percent for *positive practices*. Because there is only one unit in this region the reallocation of cut under *positive practices* does not have the significance it usually does.[6] However, the effect of doubling the ingrowth after the 25th year should still be reflected.

Many of the implications discussed in the Wisconsin-U.P. region also apply to this region. The wood-using industries would either have to shift their procurement to another area (a costly and unlikely prospect) or decrease their use of aspen. Both the materials handling and nonpulping industry difficulties could also exist. The cut would be *diminished* about 2 years later than in the combined region—about the same time as in the U.P. However, things would not be as bleak as they appear if the southern

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[6] *Cut allocation by volume does have another effect. More cut goes to the 6- and 8-inch d.b.h. classes which consequently have lower volumes, particularly in the later years. The growth percents for this unit are 0 for the 14-inch-and-larger class and less than 1 for the 10- and 12-inch classes. The redistribution of volume to d.b.h. classes where growth is low causes the* recent trends *projections to have higher growing stock levels and cut than* positive practices.

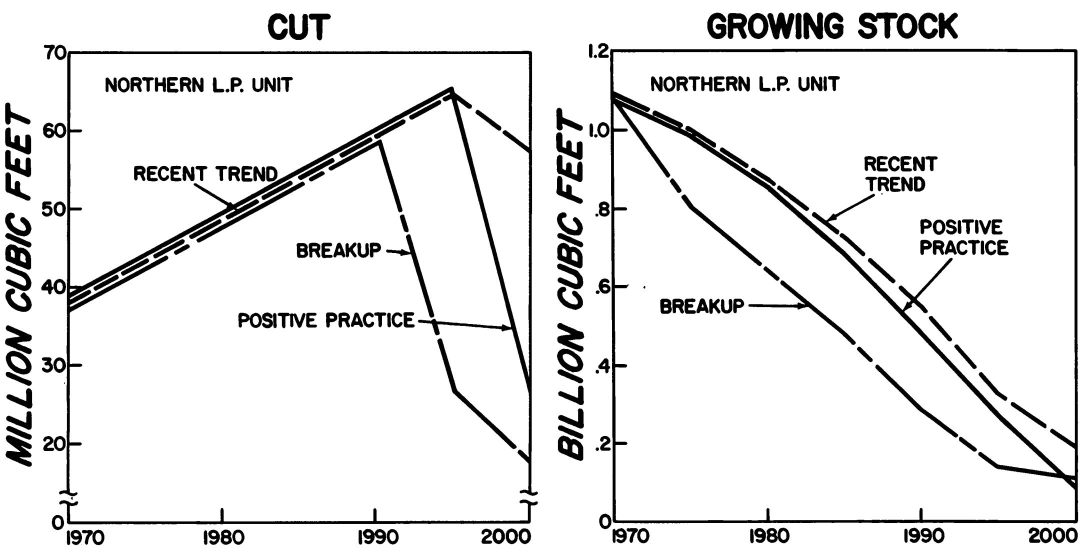

Figure 4.— Projections for Northern Lower Peninsula region, 5-year average every 5 years.

half of the L.P. Unit were able to support some of the cut under the *positive practices*. Unfortunately, time was not available to make this analysis.

The generally poor response of the resource to the *positive practices* assumptions is due, at least in part, to the inability of the model to shift cut to another unit and in part to the low growth percents in this unit. These percents, as discussed in the appendix, might increase if the positive practices are instituted resulting in increased inventory. In summary, it appears this region will not support its historical trend and diameter distribution of cut indefinitely and some rather strong steps must be taken if we desire to maintain the resource at its present level.

Minnesota

The results of the Minnesota projections are the least reliable of those reported here. The forest survey statistics are the oldest (1962) and in the interim data collection and computation techniques have been constantly improving. Moreover, the Minnesota survey included data supplied by cooperators. In many cases these data were not available for this study or were not in a form adaptable to current computer techniques and so some data from surveys of other States were substituted. For example, the growth percents for Wisconsin's Northwest Survey Unit were used for the Lake Superior and Rainy River Survey Units.

