AN ANALYSIS OF THE FOREST FIRE DETECTION ALTERNATIVES IN A 7,000 SQUARE MILE AREA IN MANITOBA

by

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FOREST FIRE RESEARCH INSTITUTE

OTTAWA, ONTARIO

INTERNAL REPORT FF-14

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INTRODUCTION

Setting up a forest fire detection system has become a bewildering myriad of complex decisions. With the advent and development of the light-aircraft three possible detection systems have been made available to the fire-control planner -- the all lookout system, the all aircraft system and the combined lookout aircraft system; each having its own advantages and disadvantages depending among other things upon the topographical characteristics of the forest area to be protected and the amount of money allocated to detection. For the selection of the best system for a particular forest area, facts concerning efficiencies and costs are essential. Without this information the fire-control planner would have very little on which to base his decision.

The "detection dollar" becomes a very important factor to consider when contemplating detection systems. The economical feasibility of each system must be carefully examined before a final decision can be made. The fire-control planner has two basic alternatives. He can either set a fixed budget to work with and find the highest level of effectiveness possible under that budget or he can decide upon the level of effectiveness he wishes to attain and then determine the least expensive way of doing so. In the past, detection systems were set-up almost on an intuitive basis. There was no way of measuring the effectiveness of the available alternatives of the whole system. After a detection network was laid out and in operation for some time, changes in the system would be implemented when they became necessary for the increased efficiency of the system. In this way the detection system could gradually be improved. This trial and error method had one obvious drawback -- time. The system had to be in operation for a number of years before its weaknesses became apparent. With ever increasing pressures to reduce losses caused by forest fires a more direct approach to the problem was needed.

Although the old approach, the trial and error method, is really the only true way of ranking in order of efficiency the various alternatives of a detection system, in practice this method takes many years. In today's world of computers and automation however, the concept of time has undergone a startling transformation. Years may now be condensed at will into hours, minutes and even into seconds. Thus by means of the computer the problem of time has been overcome. A mathematical model in the form of a large computer program can be designed to simulate a particular detection system and, using past fire and weather data of the forest area to be examined, the system may then be tested. This approach of course, must be based on the assumption that the weather and fire patterns occurring in the past will recur in the future. This may not necessarily be true but past fire data is the only data that is readily available. It must also be realized that there are many other factors that cannot be considered in such a model. It is up to the fire-control planner to combine these factors with the final computer results before making a decision as to which is the most advantageous system to use. Nevertheless this

"artificial" testing of a detection system is as close as one could come to actually testing it in real-life.

GENERAL

This report describes a study using a mathematical model to objectively analyze the cost and effectiveness of a forest fire detection system in northern Manitoba. The criterion used to measure the effectiveness of the different detection alternatives of the system was the average area (in acres) burned per fire up to the time of detection. It was predetermined to use the lookout-aircraft detection system and should be kept in mind that it was not the purpose of this study to consider whether one system was more efficient in detecting fires than another but rather to find the most effective combination and layout of the combined lookout and aircraft system for several budget levels. The analysis was based on the assumption that fires will be detected equally well by any system giving the same coverage of the area.

By using the simulation approach many different alternatives of the detection system were examined for a ten year period of fire and weather conditions that occurred during the past. The simulation model used tested the most promising alternatives of the detection system that could be operated for each of four arbitrarily chosen budget levels, $20,000, $25,000, $30,000, and $35,000[1], eventually enabling the most effective deployment of the system for each budget level to be found. The study also evaluated the usefulness of existing and proposed tower-lookouts. The technique used in this study was designed to be applied to a specific forest protection unit as existing lookout arrangements, fire pattern, daily danger index and visibility vary considerably from place to place.

AREA

The area under study was a 7,000 sq. mi. section in northern Manitoba. To simplify the task of setting up detection coverage the area was divided into five fire occurrence sectors (appendix 1). During the ten year period a total of 337 fires occurred in the 7,000 sq. mi. Of these 85 were lightning-caused and the remainder were man-caused[2].

Occurrence Sector	No. of Fires	% of all Fires	Area of Sector in sq. mi.
1	26	7.72	525
2	133	39.47	900
3	15	4.45	500
4	101	29.97	1,575
5	62	18.40	3,500
TOTALS	337	100.01%	7,000

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[1] The budget levels and lookout costs may not be truly representative considering the rising costs of today.

[2] In appendix 1 the data used in the analysis is summarized by year.

The lightning data used was obtained from the Department of Transport Weather Station at The Pas. Although this data did not give a true picture of lightning occurrence in the study area, it was however, the best available.

LOOKOUTS

In the 7,000 sq. mi. area there were 9 existing lookouts of which four, lookouts 1, 2, 3, and 4, were considered to be fixed and would not be removed regardless of the results of the study. There were also three potential lookout locations, lookouts 10, 11, and 12. The locations of all twelve lookouts can be seen in appendix 1.

Lookouts were assumed to operate on each day of the fire season and the cost of operating a lookout was set at $2,350 per year. This included depreciation, maintenance costs and wages. The limiting factor affecting the extent of lookout and aircraft coverage was daily visibility[1]. Lookouts were considered to be 100% effective within their visual range and the area burned up to the time of detection was assumed to be zero providing the fire occurred within the visual range of the lookout.

The area covered by all possible combinations of the twelve lookouts was calculated for each of the four visibility levels - 6, 9, 12, and 15 miles. Each combination would necessarily have at least four lookouts, the fixed lookouts 1, 2, 3, and 4. The combinations and area covered by each combination for each visibility level is outlined in appendix 2. A dot grid with a spacing equivalent to 1 dot/sq. mi. was used to calculate these areas with an approximate accuracy of 1%. All the dots falling within the visual range of any one of the lookouts being operated for that particular combination were counted. The area in square miles covered by the lookouts was therefore the total number of dots counted. In this way, the problems of tower overlapping and boundaries were considered.

It was necessary to know the probabilities of detecting a fire by lookouts in each occurrence sector. It was assumed that fires were equally likely to occur at any point within a fire occurrence sector. Taking this assumption into consideration and knowing the area covered by lookouts in each sector under each visibility level for each lookout combination, it was then determined that the probability of detecting a fire by lookouts during a given visibility level could be expressed as the ratio of the area covered by lookouts in a given sector to the total area of that sector.

Knowing the probability of a given fire occurring in each of the five occurrence sectors, the probabilities of a given day having one of the four visibility levels and the probability of a given lookout combination detecting a fire in each occurrence sector, it was then possible to calculate an effectiveness criterion for each lookout combination. The theory and calculation of this effectiveness criterion is developed in appendix 3. The most effective lookout combination was the one that produced the highest value of the criterion. The effectiveness criterion values for all the combinations of the lookouts are listed in appendix 4.

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[1]Four visibility levels were used, 6 mi., 9 mi., 12 mi., and 15 mi.

AREA COVERED IN SQ. MI./VIS. LEVEL

No. of Lookouts	Lookout Combination	Visibility Levels			
		0-6 mi.	7-9 mi.	10-12 mi.	13-15 mi.
4	1,2,3,4	448	992	1,636	2,414
5	1,2,3,4,10	560	1,242	2,016	2,868
6	1,2,3,4,5,10	672	1,486	2,365	3,215
7	1,2,3,4,5,9,10	784	1,726	2,680	3,496
8	1,2,3,4,5,8,9,10	896	1,966	3,056	3,845
9	1,2,3,4,5,7,8,9,10	1,008	2,200	3,440	4,296
10	1,2,3,4,5,7,8,9,10,12	1,120	2,436	3,812	4,800
11	1,2,3,4,5,7,8,9,10,11,12	1,220	2,672	4,184	5,288
12	1,2,3,4,5,6,7,8,9,10,11,12	1,332	2,760	4,232	5,352

It was decided that lookout No. 6 did not contribute significantly to the area coverage since it greatly duplicated much of the coverage already provided by lookouts 1 and 3. On a maximum visibility day, for example, lookout 6 provided only an additional 64 sq. mi. of coverage (5,352-5,288 from table above). With respect to the effectiveness criterion (appendix 4), lookouts 11 and 12 do not contribute extensively to the system both being in sector 5, a low risk area. However, if a lookout is to be added, lookout 10 would be a worthwhile addition.

AIR PATROLS

The strip width covered by an air patrol should be approximately twice the lookout visibility. However, in this study the width was reduced to equal the lookout visibility in order to insure proper coverage of every point. This reduction presumably allowed for travel time to and from the patrol area, zig-zag air patrol patterns and some lookout-air patrol overlap. In a further effort to minimize the duplication of coverage caused by flying air patrols over areas already covered by lookouts it would be essential to develop different flight patterns for each class of visibility day. On each danger class day regardless of visibility a specific number of square miles were patrolled. This area to be patrolled was based on the amount of the total detection budget to be spent on each danger class day, the speed and cost per hour of the aircraft[1] and the number of days in each visibility class. The formula used to calculate the area to be patrolled each danger class day is derived in appendix 5.

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[1]Aircraft speed and costs were based on the Cessna-172 on floats, at 105 m.p.h. and $40/hour.