Regardless of the assumptions used, the projected cut is supported in each of the units over the entire period of the projections (fig. 5). The *recent trends* and *breakup* projections show about 40 percent of the cut in d.b.h. classes 12 inches and larger in both 1968 and 1998. The *positive practices* projection, because it allocates cut in proportion to aspen volume, shows 13 percent and 50 percent in these classes in 1968 and 1998, respectively.

The results of the different assumptions are more apparent in the growing stock projections. If *recent trends* continue there is a large increase in growing stock in every survey unit. Even under the *breakup* assumptions, the Lake Superior and Rainy River Units first show increasing and then decreasing inventories although the Central Pine Unit registers a fairly sharp drop.

The *positive practices* projections show a redistribution of inventory to more realistic levels in the two larger survey units, although the total inventory is slightly lower throughout the projection period than in *recent trends*. The advantage, if any, accrues to improved volume distribution by diameter. The *positive practices* assumptions show about 5 percent more volume in the Lake Superior and Central Pine Units and about 20 percent more volume in the Rainy River Unit in the 12-inch and larger d.b.h. classes in 1998 than the *recent trends* projections.

Many foresters believe northern Minnesota has the best aspen sites in the Lake States. If this is true, the growth percents should be higher than those in the Northwest Unit and the Minnesota volume projections in the Lake Superior and Rainy River Units are conservative.

The future of aspen for timber in the Minnesota region is bright. The projected cut is supported by the resource and well distributed by d.b.h. class. The growing stock, which in two units is conservatively estimated, responds well regardless of the assumptions used. The only exception is the *breakup* projection in the Central Pine Unit which shows growing stock remaining constant for 15 years and then sharply dropping. This may indicate the resource conditions should be closely monitored in this unit in future years. The consistently high growing stock levels under other assumptions and for other survey units may indicate the region can support a cut even greater than projected.

SUMMARY AND CONCLUSIONS

We cannot expect today's apparent surplus of aspen to continue indefinitely in all regions of the Lake States if the historical trends of cut, growth, and utilization continue into the future. The degree to which historical trends cannot be followed varies by geographical location.

The northeastern survey unit in Wisconsin and all of Michigan's Upper Peninsula show a generally

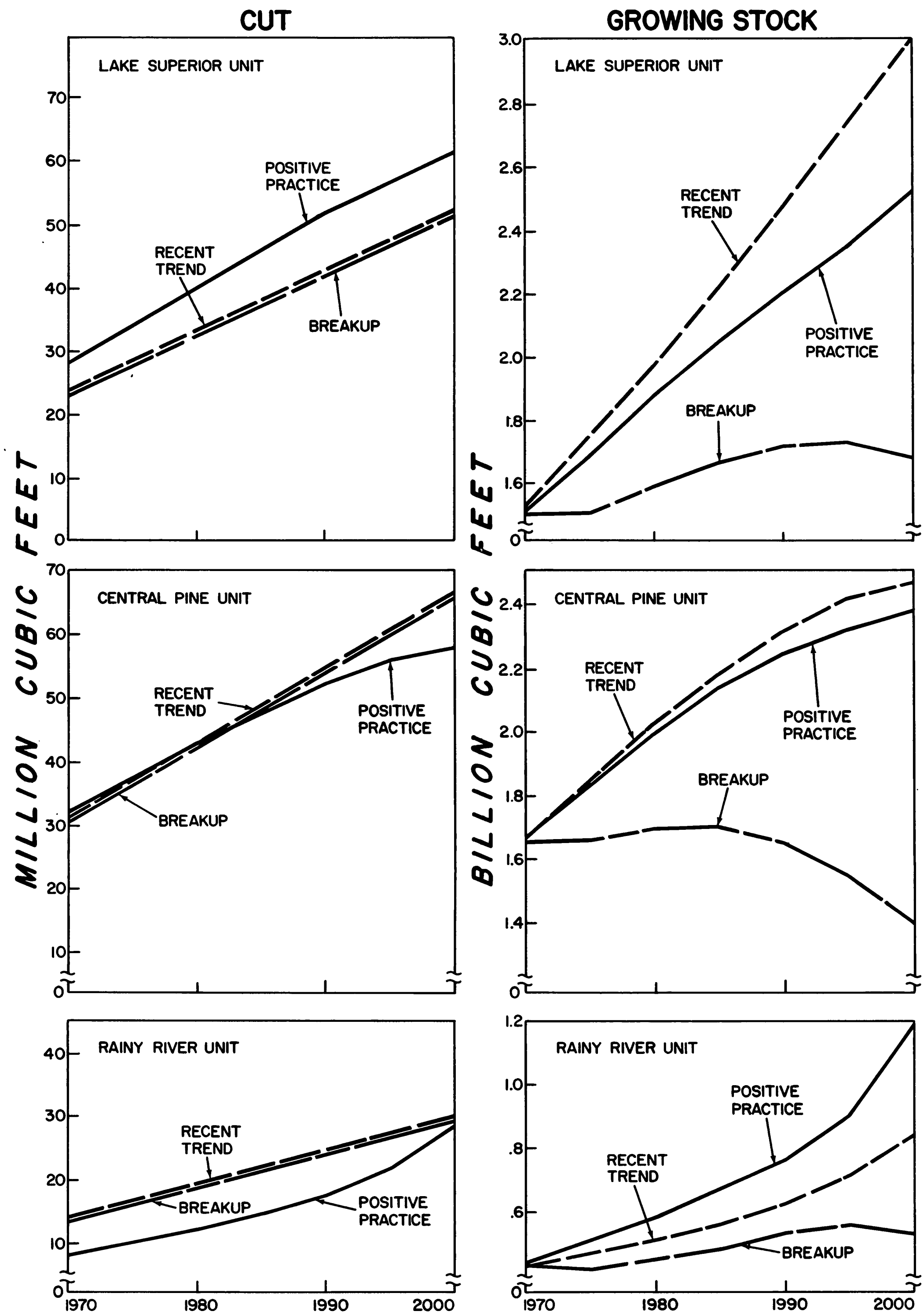

Figure 5.— Projections for Minnesota region, 5-year average every 5 years.

unfavorable picture. The historical cut is likely to be diminished in the Northeast Unit in 15 to 20 years and in the U.P. in 20 to 25 years. In addition, after cut is reduced in these units, most of it will be in the 6- and 8-inch d.b.h. classes. With a few exceptions the growing stock projections show a generally deteriorating picture. However, the *positive practices* projections indicate each survey unit can support its reallocated cut and that the overall condition of the resource can be improved from what it would have been if historical trends continued. These projections also show more cut and growing stock volume in the larger diameter classes.

Michigan's Northern Lower Peninsula supports its historical trend of cut during most of the projection period but at the expense of a constantly deteriorating resource. Even the *positive practices* projection shows a continued sharply decreasing inventory although the diameter distribution of the cut improves.

The northernmost survey units in Minnesota, which currently contain almost half the estimated aspen growing stock in the study area, have the brightest outlook. The projected cut is supported and the ending inventory is higher than present in all cases except the *breakup* projections in the Central Pine Unit. The consistently higher inventory may indicate the region can support more than the projected cut.

Unfortunately, these projections do not answer many questions for wildlife managers and sportsmen. The ability of the resource to support future deer and grouse populations depends in part on which set of assumptions most closely represents future practices. However, there is an opportunity to improve wildlife habitat, regardless of future growing stock levels, if wildlife managers are consulted when timber sales are made. The spatial design of the sale, the amount of residual stand, and other items can have either a positive or negative effect on wildlife populations.

Several conclusions can be drawn from these projections. First, forest industries drawing their aspen from Michigan and Wisconsin must plan to procure their wood elsewhere within these States, substitute other species for aspen, or cut less than the projected amount of wood during the next 15 to 25 years. Further, firms planning replacement of their capital equipment would be wise where possible to install equipment and processes that can substitute other wood species for aspen at minimum cost.