The air patrol would therefore take into account the visibility on that particular day and the number of lookouts operating. Patrols would only be flown between 0800 hours and 1900 hours on any given day. In the event of thunderstorms two patrols would always be flown. The first patrol two hours after the storm or at 0800 hours the following morning, whichever occurred first during the prescribed flying hours. The second patrol would be sent out 4 hours after the first or at 0800 hours the next morning if the prescribed flying hours had elapsed.

Air patrols were allotted by sectors. If a patrol were scheduled at a certain hour in a particular sector it was assumed that every point in the patrol path would be covered at that exact time. Every fire that started on or before that time would be detected by that patrol, provided of course that it was not previously detected by the public or an earlier patrol.

It was possible to fly a fraction of a patrol. This meant that only a part of the patrollable area could be covered, subsequently, the probability of that patrol detecting detectable fires was directly proportional to the size of the fraction of the patrol. It was particularly advantageous to fly a fraction of a patrol when not enough funds were available for a whole patrol. This enabled the use of leftover funds that would have otherwise remained unspent.

The amount of air patrol each danger class day and sector was a design variable. The range of values for this variable was restricted by available funds. The annual budget was split between lookouts and air patrols. As the number of lookouts used increased, the money available for air patrols decreased. The funds for air patrols were further divided for lightning patrols and regular air patrols. With every detection alternative tested two lightning patrols were flown for each thunderstorm[1]. The remaining air patrol money was used for regular air patrols. The cost figures for lightning patrols are based on two complete patrols per storm, the speed and cost of the aircraft, and the number of storms and visibilities expected are presented below.

LIGHTNING PATROL COSTS
FOR THE 10-YEAR PERIOD (1957-66)

Lookout Combination	4	5	6	7	8	9	10	11
10-year cost for 2 patrols/ storm	$ 65,331	$ 60,568	$ 56,778	$ 53,674	$ 49,844	$ 45,351	$ 40,277	$ 35,555

Since the study used the annual lightning cost for each lookout combination, the above costs were divided by 10 to find the yearly average. The costs for regular air patrols are calculated in appendix 9.

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[1]Only one thunderstorm was assumed per day.

For the detection model the detectable times of each fire were required. The detectable time being defined as that time at which the fire puts up enough smoke to be detected. Thus, if a fire is classed as detectable and it is within the visible range of the detecting agency then the fire will be detected. After ignition a fire outside the visible range of a lookout may not be detected immediately after it becomes detectable. However, only two times are, in fact recorded in the fire report forms, the actual detection time and the estimated ignition time. Subsequently the fire may have been detectable for some time before it was actually detected.

```
IGNITION        DETECTABLE        DETECTED
   ↓                ↓                ↓
─────────────────────────────────────────→ TIME
```
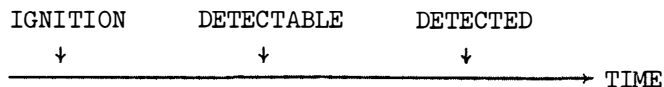
Fig. 1.   Times involved in the detection of a
          forest fire.

It was therefore necessary to make estimates of detectable times. The following assumptions were made:

1. A fire occurring on a moderate, high or extreme day would be detectable on that same day according to the time distribution described by Barrows[1]. This distribution may be seen in appendix 7.

2. If a fire started on a low danger day:

    (a) if it were a lightning fire, the distribution shown in appendix 8[2], will be used to determine the time that the fire became detectable. From the starting time until seventy-two elapsed hours, the elapsed time was added to the starting time to obtain the detectable time. After seventy-two hours, the day that the fire occurred was determined from this distribution. The specific time of detectability for these fires was determined by the Monte Carlo sampling,

    (b) if it was a man-caused fire, it was assumed that it would be detectable on the seventieth elapsed low-danger hour or on the first hour that moderate danger occurred, whichever occurred first.

    The study took into account the fact that a considerable proportion of the total number of forest fires occurring in and around the area under study, would

[1]Barrows, u. c. 1951. Forest Fires in the Northern Rocky Mountains. Station Paper 28, Northern Rocky Mountains Forest and Range Experiment Station, Forest Service, U.S.D.A.

[2]Kourtz, P. H. 1967. Lightning Behaviour and Lightning Fires in Canadian Forests. Departmental Publication 1179. Department of Forestry and Rural Development, Canada.

be detected by the public. The public refers to commercial aircraft, tourists, local residents and other agencies that use the forests. On the other hand, such factors as the altitude of the air patrols and the versatility of the lookout and aircraft observers could not be considered in the study. It was necessary, for example, to assume that the lookout and aircraft observers were one-hundred percent efficient.

Many different detection alternatives were examined for each of the four budget levels. Each alternative was composed of one of the eight best lookout combinations, two lightning patrols per storm and as many regular air patrol flights as the remainder of the budget being used would allow. In setting up a detection alternative it was necessary to:

1. define the detection budget to be examined

2. select one of the eight best lookout combinations

3. based on the money remaining for air patrols, determine

   (a) in which sectors it would be most feasible to fly air patrols (considering lookout locations and the cost of patrolling the individual sectors)

   (b) on which danger-class days to fly the patrols

   (c) the number of patrols or fractions of patrols to fly

   (d) the time schedule for these patrols (0800 hours to 1900 hours inclusive).

Because of the infinite number of detection alternatives and combinations within alternatives that were possible, only those alternatives that promised the most advantageous results were examined.

CRITERION

It was then necessary to select a measure of effectiveness in order to rate each alternative tested. For this, the criterion selected was the average area (in acres) burned per fire up to the time of detection. Therefore, the best alternative was that alternative that resulted in the lowest average area burned per fire up to the time of detection. The fire model used to calculate this area was the United Aircraft model[1].

RESULTS

While setting up the various detection alternatives it soon became apparent that it was generally ineffective and in some cases economically impossible to fly

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[1] United Aircraft of Canada Limited, 1964, Report of a Study into the use of aircraft in the control of forest fires.
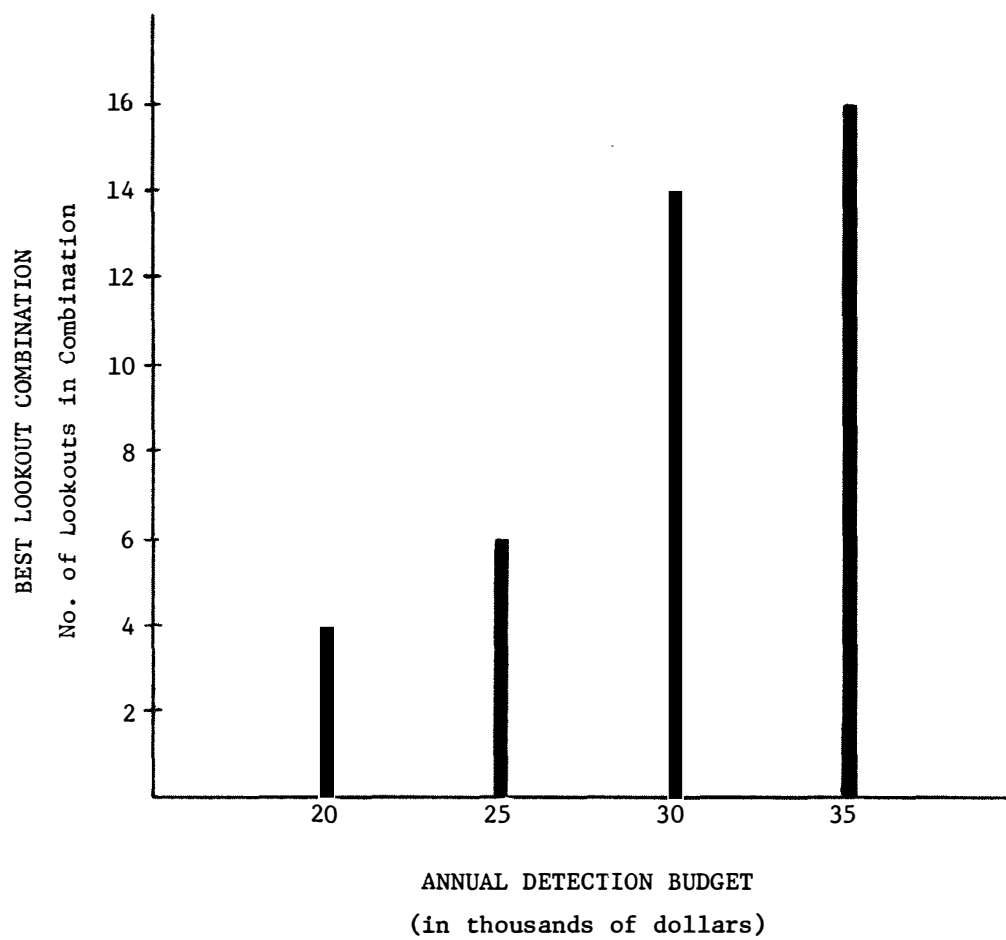
Figure 2. Most effective number of lookouts for each detection budget.
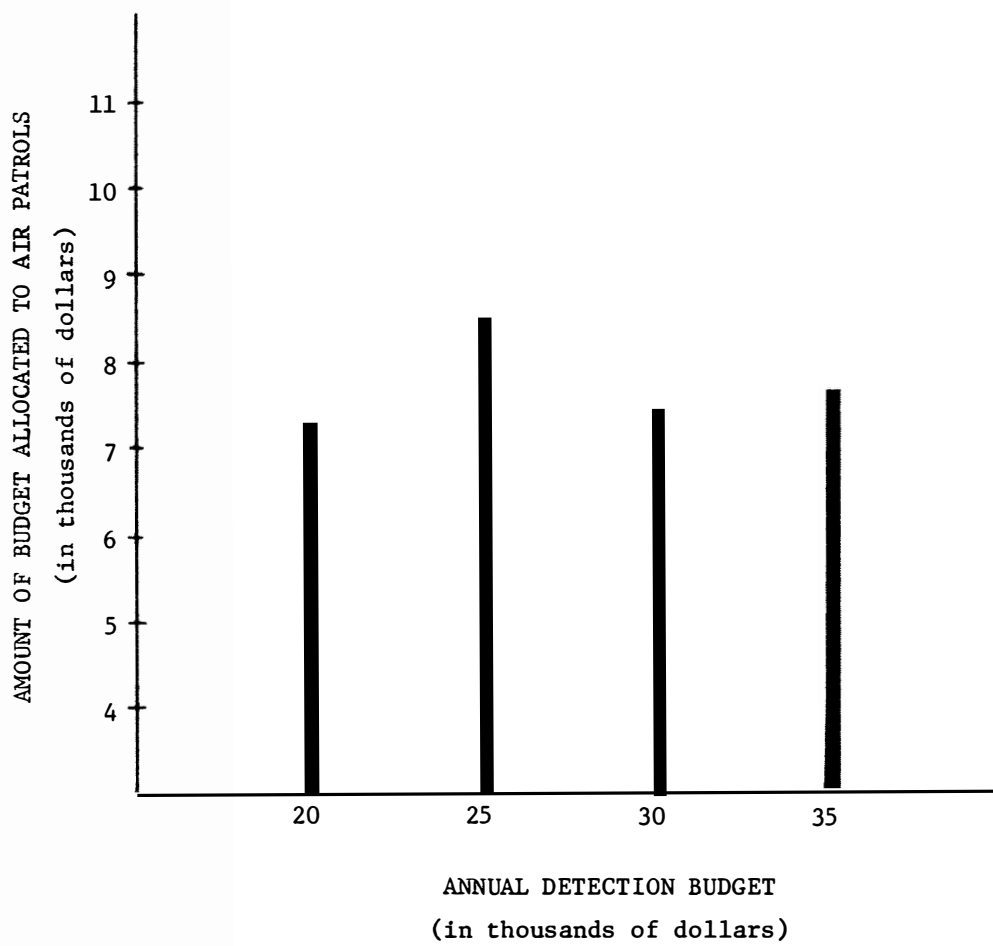
Figure 3. Amount to spend on aircraft for each budget level.

The numbers alongside the points indicate the tower combination used.
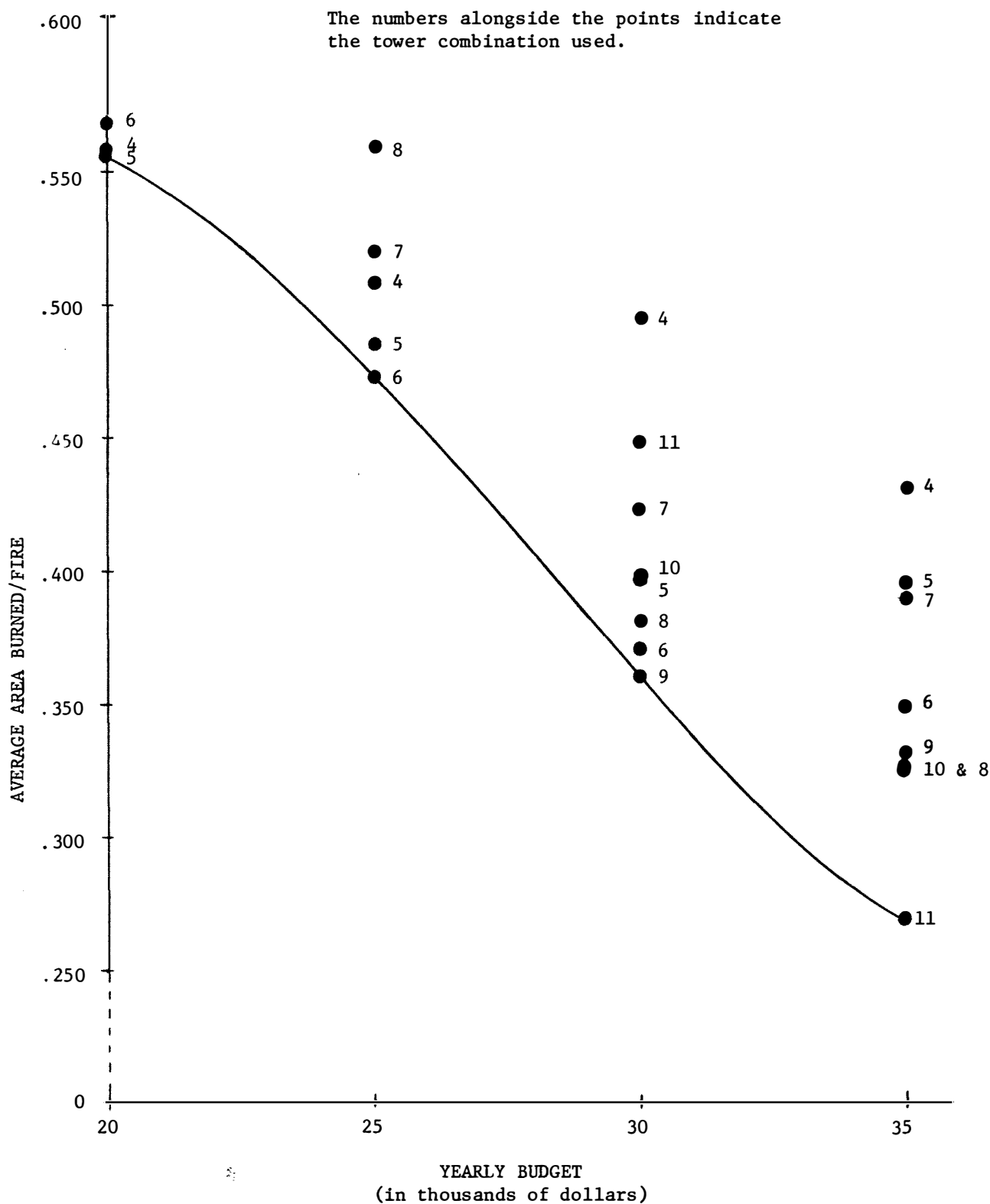
Figure 4. Most effective allocations of each budget per tower combination.

regular air patrols in any sector on moderate or low danger days. Sector five, due to its size (3,500 sq. mi.), was extremely expensive to patrol. For this reason, although only 18.4% of the fires occurred in this sector, not enough detection coverage could be provided within the allowed budget. Subsequently, the probability of detecting fires in this sector remained low in relation to the other sectors. However, at such times that funds were available and limited air patrol coverage was provided in sector five, patrols flown on extreme danger days proved to be the most advantageous. Patrols on high danger days were not often attempted as they were too expensive even when operating on the maximum budget level of $35,000 per year.

In sector number three there were never any air patrols flown as it was a very low risk area (4.5% of all fires). Sector number one was similarly a low risk area and air patrols were rarely flown there. Sector number two contained the highest percentage (39.5%) of the fires. This sector was only 900 sq. mi. in area and much of this area was covered by permanent lookouts one and three. Therefore, the cost of air patrols in sector two was low and the sector could be patrolled on both extreme and high danger days at almost any budget level with almost any lookout combination. In sector number four the same situation existed as in sector number two. Although this sector was larger in area than sector number two, permanent lookout number four and potential lookout ten provided detection coverage of the greater part of the sector leaving only a small area to be patrolled by air.

Figure 2 indicates the amount that should be spent on lookouts for each detection budget. Figure 3 indicates the amount that should be spent on air patrols for each budget level. Figure 4 presents the discrete solution for this particular analysis. The most effective results for each of the four budget levels can be found by projecting a vertical line from the horizontal axis at the appropriate budget level and from the point at which this line intersects the curve, projecting a horizontal line to the vertical axis. For example if the annual detection budget were $25,000, the most efficient result that could be obtained is an average area burned of 0.473 acres per fire. This could be achieved by using six lookouts (from Fig. 2), numbers 1, 2, 3, 4, 5, and 10, at a cost of $14,100 (6 X $2,350) and spending the remaining $10,900 on aircraft patrols (including two lightning patrols per storm).