Second, the diminished cuts of aspen are almost always accompanied by increased cutting in small diameter trees. If these diameters are unacceptable, users will have to reduce their cut even further. In addition, the smaller diameters may mean increased materials handling costs from harvesting through the chipper or saw and increased difficulty and expense for industries requiring large diameter aspen as a raw material.

On the other hand, the *positive practices* projections indicate, particularly in the Wisconsin-U.P. region, that actions taken by land managers could maintain an even and increasing flow of aspen from most survey units over time while improving the relative condition of growing stock inventories.

However, the actions necessary to effect a change mean that costs must be borne by the public and/or private sectors. As in most forestry investments, the costs are incurred today whereas the benefits are received in the future and it is not always certain that the parties bearing the costs will receive the benefits. Whether these costs would, or more importantly, should be incurred is not answered by this study. We have demonstrated, however, that it is possible to maintain both an increasing aspen cut and the resource in the Lake States if we choose to do so.

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APPENDIX

This appendix explains the projection model more fully and presents and discusses the estimated values of the variables used in the projections.

Calculating Commercial Forest Area

The first step in the program is calculating commercial forest area (fig. 2). The change in commercial forest area in a type within a survey unit is the product of the acres in that type at the beginning of the year and the percent of acreage changed in the aspen type (PACHG) between the two most recent forest surveys. The amount of breakup occurring in the intersurvey period is therefore automatically reflected in the acreage change.

The net change may be either positive or negative. However, we know some acres enter commercial forest from such things as abandoned farms even while others leave, so it was assumed that a net acreage decrease consisted of 1 acre entering the system for every 2 acres leaving it. Conversely, a net increase was assumed to have 1 acre leaving for every 2 acres entering.

The changes in growing stock volume due to changes in acreage are derived from these estimates and assumptions. Subtracted from growing stock volume is the average volume per acre (by type and survey unit) in the current year of the projection multiplied by the acres calculated above having a negative sign. Additions to volume are the number of acres with a positive sign that would have entered 25 years before times 100 cubic feet per acre for nonaspen types and 400 cubic feet per acre for the aspen type.

The latter step assumes there is no volume on additions to acreage and that it takes 25 years for measurable volume to appear. The estimate of 25 years and 400 cubic feet is based on Kittredge and Gevorkiantz (1929) and Schlaegel (1971). Due to lack of better data the nonaspen ingrowth was set at 25 percent of this or 100 cubic feet per acre.

Calculating and Allocating Cut

Annual cut is calculated and allocated next. First, the cords of aspen pulpwood cut in a particular year and State are calculated and this figure is divided by the proportion of cut used for pulpwood (PCTPW) and multiplied by 80.0 to obtain cubic feet. This is the total estimated aspen cut in the State.

The cut allocated to a survey unit is the State cut multiplied by the historical proportion of the cut coming from that survey unit (PSUCUT). The amount of diminished cut from any preceding survey units is then added in proportion to the remaining original State cut. For example, if there are three survey units in a State, with historical proportions of the cut of 0.2, 0.3, and 0.5 respectively, and if the first survey unit cut has diminished 1,000,000 cubic feet, the second unit will be allocated $0.3/(0.3 + 0.5) =$ three-eighths or 375,000 cubic feet and the third unit will be allocated five-eighths or 625,000 cubic feet.

Survey unit cut is then allocated to d.b.h. class within the survey unit based on the historical proportion of the cut coming from each d.b.h. class (PBHCUT). The cut in a particular d.b.h. class is next allocated to cover type in the proportion of the aspen growing stock volume in that type and d.b.h. class to the total aspen growing stock volume in the d.b.h. class in the survey unit.

Under this system of allocation, it is assumed the user will try first to maintain the geographical location (survey unit) from which his cut has historically come because it is probably where his freight cost is at a *minimum* (Wynd and Manthy 1971) and his procurement organization is already established and functioning there. The diameter of the trees is assumed next in importance because of its effect on materials handling costs in both the woods and the mill. The buyer is assumed not to care what cover type the aspen is in as long as the diameter is large enough and there is a high enough volume per acre (the latter is accounted for by PCUGS below). For lack of better data, it is assumed the proportion of aspen growing stock in a cover type reflects its availability.

The amount of cut is then limited so it does not exceed a certain percentage of the growing stock (PCUGS). If it does not exceed that percentage the volume in that type, d.b.h. class, and survey unit for the beginning of the next year is calculated. If it is equal to or greater than that percentage, the cut for that type and d.b.h. is set to zero and the amount of the cut is distributed to the other types in that d.b.h. class in proportion to their aspen growing stock volume.

The cut in these types is again tested. If it passes the test, the volume for the beginning of the next time period is calculated. If it fails the test, the cut in that type is set back to what it was before the diminished cut was added and that part of the diminished cut is added to the cut in the pure aspen type and distributed over all d.b.h. classes.

The cut in each d.b.h. class in the aspen type is tested again. If the test is passed, the new volume is calculated; if it is failed, the volume in that d.b.h. class is set to what it was before the diminished cut was added and the diminished cut is added to the remaining survey units as explained above.

The rationale for this procedure is the same as before. It implies that costs of moving to a different survey unit exceed the costs of cutting smaller diameter trees and therefore any diameters available within the aspen type are cut before changing survey units.

Calculating Growth

The third step is to calculate growth for a type and d.b.h. class. The program first tests for a maximum volume per acre. This constraint was set high enough (1,000 cubic feet per acre) to be virtually ineffective because it was impossible to estimate a maximum volume *by d.b.h. class* and type. However, average volume per acre for all d.b.h. classes in each type and survey unit were checked visually for reasonableness.

Next, growth out of a particular diameter class was calculated as a proportion of the volume in that diameter class (PGOUT). This becomes the growth into the next diameter class for all but the 6-inch class. This step reflects the growth of trees out of one d.b.h. class and into the next.

The growth into the 6-inch d.b.h. class, on acreage that has been commercial forest, reflects the amount of aspen reproduction. In the pure aspen type the absolute cubic foot ingrowth (ASINGRW) is added; in a nonaspen type the proportion of ingrowth to the volume of the 6-inch class (PGIN) is multiplied by the volume in the 6-inch class to obtain the ingrowth estimate. This procedure reverses the direction of causality and is purely empirical, but was forced by lack of data.

Calculating Beginning Volume

The final step is to calculate growing stock volume for the beginning of the next year for a specific d.b.h. class within a cover type and survey unit by the formula:

$$(1)\ \mathrm{VOLT}_{t+1}=\mathrm{VOLT}_t-\mathrm{CUT}_t+\mathrm{AAVOLT}_t-\mathrm{SAVOLT}_t+\mathrm{GRWTHP}\left(\frac{\mathrm{CUT}_t}{2}+\frac{\mathrm{AAVOLT}_t}{2}+\mathrm{VOLT}_t-\mathrm{CUT}_t-\mathrm{SAVOLT}_t\right)+\mathrm{GIN}_t-\mathrm{GOUT}_t$$

where:

t	=	the t^{th} time period (year) of the projection.
VOLT	=	the total growing stock volume for a specific d.b.h. class within a cover type and survey unit.
CUT	=	the estimated cut as explained above in "CALCULATING AND ALLOCATING CUT."
AAVOLT	=	total additions to growing stock volume due to additions to commercial forest acreage as explained above in "CALCULATING COMMERCIAL FOREST ACRES."
SAVOLT	=	total subtractions from growing stock volume due to subtractions from commercial forest acreage as explained above in "CALCULATING COMMERCIAL FOREST ACRES."
GRWTHP	=	growth percent for a specific d.b.h. class and survey unit.
GIN	=	volume of ingrowth as explained above in "CALCULATING GROWTH."
GOUT	=	volume of outgrowth as explained above in "CALCULATING GROWTH."

A fuller discussion of this formula and its theoretical considerations is found in Leuschner (1972).

Estimating the Variables

The variables are discussed in the order mentioned in the preceding sections on the projection model.

Commercial Forest Acres

The commercial forest acreage by survey unit and cover type are published in all forest survey reports. The projection model required all estimates be for the year 1968. There was no need to update Wisconsin acres, because the year of the survey was 1968.