It must be realized that there are many factors that could not be considered in the study which influence a decision regarding the best detection system to employ for a particular forest area. One of these factors is the value of the forest area being protected. Obviously, some acres of forest are much more valuable than others. As yet the value of a forest and the damage caused by fire cannot be satisfactorily appraised. When a suitable method is achieved it will be possible to measure the effectiveness of a system in the more useful terms of forest values. Other important factors are the ability of the lookout and aircraft observers, and the versatility of both lookouts and aircraft.
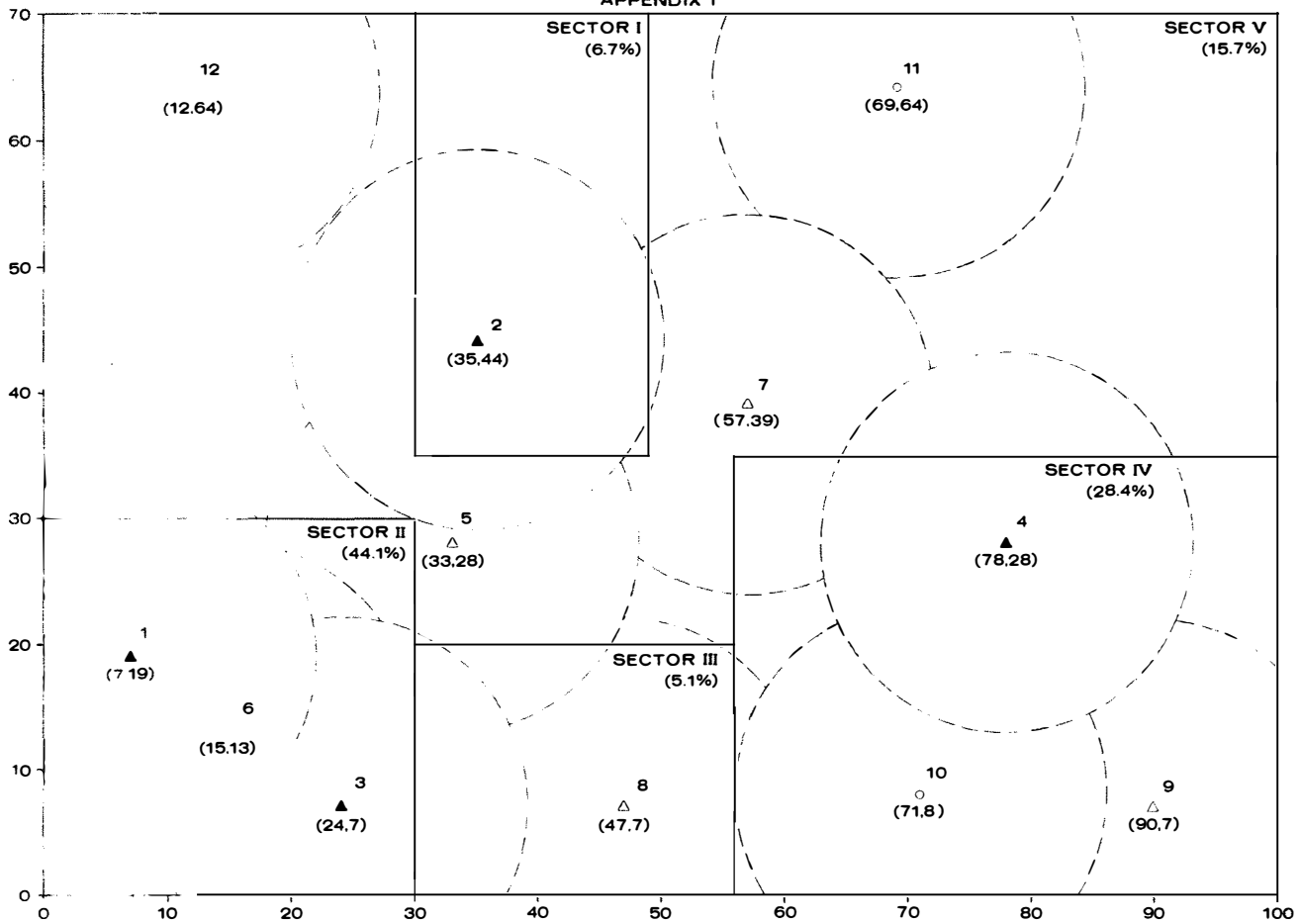
Location of present and proposed Lookout Towers and
Sectors with percent of area occupied by each Sector

Existing Towers - will not be removed........▲
Existing Towers - can be removed............△
Proposed new Tower locations ....o

Best Lookout Combinations

5 Towers - #1,2,3,4,10
6 Towers - #1,2,3,4,10,5
7 Towers - #1,2,3,4,10,5,9
8 Towers - #1,2,3,4,10,5,9,8
9 Towers - #1,2,3,4,10,5,9,8,7
10 Towers - #1,2,3,4,10,5,9,8,7,12
11 Towers - #1,2,3,4,10,5,9,8,7,12,11

Scale in inches

10   0   10   20miles

12
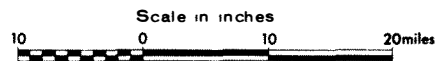
SUMMARY OF DATA (1957-1966)

YEAR	FIRES			VISIBILITY LEVELS				DANGER LEVELS			
	Lightning	Man-Caused	Total	0-6 Days	7-9 Days	10-12 Days	13-15 Days	0-4 Days	5-8 Days	9-12 Days	13-16 Days
57	10	28	38	5	2	5	173	46	107	28	4
58	2	14	16	5	4	2	173	84	61	35	4
59	5	20	25	5	3	7	169	98	79	7	0
60	35	37	72	20	5	25	134	44	72	50	18
61	5	55	60	45	5	21	113	51	53	62	18
62	7	24	31	9	6	26	143	89	69	25	1
63	4	17	21	22	1	25	136	83	93	8	0
64	15	35	50	31	1	27	125	90	58	27	9
65	1	2	3	22	3	41	118	94	82	8	0
66	1	20	21	23	1	50	110	90	74	20	0
TOTALS	85	252	337	187	31	229	1394	769	748	270	54

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AREA COVERED BY LOOKOUTS

IN THE 7000 SQUARE

MILE BLOCK (Sq. Miles)

Lookouts Operated	Visibility in Sq. Miles			
	6	9	12	15
1, 2, 3, 4	448	992	1636	2414

For each combination
following, lookouts
1, 2, 3 and 4 were
operated.

Lookouts Operated	6	9	12	15
5	560	1236	1985	2761
6	548	1088	1690	2452
7	560	1248	2075	2941
8	560	1232	2012	2885
9	560	1232	2000	2830
10	560	1242	2016	2868
11	560	1220	1998	2948
12	560	1220	1998	2913
5, 6	660	1332	2039	2781
5, 7	672	1492	2424	3272
5, 8	672	1476	2361	3185
5, 9	672	1476	2349	3177
5, 10	672	1486	2365	3215
5, 11	672	1464	2347	3295
5, 12	672	1344	2347	3260
6, 7	660	1328	2129	2979
6, 8	660	1328	2066	2923
6, 9	660	1328	2054	2868
6, 10	660	1338	2070	2906
6, 11	660	1316	2052	2986
6, 12	660	1316	2052	2951
7, 8	672	1488	2451	3412
7, 9	672	1488	2439	3357
7, 10	672	1498	2455	3395
7, 11	672	1476	2437	3455
7, 12	672	1476	2437	3440
8, 9	672	1472	2376	3301
8, 10	672	1482	2392	3264
8, 11	672	1460	2374	3419
8, 12	672	1460	2374	3384

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Lookouts Operated	6	9	12	15
9, 10	672	1482	2331	3149
9, 11	672	1460	2362	3364
9, 12	672	1460	2362	3329
10, 11	672	1470	2378	3402
10, 12	672	1470	2378	3367
11, 12	672	1448	2360	3447
5, 6, 7	772	1588	2478	3292
5, 6, 8	772	1572	2415	3205
5, 6, 9	772	1572	2403	3197
5, 6, 10	772	1582	2419	3235
5, 6, 11	772	1560	2401	3315
5, 6, 12	772	1560	2401	3280
5, 7, 8	784	1732	2800	3696
5, 7, 9	784	1732	2788	3688
5, 7, 10	784	1742	2804	3726
5, 7, 11	784	1720	2786	3786
5, 7, 12	784	1720	2786	3771
5, 8, 9	784	1716	2725	3601
5, 8, 10	784	1726	2741	3564
5, 8, 11	784	1704	2723	3719
5, 8, 12	784	1704	2723	3684
5, 9, 10	784	1726	2680	3496
5, 9, 11	784	1704	2711	3711
5, 9, 12	784	1704	2711	3676
5, 10, 11	784	1714	2727	3749
5, 10, 12	784	1714	2727	3714
5, 11, 12	784	1692	2709	3794
6, 7, 8	772	1584	2505	3450
6, 7, 9	772	1584	2493	3395
6, 7, 10	772	1594	2509	3433
6, 7, 11	772	1572	2491	3493
6, 7, 12	772	1572	2491	3478
6, 8, 9	772	1568	2430	3339
6, 8, 10	772	1578	2446	3302
6, 8, 11	772	1556	2428	3457
6, 8, 12	772	1556	2428	3422
6, 9, 10	772	1578	2385	3187
6, 9, 11	772	1556	2416	3402
6, 9, 12	772	1556	2416	3367
6, 10, 11	772	1566	2432	3440
6, 10, 12	772	1566	2432	3405
6, 11, 12	772	1544	2414	3485
7, 8, 9	784	1728	2815	3828
7, 8, 10	784	1738	2831	3791
7, 8, 11	784	1716	2813	3926
7, 8, 12	784	1716	2813	3911
7, 9, 10	784	1738	2770	3676

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Lookouts Operated	6	9	12	15
7, 9, 11	784	1716	2801	3871
7, 9, 12	784	1716	2801	3856
7, 10, 11	784	1726	2817	3909
7, 10, 12	784	1726	2817	3894
7, 11, 12	784	1704	2799	3954
8, 9, 10	784	1722	2707	3545
8, 9, 11	784	1700	2738	3835
8, 9, 12	784	1700	2738	3800
8, 10, 11	784	1710	2754	3798
8, 10, 12	784	1710	2754	3763
8, 11, 12	784	1688	2736	3918
9, 10, 11	784	1710	2693	3683
9, 10, 12	784	1710	2693	3648
9, 10, 12	784	1688	2724	3863
10, 11, 12	784	1698	2740	3901
5, 6, 7, 8	884	1828	2854	3716
5, 6, 7, 9	884	1828	2842	3708
5, 6, 7, 10	884	1838	2858	3746
5, 6, 7, 11	884	1816	2840	3806
5, 6, 7, 12	884	1816	2840	3791
5, 6, 8, 9	884	1812	2779	3621
5, 6, 8, 10	884	1822	2795	3584
5, 6, 8, 11	884	1800	2777	3739
5, 6, 8, 12	884	1800	2777	3704
5, 6, 9, 10	884	1822	2734	3516
5, 6, 9, 11	884	1800	2765	3731
5, 6, 9, 12	884	1800	2765	3696
5, 6, 10, 11	884	1810	2781	3769
5, 6, 10, 12	884	1810	2781	3734
5, 6, 11, 12	884	1788	2763	3814
5, 7, 8, 9	896	1972	3164	4112
5, 7, 8, 10	896	1982	3180	4075
5, 7, 8, 11	896	1960	3162	4210
5, 7, 8, 12	896	1960	3162	4195
5, 7, 9, 10	896	1982	3119	4007
5, 7, 9, 11	896	1960	3150	4202
5, 7, 9, 12	896	1960	3150	4187
5, 7, 10, 11	896	1970	3166	4240
5, 7, 10, 12	896	1970	3166	4225
5, 7, 11, 12	896	1948	3148	4285
5, 8, 9, 10	896	1966	3056	3845
5, 8, 9, 11	896	1944	3087	4135
5, 8, 9, 12	896	1944	3087	4100
5, 8, 10, 11	896	1954	3103	4098
5, 8, 10, 12	896	1954	3103	4063
5, 8, 11, 12	896	1932	3085	4218
5, 9, 10, 11	896	1954	3042	4030

Lookouts Operated	6	9	12	15
5, 9, 10, 12	896	1954	3042	3995
5, 9, 11, 12	896	1932	3073	4210
5, 10, 11, 12	896	1942	3089	4248
6, 7, 8, 9	884	1824	2869	3866
6, 7, 8, 10	884	1834	2885	3829
6, 7, 8, 11	884	1812	2867	3964
6, 7, 8, 12	884	1812	2867	3949
6, 7, 9, 10	884	1834	2824	3714
6, 7, 9, 11	884	1812	2855	3909
6, 7, 9, 12	884	1812	2830	3860

Dot spacing changes to 4 mi
per dot from 1 mi per dot.

Lookouts Operated	6	9	12	15
6, 7, 10, 11	884	1808	2844	3916
6, 7, 10, 12	884	1808	2844	3892
6, 7, 11, 12	884	1800	2844	3976
6, 8, 9, 10	884	1788	2708	3536
6, 8, 9, 11	884	1780	2756	3884
6, 8, 9, 12	884	1780	2756	3800
6, 8, 10, 11	884	1788	2768	3804
6, 8, 10, 12	884	1788	2768	3760
6, 8, 11, 12	884	1780	2768	3936
6, 9, 10, 11	884	1788	2720	3696
6, 9, 10, 12	884	1788	2720	3652
6, 9, 11, 12	884	1780	2768	3888
6, 10, 11, 12	884	1788	2780	3920
7, 8, 9, 10	896	1956	3096	4016
7, 8, 9, 11	896	1948	3144	4304
7, 8, 9, 12	896	1948	3144	4280
7, 8, 10, 11	896	1956	3156	4264
7, 8, 10, 12	896	1956	3156	4240
7, 8, 11, 12	896	1948	3156	4396
7, 9, 10, 11	896	1956	3108	4156
7, 9, 10, 12	896	1956	3108	4132
7, 9, 11, 12	896	1948	3156	4348
7, 10, 11, 12	896	1956	3168	4380
8, 9, 10, 11	896	1936	3032	4044
8, 9, 10, 12	896	1936	3032	4000
8, 9, 11, 12	896	1928	3080	4308
8, 10, 11, 12	896	1936	3092	4268
9, 10, 11, 12	896	1936	3044	4160
5, 6, 7, 8, 9	996	2044	3164	4080
5, 6, 7, 8, 10	996	2054	3176	4040
5, 6, 7, 8, 11	996	2044	3176	4196
5, 6, 7, 8, 12	996	2044	3176	4172

Lookouts Operated	6	9	12	15
5, 6, 7, 9, 10	996	2052	3128	3976
5, 6, 7, 9, 11	996	2044	3176	4192
5, 6, 7, 9, 12	996	2044	3176	4168
5, 6, 7, 10, 11	996	2052	3188	4224
5, 6, 7, 10, 12	996	2052	3188	4200
5, 6, 7, 11, 12	996	2044	3188	4284
5, 6, 8, 9, 10	996	2032	3052	3820
5, 6, 8, 9, 11	996	2024	3100	4128
5, 6, 8, 9, 12	996	2024	3100	4084
5, 6, 8, 10, 11	996	2032	3112	4088
5, 6, 8, 10, 12	996	2032	3112	4044
5, 6, 8, 11, 12	996	2024	3112	4044
5, 6, 9, 10, 11	996	2024	3064	4024
5, 6, 9, 10, 12	996	2024	3064	3980
5, 6, 9, 11, 12	996	2024	3112	4216
5, 6, 10, 11, 12	996	2024	3124	4248
5, 6, 8, 9, 10	1008	2200	3440	4296
5, 7, 8, 9, 11	1008	2192	3488	4584
5, 7, 8, 9, 12	1008	2192	3488	4560
5, 7, 8, 10, 11	1008	2200	3500	4544
5, 7, 8, 10, 12	1008	2200	3500	4520
5, 7, 8, 11, 12	1008	2192	3500	4676
5, 7, 9, 10, 11	1008	2192	3452	4480
5, 7, 9, 10, 12	1008	2192	3452	4456
5, 7, 9, 11, 12	1008	2192	3500	4672
5, 7, 10, 11, 12	1008	2200	3512	4704
5, 8, 9, 10, 11	1008	2180	3376	4348
5, 8, 9, 10, 12	1008	2180	3376	4300
5, 8, 9, 11, 12	1008	2172	3424	4608
5, 8, 10, 11, 12	1008	2180	3436	4568
5, 9, 10, 11, 12	1008	2180	3388	4504
6, 7, 8, 9, 10	996	2044	3144	4056
6, 7, 8, 9, 11	996	2036	3192	4344
6, 7, 8, 9, 12	996	2036	3192	4320
6, 7, 8, 10, 11	996	2044	3204	4304
6, 7, 8, 10, 12	996	2044	3204	4280
6, 7, 8, 11, 12	996	2036	3204	4436
6, 7, 9, 10, 11	996	2044	3156	4196
6, 7, 9, 10, 12	996	2044	3156	4172
6, 7, 9, 11, 12	996	2036	3204	4388
6, 7, 10, 11, 12	996	2044	3216	4420
6, 8, 9, 10, 11	996	2024	3080	4084
6, 8, 9, 11, 12	996	2016	3128	4348
6, 8, 10, 11, 12	996	2024	3140	4308
6, 9, 10, 11, 12	996	2024	3092	4200