An unpublished estimate of commercial forest acreage was available at the North Central Forest Experiment Station for Michigan and Minnesota. The compound rate of change between this estimate and the survey year was calculated and the commercial forest acreage in each of the cover types and survey units changed in this proportion. The amount of error in Michigan is probably negligible because the update was only for 2 years; that in Minnesota may be greater because the update was 6 years.

Percent Acreage Change (PACH)

This variable was used to calculate the annual net acreage change in commercial forest acres. It was derived from the compound rate of change in the aspen-birch type between the two most recent forest surveys in Michigan and Wisconsin (table 8, 1st column). In Minnesota the overall compound rate of change in commercial forest acreage discussed in the last paragraph above was used for each survey unit because cover type definitions changed significantly between surveys.

State Pulpwood Cut

The derivation of the basic model for calculating cut is contained in Leuschner.[2] The cut estimate represents the intersection of short term supply and demand functions where demand is price inelastic. The simultaneous solution of these functions results in a model where the quantity cut is a function of woodpulping capacity in the State. This made it necessary to project woodpulping capacity which was accomplished by a simple time trend (table 9). The regression equations used to calculate both cut and capacity by State are:

(2) $CAP_{Mi} = 675.524 + 83.071\ T$
$R^2 = 0.85;\ F = 105.4;\ d.f. = 1/19;\ DW = 0.665$

(3) $CUT_{Mi} = 97.420 + 0.257\ CAP_{Mi}$
$R^2 = 0.75;\ F = 55.6;\ d.f. = 1/19;\ DW = 1.363$

(4) $CAP_{Mn} = 1{,}251.638 + 61.829\ T$
$R^2 = 0.94;\ F = 213.1;\ d.f. = 1/13;\ DW = 1.145$

(5) $CUT_{Mn} = -393.525 + 0.364\ CAP_{Mn}$
$R^2 = 0.84;\ F = 73.1;\ d.f. = 1/13;\ DW = 1.313$

(6) $CAP_{Wi} = 3{,}162.026 + 87.464\ T$
$R^2 = 0.97;\ F = 673.5;\ d.f. = 1/20;\ DW = 1.183$

(7) $CUT_{Wi} = -797.579 + 0.302\ CAP_{Wi}$
$R^2 = 0.91;\ F = 192.1;\ d.f. = 1/18;\ DW = 2.152$

where:
- Mi = the State of Michigan
- Mn = the State of Minnesota
- Wi = the State of Wisconsin
- CAP = the woodpulping capacity of pulp and paper mills in the State in daily tons.
- CUT = the annual cut of aspen pulpwood in the State in thousands of cords.
- T = a time trend where T = 1948 = 1.
- DW = The Durbin-Watson statistic for serial correlation.

Table 8.— Estimated values for projection variables.

Survey Unit	Acreage change	Proportion of State cut to S.U.	Ingrowth into aspen type	Ingrowth into nonaspen types
	Percent		M cu. ft.	Percent
Michigan:				
Eastern Upper Peninsula	-2.4	0.20	2,585	2.7
Western Upper Peninsula	- .1	.30	4,827	2.9
Northern Lower Peninsula	- .2	.50	7,370	2.7
Minnesota:				
Lake Superior	- .2	.35	1,696	4.7
Central Pine	- .2	.45	1,435	2.8
Rainy River	- .2	.20	315	9.3
Wisconsin:				
Northeast	-1.1	.58	6,361	3.7
Northwest	-1.6	.35	13,474	5.7
Central	1.4	.07	7,718	7.1

The calculation of capacity as a time trend has its obvious disadvantages. However, a full scale study of capacity trends in the Lake States was impossible because of the time and money it would have involved. The time trend approach did not seem unreasonable in this light and because we want to project the long term trend rather than the level in any specific year.