Lookouts Operated	6	9	12	15
7, 8, 9, 10, 11	1008	2192	3468	4544
7, 8, 9, 10, 12	1008	2192	3468	4520
7, 8, 9, 11, 12	1008	2184	3516	4808
7, 8, 10, 11, 12	1008	2192	3528	4768
7, 9, 10, 11, 12	1008	2192	3480	4660
8, 9, 10, 11, 12	1008	2172	3404	4548
5, 6, 7, 8, 9, 10	1108	2288	3488	4320
5, 6, 7, 8, 9, 11	1108	2280	3536	4608
5, 6, 7, 8, 9, 12	1108	2280	3536	4584
5, 6, 7, 8, 10, 11	1108	2288	3548	4568
5, 6, 7, 8, 10, 12	1108	2288	3548	4544
5, 6, 7, 8, 11, 12	1108	2280	3548	4700
5, 6, 7, 9, 10, 11	1108	2288	3500	4504
5, 6, 7, 9, 10, 12	1108	2288	3500	4480
5, 6, 7, 9, 11, 12	1108	2280	3548	4696
5, 6, 7, 10, 11, 12	1108	2288	3560	4728
5, 6, 8, 9, 10, 11	1108	2268	3424	4368
5, 6, 8, 9, 10, 12	1108	2268	3424	4324
5, 6, 8, 9, 11, 12	1108	2260	3472	4632
5, 6, 8, 10, 11, 12	1108	2268	3484	4592
5, 6, 9, 10, 11, 12	1108	2268	3436	4528
5, 7, 8, 9, 10, 11	1120	2436	3812	4824
5, 7, 8, 9, 10, 12	1120	2436	3812	4800
5, 7, 8, 9, 11, 12	1120	2424	3860	5088
5, 7, 8, 10, 11, 12	1120	2436	3872	5048
5, 7, 9, 10, 11, 12	1120	2436	3824	4984
5, 8, 9, 10, 11, 12	1120	2416	3748	4848
6, 7, 8, 9, 10, 11	1108	2280	3516	4584
6, 7, 8, 9, 10, 12	1108	2280	3516	4560
6, 7, 8, 9, 11, 12	1108	2272	3564	4848
6, 7, 8, 10, 11, 12	1108	2280	3576	4808
6, 7, 9, 10, 11, 12	1108	2280	3528	4700
6, 8, 9, 10, 11, 12	1108	2260	3452	4588
7, 8, 9, 10, 11, 12	1120	2428	3840	5048
5, 6, 7, 8, 9, 10, 11	1220	2524	3860	4848
5, 6, 7, 8, 9, 10, 12	1220	2524	3860	4824
5, 6, 7, 8, 9, 11, 12	1220	2516	3908	5112
5, 6, 7, 8, 10, 11, 12	1220	2524	3920	5072
5, 6, 7, 9, 10, 11, 12	1220	2524	3872	5008
5, 6, 8, 9, 10, 11, 12	1220	2504	3796	4872
5, 7, 8, 9, 10, 11, 12	1220	2672	4184	5288
6, 7, 8, 9, 10, 11, 12	1220	2516	3888	5088
5, 6, 7, 8, 9, 10, 11, 12	1332	2760	4232	5352

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CRITERION FOR SELECTING THE BEST LOOKOUTS

Let H be the event of a fire occurring in any one of N sectors.

Let Ei be the event of a fire occurring in sector i.

Let Fi/Vj be the event of detecting by lookout a fire in sector i under Vj, (J = 1, ...4) visibility.

Then: $P(((Fi/Vj)Ei)/H)$ represents the probability of detecting a fire by lookouts in occurrence section i under Vj visibility given that a fire has occurred and

$$P(((Fi/Vj)Ei)/H) = P((Fi/Vj)/H) \cdot P(Ei/H)$$

Let (D/Vj)/H be the event of detecting a fire by lookouts under Vj visibility.

Since the events Fi/Vj $\cdot$ Ei/H, (i = 1, -----N) are mutually exclusive (given that a fire occurs, it can only occur in 1 of the N sectors. Thus

$$(P((F_1/Vj \cdot E_1)/H) \; (P((F_2/Vj \cdot E_2)/H = 0 \qquad).$$

∴ $$P(Q/H) = \sum_{i=1}^{n} P((Fi/Vj)/H) \cdot P(Ei/H)$$

Let Q/H be the event of detecting a fire by lookouts given that a fire has occurred.

∴ $$P(Q/H) = \sum_{j=1}^{4} P((D/Vj)/H) \cdot P(Vj)$$

Example

  Suppose that if a fire occurs there is a

  (a)   0.60   probability that it occurs in sector 1.

  (b)   0.30   probability that it occurs in sector 2.

  (c)   0.10   probability that it occurs in sector 3.

(These values can be determined from fire occurrence maps.)

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$$\therefore P(E_1/H) = 0.60$$

$$P(E_2/H) = 0.30$$

$$P(E_3/H) = \underline{0.10}$$

$$1.00$$

An assumption is made that there is an equally likely chance for a fire to occur in any location within any occurrence sector. Based on this assumption, the probability of detecting a fire by lookouts in sector i under visibility condition Vj is the ratio of the area covered by lookouts in sector i under visibility Vj (Kij) to the area of sector i (Ai) given that a fire occurs and that it occurs in sector i.

Thus $P((Fi/Vj)/H) = \dfrac{Kij}{Ai}$

Kij can be found by measuring the area covered in each sector under each of the 4 visibility levels.

Suppose these values are:

J	$P((F_1/Vj)/H)$	$P((F_2/Vj)/H)$	$P((F_3/Vj)/H)$
1	0.15	0.20	0.10
2	0.20	0.30	0.15
3	0.25	0.40	0.25
4	0.35	0.50	0.35

Thus:

$$P((D/V_1)/H) = \sum_{i=1}^{3} P((Fi/V_1)/H) \cdot P(Ei/H)$$

$$= (0.15)(0.60) + (0.20)(0.30) + (0.10)(0.10)$$

$$= 0.160$$

$$P((D/V_2)/H) = (0.20)(0.60) + (0.30)(0.30) + (0.15)(0.10)$$

$$= 0.225$$

$P(D/V_3)/H) = (0.25) (0.60) + (0.40) (0.30) + (0.25) (0.10)$

$= 0.295$

$P((D/V_4)/H) = (0.35) (0.60) + (0.50) (0.30) + (0.35) (0.10)$

$= 0.395$

Suppose the visibility probabilities were as follows:

$P(V_1) = 0.10$

$P(V_2) = 0.20$

$P(V_3) = 0.30$

$P(V_4) = 0.40$
_____
1.00

These could be estimated from daily weather records.

Then:

$$P(Q/H) = \sum_{j=1}^{4} P((D/V_j)/H) \cdot P(V_j)$$

$= (0.16) (0.10) + (0.22) (0.20) + (0.29) (0.30) + (0.39) (0.40)$

$= 0.3075$

Therefore, given that a fire has occurred, the probability that lookouts will detect it is 0.30.

This presents a criterion to evaluate the effectiveness of a specific lookout alternative. For example, out of all possible lookout arrangements of x lookouts out of a total of N, the arrangement that resulted in the highest $P(Q/H)$ would be the most effective.

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LOOKOUTS OPERATED   CRITERION*

(Included in each combination were the
following: lookouts 1, 2, 3, and 4.)

FIVE LOOKOUTS	5		0.536
	6		0.508
	7		0.513
	8		0.529
	9		0.548
	10		0.552
	11		0.502
	12		0.501
SIX LOOKOUTS	5,	6	0.555
	5,	7	0.567
	5,	8	0.581
	5,	9	0.602
	5,	10	0.606
	5,	11	0.557
	5,	12	0.556
	6,	7	0.539
	6,	8	0.555
	6,	9	0.574
	6,	10	0.578
	6,	11	0.528
	6,	12	0.527
	7,	8	0.559
	7,	9	0.579
	7,	10	0.584
	7,	11	0.533
	7,	12	0.532
	8,	9	0.595
	8,	10	0.590
	8,	11	0.551
	8,	12	0.548
	9,	10	0.601
	9,	11	0.568
	9,	12	0.567
	10,	11	0.572
	10,	12	0.571
	11,	12	0.522

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* Best combination results in the highest criterion value.

CRITERION

SEVEN LOOKOUTS				CRITERION
	5,	6,	7	0.586
	6,	6,	8	0.600
	5,	6,	9	0.621
	5,	6,	10	0.625
	5,	6,	11	0.576
	5,	6,	12	0.575
	5,	7,	8	0.610
	5,	7,	9	0.633
	5,	7,	10	0.637
	5,	7,	11	0.587
	5,	7,	12	0.587
	5,	8,	9	0.647
	5,	8,	10	0.641
	5,	8,	11	0.602
	5,	8,	12	0.601
	5,	9,	10	0.655
	5,	9,	11	0.623
	5,	9,	12	0.622
	5,	10,	11	0.627
	5,	10,	12	0.626
	5,	11,	12	0.576
	6,	7,	8	0.585
	6,	7,	9	0.605
	6,	7,	10	0.610
	6,	7,	11	0.559
	6,	7,	12	0.558
	6,	8,	9	0.621
	6,	8,	10	0.616
	6,	8,	11	0.577
	6,	8,	12	0.575
	6,	9,	10	0.627
	6,	9,	11	0.594
	6,	9,	12	0.593
	6,	10,	11	0.598
	6,	10,	12	0.597
	6,	11,	12	0.548
	7,	8,	9	0.625
	7,	8,	10	0.621
	7,	8,	11	0.580
	7,	8,	12	0.579
	7,	9,	10	0.632
	7,	9,	11	0.599
	7,	9,	12	0.598
	7,	10,	11	0.603
	7,	10,	12	0.602
	7,	11,	12	0.552
	8,	9,	10	0.639
	8,	9,	11	0.617
	8,	9,	12	0.614

CRITERION

				CRITERION
SEVEN LOOKOUTS (continued)	8,	10,	11	0.611
	8,	10,	12	0.609
	8,	11,	12	0.570
	9,	10,	11	0.621
	9,	10,	12	0.620
	9,	11,	12	0.588
	10,	11,	12	0.593