Table 9.— Projected woodpulping capacity by State (In daily tons)

State	Year 1970	1980	1990	2000
Michigan	2,586	3,417	4,248	5,078
Minnesota	2,674	3,292	3,910	4,529
Wisconsin	5,174	6,048	6,923	7,798

Proportion of Cut that is Pulpwood (PCTPW)

The estimate of cut must be increased to account for other uses of aspen because the regressions estimate only cords of pulpwood. This variable was estimated as of the forest survey year and is derived from the "cut by product" statistics presented in the survey. One value was used for the entire State:

State	*PCTPW*
Michigan	0.80
Minnesota	.68
Wisconsin	.85

PCTPW is somewhat lower in Minnesota than the other two States indicating that more aspen is used for nonpulpwood products. If this figure is too low the total Minnesota cut is estimated too high and even higher inventory levels would be found in Minnesota than are reported.

Proportion of State Cut to Survey Unit (PSUCUT)

The proportion of cut from a survey unit was obtained by plotting the aspen pulpwood cut by survey unit for 1959 through 1969. The approximate rather than precise proportion was chosen recognizing that the historical proportions would not remain precisely the same throughout the projection. Data were from Blyth (1970) and earlier reports of the same title. Notice the sum of PSUCUT for a State equals 1.0 (table 8, 2nd column).

Proportion of Cut by d.b.h. Class (PBHCUT)

These values were estimated from forest survey stump counts made in the year of the survey. Actual proportions of volume cut were estimated and the distribution ocularly smoothed (table 10). Wisconsin estimates were used in Minnesota because Minnesota apparently had missing data. They were also used for the entire Wisconsin-U.P. region because the program allowed for only one estimate per d.b.h. class and Wisconsin's was judged likely to be most correct for the majority of the volume cut in the region.

Proportion of Cut to Growing Stock (PCUGS)

This variable is the proportion of growing stock to which projected cut is constrained and is another variable easy to include but difficult to evaluate. It was estimated by calculating the proportion of growing stock by State, with a density at least 5 cords per

Table 10.— Proportion of cut initially allocated to d.b.h. class

D. b.h. class	Region: Minnesota	Wisconsin - U.P.	Northern Lower Peninsula
6	0.07	0.07	0.10
8	.22	.22	.20
10	.30	.30	.30
12	.22	.22	.20
14	.07	.07	.10
16	.05	.05	.05
18	.04	.04	.02
20	.02	.02	.02
22+	.01	.01	.01
Total	1.00	1.00	1.00

Table 11.— Proportion of cut to growing stock

Forest type	Region		
	Minnesota	Wisconsin - U.P.	Northern Lower Peninsula
Red, white, and jack pine	0.38	0.29	0.34
Balsam fir-white spruce	.58	.37	.24
Black spruce, tamarack, and cedar	.25	.19	.59
Northern hardwoods	.57	.41	.32
Oak-hickory	.34	.37	.35
Aspen	.90	.94	.95
Birch	.45	.38	.36
Other	0	0	0

acre in the nonaspen types and 2½ cords per acre in the aspen type (table 11). Cut in each d.b.h. class (within a type and survey unit) had to be less than the product of this variable and the growing stock in that class. The Wisconsin data were used for the entire Wisconsin-U.P. region following the rationale discussed under PBHCUT.

The reader may feel the proportions used are too high. However, a larger proportion than the reader suspects may be available over the long run due to such things as changes in ownership and decreasing harvesting costs. (Remember, absolute land withdrawal is accounted for in the reduction of commercial forest acreage.) PCUGS was estimated using density because this may be one of the more constant limiting factors.

If estimates of PCUGS are too high, too much growing stock was available for cutting and the diminished cuts occurred later than they should have. Diminished cuts could take place in other survey units as well, depending on how high the estimates were. There would also be higher levels of growing stock at the end of the projection period because lower estimates of PCUGS would mean less growing stock would be subtracted as cut.

Proportion of Volume Growing Out (PGOUT)

Growth of volume between d.b.h. classes must be estimated because the program estimates volume and growth by d.b.h. The growth out of one d.b.h. class becomes the growth into the next. The Wisconsin forest survey included a radial growth equation for the aspen-birch type which was used to estimate the proportion of the volume growing out of one diameter class into the next (table 12).