					CRITERION
EIGHT LOOKOUTS	5,	6,	7,	8	0.629
	5,	6,	7,	9	0.652
	5,	6,	7,	10	0.656
	5,	6,	7,	11	0.606
	5,	6,	7,	12	0.606
	5,	6,	8,	9	0.666
	5,	6,	8,	10	0.661
	5,	6,	8,	11	0.621
	5,	6,	8,	12	0.620
	5,	6,	9,	10	0.674
	5,	6,	9,	11	0.642
	5,	6,	9,	12	0.641
	5,	6,	10,	11	0.647
	5,	6,	10,	12	0.645
	5,	6,	11,	12	0.595
	5,	7,	8,	9	0.676
	5,	7,	8,	10	0.672
	5,	7,	8,	11	0.630
	5,	7,	8,	12	0.630
	5,	7,	9,	10	0.686
	5,	7,	9,	11	0.653
	5,	7,	9,	12	0.653
	5,	7,	10,	11	0.657
	5,	7,	10,	12	0.657
	5,	7,	11,	12	0.607
	5,	8,	9,	10	0.690
	5,	8,	9,	11	0.668
	5,	8,	9,	12	0.667
	5,	8,	10,	11	0.663
	5,	8,	10,	12	0.662
	5,	8,	11,	12	0.622
	5,	9,	10,	11	0.676
	5,	9,	10,	12	0.675
	5,	9,	11,	12	0.642
	5,	10,	11,	12	0.646
	6,	7,	8,	9	0.651
	6,	7,	8,	10	0.647
	6,	7,	8,	11	0.606
	6,	7,	8,	12	0.605
	6,	7,	9,	10	0.658
	6,	7,	9,	11	0.625

CRITERION

EIGHT LOOKOUTS (continued)					CRITERION
6,	7,	9,	12		0.624
6,	7,	10,	11		0.629
6,	7,	10,	12		0.628
6,	7,	11,	12		0.578
6,	8,	9,	10		0.665
6,	8,	9,	11		0.643
6,	8,	9,	12		0.640
6,	8,	10,	11		0.637
6,	8,	10,	12		0.635
6,	8,	11,	12		0.596
6,	9,	10,	11		0.647
6,	9,	10,	12		0.646
6,	9,	11,	12		0.614
6,	10,	11,	12		0.619
7,	8,	9,	10		0.668
7,	8,	9,	11		0.646
7,	8,	9,	12		0.645
7,	8,	10,	11		0.642
7,	8,	10,	12		0.641
7,	8,	11,	12		0.599
7,	9,	10,	11		0.652
7,	9,	10,	12		0.651
7,	9,	11,	12		0.618
7,	10,	11,	12		0.622
8,	9,	10,	11		0.660
8,	9,	10,	12		0.658
8,	9,	11,	12		0.636
8,	10,	11,	12		0.630
9,	10,	11,	12		0.641

NINE LOOKOUTS					CRITERION
5,	6,	7,	8,	9	0.695
5,	6,	7,	8,	10	0.692
5,	6,	7,	8,	11	0.649
5,	6,	7,	8,	12	0.649
5,	6,	7,	9,	10	0.705
5,	6,	7,	9,	11	0.672
5,	6,	7,	9,	12	0.672
5,	6,	7,	10,	11	0.676
5,	6,	7,	10,	12	0.676
5,	6,	7,	11,	12	0.626
5,	6,	8,	9,	10	0.709
5,	6,	8,	9,	11	0.687
5,	6,	8,	9,	12	0.686
5,	6,	8,	10,	11	0.682
5,	6,	8,	10,	12	0.681
5,	6,	8,	11,	12	0.641
5,	6,	9,	10,	11	0.695
5,	6,	9,	10,	12	0.694

CRITERION

NINE LOOKOUTS (continued)	5,	6,	9,	11,	12	0.661
	5,	6,	10,	11,	12	0.665
	5,	7,	8,	9,	10	0.719
	5,	7,	8,	9,	11	0.696
	5,	7,	8,	9,	12	0.696
	5,	7,	8,	10,	11	0.693
	5,	7,	8,	10,	12	0.693
	5,	7,	8,	11,	12	0.650
	5,	7,	9,	10,	11	0.706
	5,	7,	9,	10,	12	0.706
	5,	7,	9,	11,	12	0.673
	5,	7,	10,	11,	12	0.678
	5,	8,	9,	10,	11	0.711
	5,	8,	9,	10,	12	0.710
	5,	8,	9,	11,	12	0.688
	5,	8,	10,	11,	12	0.683
	5,	9,	10,	11,	12	0.695
	6,	7,	8,	9,	10	0.694
	6,	7,	8,	9,	11	0.672
	6,	7,	8,	9,	12	0.671
	6,	7,	8,	10,	11	0.668
	6,	7,	8,	10,	12	0.667
	6,	7,	8,	11,	12	0.625
	6,	7,	9,	10,	11	0.678
	6,	7,	9,	10,	12	0.677
	6,	7,	9,	11,	12	0.644
	6,	7,	10,	11,	12	0.649
	6,	8,	9,	10,	11	0.686
	6,	8,	9,	10,	12	0.684
	6,	8,	9,	11,	12	0.662
	6,	8,	10,	11,	12	0.656
	6,	9,	10,	11,	12	0.667
	7,	8,	9,	10,	11	0.689
	7,	8,	9,	10,	12	0.688
	7,	8,	9,	11,	12	0.665
	7,	8,	10,	11,	12	0.661
	7,	9,	10,	11,	12	0.671
	8,	9,	10,	11,	12	0.679

TEN LOOKOUTS	5,	6,	7,	8,	9,	10	0.738
	5,	6,	7,	8,	9,	11	0.715
	5,	6,	7,	8,	9,	12	0.715
	5,	6,	7,	8,	10,	11	0.712
	5,	6,	7,	8,	10,	12	0.712
	5,	6,	7,	8,	11,	12	0.670
	5,	6,	7,	9,	10,	11	0.725
	5,	6,	7,	9,	11,	12	0.725
	5,	6,	7,	9,	11,	12	0.692
	5,	6,	7,	10,	11,	12	0.697

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CRITERION

TEN LOOKOUTS								CRITERION
(continued)	5,	6,	8,	9,	10,	11		0.730
	5,	6,	8,	9,	10,	12		0.729
	5,	6,	8,	9,	11,	12		0.707
	5,	6,	8,	10,	11,	12		0.702
	5,	6,	9,	10,	11,	12		0.714
	5,	7,	8,	9,	10,	11		0.739
	5,	7,	8,	9,	10,	12		0.739
	5,	7,	8,	9,	11,	12		0.716
	5,	7,	8,	10,	11,	12		0.713
	5,	7,	9,	10,	11,	12		0.726
	5,	8,	9,	10,	11,	12		0.731
	6,	7,	8,	9,	10,	11		0.715
	6,	7,	8,	9,	10,	12		0.714
	6,	7,	8,	9,	11,	12		0.691
	6,	7,	8,	10,	11,	12		0.687
	6,	7,	9,	10,	11,	12		0.697
	6,	8,	9,	10,	11,	12		0.705
	7,	8,	9,	10,	11,	12		0.708

ELEVEN LOOKOUTS								
	5,	6,	7,	8,	9,	10,	11	0.738
	5,	6,	7,	8,	9,	10,	12	0.738
	5,	6,	7,	8,	9,	11,	12	0.715
	5,	6,	7,	8,	10,	11,	12	0.712
	5,	6,	7,	9,	10,	11,	12	0.725
	5,	6,	8,	9,	10,	11,	12	0.730
	5,	7,	8,	9,	10,	11,	12	0.739
	6,	7,	8,	9,	10,	11,	12	0.715

AREA TO BE PATROLLED

(for a given sector)

Variable Name	Meaning
S	speed of the aircraft in miles per hour
C	cost per hour of the aircraft
V (I)	four levels of visibility, I = 6, 9, 12 or 15
N (I, J)	the number of days having I visibility and J danger (four danger classes, J = 1, 2, 3, or 4)
A (J, K)	area to be patrolled each J danger class day in sector K (five sectors, K = 1, 2, 3, 4, or 5)
Amt (J, K)	amount available to spend on a J danger class day in sector K

A (J, K) is the unknown. It is known though, that A (J, K) must be such that the total cost of patrolling on J danger days regardless of the visibility must be Amt (J, K). For a given danger class J then:

$$\text{Amt } (J, K) = \sum_{I-6}^{15,3} N (I, J) \times A (J, K) \times C / S \times V (I)$$

$$= A (J, K) \times \frac{C}{S} \sum_{I-6}^{15,3} \frac{N (I, J)}{V (I)}$$

OR

$$A (J, K) = \frac{\text{Amt } (J, K) \times S}{C} \times \left(\sum_{I-6}^{15,3} \frac{N (I, J)}{V (I)} \right)^{-1}$$

HOURLY DANGER INDEX CLASS VALUES USED

IN THE FIRE MODEL

HOUR OF DAY	LOW	MODERATE	HIGH	EXTREME
1	1	1	1	2
2	1	1	1	2
3	1	1	1	2
4	1	1	1	2
5	1	1	1	2
6	1	1	1	2
7	1	1	2	2
8	1	1	2	2
9	1	1	2	2
10	1	1	2	3
11	1	2	2	3
12	1	2	3	4
13	1	2	3	4
14	1	2	3	4
15	1	2	3	4
16	1	2	3	4
17	1	2	3	4
18	1	2	3	4
19	1	2	2	3
20	1	2	2	3
21	1	1	2	3
22	1	1	2	3
23	1	1	2	2
24	1	1	2	2

Beall, H. W. 1946. Forest Fire Danger Tables. Forest Fire Research Note No. 12, Canada Department of Mines and Resources, Lands, Parks and Forests Branch, Dominion Forest Service.

FIRE MODEL* PREDICTIONS OF AREA BURNED

ELAPSED TIME (HOURS)	LOW	(Area Burned in Acres) MODERATE	HIGH	EXTREME
1	.11	.244	.697	3.48
2	.122	.506	2.56	22.1
3	.134	.938	6.83	78.1
4	.146	1.6	15	203
5	.16	2.56	29	440
6	.175	3.91	50.9	840
7	.191	5.72	83.5	1,460
8	.207	8.1	130	2,390
9	.225	11.2	193	3,690
10	.244	15	276	5,460
11	.264	19.8	385	7,810
12	.286	25.6	522	10,800
13	.308	32.6	694	14,700
14	.332	41	904	19,500
15	.358	50.9	1,160	25,300
16	.384	62.5	1,460	32,400
17	.412	76	1,830	40,900
18	.442	91.6	2,250	51,000
19	.473	109	2,750	62,800
20	.506	130	3,320	76,500
21	.541	153	3,980	92,400
22	.577	179	4,740	111,000
23	.615	208	5,590	131,000
24	.656	240	6,560	155,000
25	.697	276	7,640	182,000
26	.741	317	8,860	212,000
27	.787	361	10,200	245,000
28	.835	410	11,700	283,000
29	.886	463	13,400	324,000
30	.938	522	15,200	370,000

*From the United Aircraft model.

DAILY FIRE OCCURRENCE TIME *

HOUR	PROBABILITY
1	0 – .023
2	.024 – .042
3	.043 – .056
4	.057 – .075
5	.076 – .103
6	.104 – .142
7	.143 – .196
8	.197 – .244
9	.245 – .288
10	.289 – .325
11	.326 – .361
12	.362 – .399
13	.400 – .443
14	.444 – .500
15	.501 – .567
16	.568 – .645
17	.646 – .726
18	.727 – .795
19	.796 – .854
20	.855 – .910
21	.911 – .952
22	.953 – .978
23	.979 –1.000
24	1.000 –1.000

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*Barrows, 1951.

LIGHTNING FIRE DISTRIBUTION*

HOUR	PROBABILITY
1	0 - .192
2	.193 - .239
3	.240 - .262
4	.263 - .280
5	.281 - .291
6	.292 - .304
7	.305 - .315
8	.316 - .324
9	.325 - .335
10	.336 - .342
11	.343 - .358
12	.359 - .370
13	.371 - .382
14	.383 - .397
15	.398 - .412
16	.413 - .429
17	.430 - .440
18	.441 - .455
19	.456 - .469
20	.470 - .488
21	.489 - .503
22	.504 - .521
23	.522 - .532
24	.533 - .548
25	.549 - .559
26	.560 - .570
27	.571 - .583
28	.584 - .593
29	.594 - .607
30	.608 - .618
31	.619 - .629
32	.630 - .640
33	.641 - .652
34	.653 - .663
35	.664 - .673
36	.674 - .683
37	.684 - .692
38	.693 - .701
39	.702 - .710
40	.711 - .719

*Barrows, 1951.

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HOUR	PROBABILITY
41	.720 - .728
42	.729 - .737
43	.738 - .743
44	.744 - .751
45	.752 - .759
46	.760 - .766
47	.767 - .772
48	.773 - .779
49	.780 - .784
50	.785 - .789
51	.790 - .795
52	.796 - .799
53	.800 - .804
54	.805 - .807
55	.808 - .812
56	.813 - .816
57	.817 - .820
58	.821 - .824
59	.825 - .827
60	.828 - .831
61	.832 - .835
62	.836 - .837
63	.838 - .840
64	.841 - .843
65	.844 - .845
66	.846 - .847
67	.848 - .848
68	.849 - .850
69	.851 - .852
70	.853 - .854
71	.855 - .855
72	.856 - .856
73	.857 - .859
74	.860 - .862
75	.863 - .864
76	.865 - .865
77	.866 - .866
78	.867 - .868
79	.869 - .870
80	.871 - .871
81	.872 - .872
82	.873 - .874
83	.875 - .875
84	.876 - .877
85	.878 - .878
86	.879 - .880
87	.881 - .881
88	.882 - .883
89	.884 - .885
90	.886 - .886

HOUR	PROBABILITY
91	.887 – .888
92	.889 – .889
93	.890 – .890
94	.891 – .891
95	.891 – .891
96	.892 – .892
5	.894 – .925
6	.926 – .949
7	.950 – .968
8	.968 – .968
9	.969 – .978
10	.979 – .982
11	.983 –1.000
12	1.000 –1.000

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CALCULATION OF AIR PATROL COST

Flts(I,D) = No. of patrols over area not covered in Sector I on a danger class day of D.

V = Visibility class day (miles).

S = Speed of aircraft (mph).

A(I,V) = The area not covered by lookouts in Sector I during a visibility of V miles.

C = cost/hr of aircraft.

V x S = area/hr covered during a visibility of V and a speed of S.

N(D,V) = No. of days in each danger-visibility class.

$\dfrac{A(I,V)}{V \times S}$ = Hours required to cover once the area not covered by lookouts in Sector I during visibility of V.

$\dfrac{A(I,V)}{V \times S}$ x C = Cost to patrol once the above area.

Flts(I,D) x $\dfrac{A(I,V)}{V \times S}$ x C = Cost of patrolling Sector I, Flts(I,D) times for a given danger.

N(D,V) x Flts(I,D) x $\dfrac{A(I,V)}{V \times S}$ x C = The cost of patrolling Sector I, Flts(I,D) for a visibility of V and a danger of D.

Keeping the Sector and Danger constant, then:

$\displaystyle\sum_{V=1}^{4}$ N(D,V) x Flts(I,D) x $\dfrac{A(I,V)}{V \times S}$ x C = The total cost of patrolling Flts(I,D) times on a danger of D in Sector I.

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Let the total cost = TC(I,D)

$$TC(I,D) = \left(N(D,1) \times Flts(I,D) \times \frac{A(I,1)}{15 \times S} \times C \right) +$$

$$\left(N(D,2) \times Flts(I,D) \times \frac{A(I,2)}{12 \times S} \times C \right) +$$

$$\left(N(D,3) \times Flts(I,D) \times \frac{A(I,3)}{9 \times S} \times C \right) +$$

$$\left(N(D,4) \times Flts(I,D) \times \frac{A(I,4)}{6 \times S} \times C \right)$$

$$TC(I,D) = \frac{Flts(I,D) \times C}{S} \left(\frac{N(D,1) \times A(I,1)}{15} + \frac{N(D,2) \times A(I,2)}{12} \right.$$

$$\left. + \frac{N(D,3) \times A(I,3)}{9} + \frac{N(D,4) \times A(I,4)}{6} \right)$$

$$Flts(I,D) = \frac{TC(I,D) \times S}{C} \left(\frac{15}{N(D,1) \times A(I,1)} + \frac{12}{N(D,2) \times A(I,2)} \right.$$

$$\left. + \frac{9}{N(D,3) \times A(I,3)} + \frac{6}{N(D,4) \times A(I,4)} \right)$$

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LOWEST AVERAGE AREA BURNED/LOOKOUT COMBINATION
(PER ANNUAL BUDGET)

Lookout Combina-tion	YEARLY BUDGET LEVELS											
	$20,000			$25,000			$30,000			$35,000		
	Av. Area Burned	Lookout Cost	Aircraft Cost	Av. Area Burned	Lookout Cost	Aircraft Cost	Av. Area Burned	Lookout Cost	Aircraft Cost	Av. Area Burned	Lookout Cost	Aircraft Cost
		$	$		$	$		$	$		$	$
4	0.558	9,400	10,600	0.508	9,400	15,600	0.495	9,400	20,600	0.431	9,400	25,600
5	0.555	11,750	8,250	0.486	11,750	13,250	0.395	11,750	18,250	0.395	11,750	23,250
6	0.567	14,100	5,900	0.473	14,100	10,900	0.371	14,100	15,900	0.348	14,100	20,900
7				0.545	16,450	8,550	0.424	16,450	13,550	0.389	16,450	18,550
8				0.559	18,800	6,200	0.381	18,800	11,200	0.325	18,800	16,200
9							0.360	21,150	8,850	0.331	21,150	13,850
10							0.396	23,500	6,500	0.326	23,500	11,500
11							0.449	15,850	4,150	0.268	25,850	9,150

Table shows resulting criterion values (average area burned/fire) for each of the 11 best lookout combinations for each budget level. Also shown is division of annual budget between lookout and air patrol coverage.