Table 12.— Proportion of volume growing out of a diameter class

D.b.h. class	Proportion	D.b.h. class	Proportion
6	0.059	16	0.076
8	.074	18	.052
10	.084	20	.028
12	.089	22+	.500
14	.086		

The value for the 22-inch and larger class was arbitrarily set at 0.5. This means that half of any volume in that class is "killed" in any particular year unless it is cut. This assumption seems reasonable in light of the relatively short life span of aspen and the age a tree must have reached to enter this diameter class.

The values in table 12 are from Wisconsin data but were used for all survey units because in Minnesota there were no radial growth equations and in Michigan it would have been necessary to have an estimate of site index, basal area, and stand age for each d.b.h. class, and these were impossible to obtain.

Aspen Ingrowth (ASINGRW and PGIN)

Ingrowth into the 6-inch d.b.h. class was estimated separately for the aspen and nonaspen types. Consultation with the forest survey project revealed net annual growth in the 4-inch class was an estimate of the ingrowth into the 6-inch class and the growth on that ingrowth. Consequently, this figure, estimated by survey unit, was assumed to be the ingrowth into the aspen type over the entire projection period (table 8, 3rd column).

Estimating ingrowth of aspen into the nonaspen types was a problem because there were no data. Therefore, the net annual growth in the 4-inch d.b.h. class in the aspen type was taken as a proportion of the aspen growing stock volume in the 6-inch d.b.h. class and used to estimate the ingrowth into the nonaspen types (table 8, 4th column). Each year the growing stock volume in the various nonaspen 6-inch d.b.h. classes was multiplied by PGIN to obtain the estimate of aspen ingrowth. As mentioned, this procedure reverses the causality and is purely empirical. However, no other reasonable alternative appeared available.

Growth Percent (GRWTHP)

Growth percent was estimated for each d.b.h. class in each survey unit by dividing the net annual growth by the growing stock volume (table 13). The estimate therefore includes (1) increment on trees in the d.b.h. class at the beginning and end of the year; (2) increment on trees entering the class during the year (but not the volume of the trees entering the class); and (3) mortality.

The estimate does not take into account trees that become unmerchantable during the year. Unfortunately, there was no way to estimate this volume but it was decided that the amount of the loss was probably insignificant in relation to the total amount of the estimate. Nonetheless, there is an upward bias in GRWTHP causing an upward bias in estimates of growing stock volume.

This is counterbalanced somewhat in the *positive practices* projections. Net annual growth is likely to be a function of stand age, condition, and other variables. This may be partly reflected in the lower growth percents in Michigan where the stands tend to be the oldest and past cutting the heaviest. The positive management practices simulated by these projections would probably increase the net annual growth and hence increase GRWTHP. If this is true the growing stock volumes in *positive practices* are biased downward by some amount.

Table 13.—Recent trends *growth percents by d.b.h. class and survey unit*

Survey Unit	D. b. h. class								
	6	8	10	12	14	16	18	20	22+
Michigan:									
Eastern Upper Peninsula	3.4	1.8	1.6	1.2	1.1	0.8	0.1	0.1	0.0
Western Upper Peninsula	3.4	1.6	1.4	1.1	.9	.6	.1	.0	.0
Northern Lower Peninsula	3.3	1.4	.8	.3	.0	.0	.0	.0	.0
Minnesota:									
Lake Superior	Assumed same as Northwest								
Central Pine	3.7	5.2	4.9	2.2	1.2	.8	.4	.2	.0
Rainy River	Assumed same as Northwest								
Wisconsin:									
Northeast	4.8	4.6	4.2	3.6	2.8	2.0	1.3	.9	.6
Northwest	4.9	4.7	4.3	3.6	2.8	1.8	1.1	.4	.5
Central	4.7	4.7	4.6	4.1	3.4	2.7	1.3	1.1	.0

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- Participating with all State forestry agencies in cooperative programs to protect, improve, and wisely use our Country's 395 million acres of State, local, and private forest lands.
- Managing and protecting the 187-million acre National Forest System.

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