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AN EXPERIMENTAL SYSTEM TO PREDICT HOURLY FOREST FIRE OCCURRENCE AND TO ASSIST IN AERIAL DETECTION ROUTE PLANNING

BY

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An Experimental System to Predict Hourly Forest Fire Occurrence and to Assist in Aerial Detection Route Planning

Historical Background of the Study:

The Forest Fire Research Institute began to apply the techniques of operations research to fire control problems in a serious manner in 1970. At that time a very sophisticated high-altitude infrared detection device had just been constructed by the U.S. Forest Service and we set about to determine whether or not such a device would have an application in Canada.

After completion of that study came a request from Ontario to study the problems of visual air patrolling. At that time Quebec had completely switched to air patrols and Ontario was mid-way through the conversion from lookouts to air patrolling. Ontario had had enough experience with air patrols by 1972 to confirm the large savings associated with this method, however, in general, the effectiveness of the patrols was no better than that of the lookouts.

After studying the air patrol system we concluded that the best way to improve it was to improve our predictions of when and where fires were going to occur and to use these to schedule and route the flights better. Thus our resulting research was partitioned into two parts. Part one dealt with the development of a scheme to predict when and where fires might occur and part two dealt with the routing of flights given a fire occurrence forecast.

About 50 per cent of the fires of Northern Ontario and Quebec are lightning caused. These fires presented a major problem in that there was no reliable method to predict their occurrence. A special study was started to investigate the various methods of thunderstorm tracking. It was felt that if we could identify those areas over which storms had passed the lightning-fire search area would be substantially reduced. Weather radar, long range spherics devices and satellite surveillance methods were rejected mainly because of their high costs. A very attractive alternative was a network of limited range lightning sensors. These sensors would have a maximum range between 20 to 30 miles and would count at least some of the lightning strikes falling within this radius. They would be located at each forestry weather station. The lightning count of the previous 24 hour period would be read each morning and plots of thunderstorm occurrence then would be made.

We built and tested many different types of counters -- infrared heat sensors, radio receiver types, magnetic pulse detectors and electrostatic field detectors. Finally, we settled on the electrostatic field type as being the most effective and located 20 of these at fire control weather stations in a manner that pretty well covered northwestern Ontario (60,000 sq. miles). The cost of each sensor was about $225. (Slides 1 - 7).

By the end of that 1973 season we could see that the counter network could track storms very well but more important -- we discovered a very crude but fairly reliable scheme for predicting when and where lightning fires were likely to occur. Based only on the 1973 observations we concluded that if more than 50 counts were recorded on a sensor and the medium fuel moisture content measured before the storm at the sensor's weather station were dry, the area in the vicinity of the sensor could expect, on the average, about a fire every 2000 square miles. If the fuels were wet, only a fire every 10,000 square miles was expected. And, of course, if there were fewer than 50 counts no lightning fires were expected. (Slides 8 - 10).

With regard to predicting man-caused fires it has been well known that the occurrence of man-caused fires is highly correlated with the dryness of fine fuels in a specific area. Historical data provide a good basis to determine the average number of man-caused fires per fine fuel moisture class day associated with a particular weather station area. Also, in a similar manner the effectiveness of the public in detecting fires in local areas, could be estimated from historical data.

We assembled all these data and relationships into a computer program that predicted the number of fires that should be located each hour in each 400 square mile cell of a grid covering northwestern Ontario. Each cell of the grid was associated with a nearest weather station.

Parallel to our fire prediction work we researched methods for routing aircraft through grid structures containing various numbers of fires in the cells. Eventually a procedure was devised that could determine the best route through the grid of cells such that the sum of the fires along the chosen route was higher than along any other route and such that the aircraft returned to its home base before it ran out of fuel. This procedure was linked to the fire prediction system so that air patrol routes and their potential effectiveness could be evaluated at any time of the day.

To test this system, we first simulated in the computer its operation during the 1972 northwestern Ontario fire season. We attempted to answer the question "how would the system have performed had we relied upon it during the 1972 season?" This, of course involved a comparison of the computer predicted results to the actual 1972 field experience. For this test the computer dispatched patrols at the same time that patrols were actually sent out that season. The computer-routed patrols came within 10 miles of 176 of the 1972 fires (total of 524) and the actual patrols came within 125 fires. When the machine was allowed to select the take-off times, 107 computer-planned patrols came within 10 miles of 105 fires compared to 271 actual patrols coming within 10 miles of 125 fires.

Encouraged by these results we set out to build a computerized fire prediction and patrol system that could be used on a daily basis. In the spring of 1974 we installed two such systems, one in northwestern Ontario at Dryden and one in Southwestern Quebec at Maniwaki.

Unfortunately northwestern Ontario had a disastrous fire year beginning in June and lasting the remainder of the season. Little or no time was available to conduct this experiment. The 1974 season was effectively a lost research year with regard to testing the system there. We were more fortunate in Southwestern Quebec, however, and it is this experience that I want to describe.

1974 Quebec Experience in Using the Fire Occurrence and Prediction and Patrol Route Planning System

The 30,000 square mile area in which the experimental system was established fell under the protection of the Societe de Conservation de L'Outaouais. This area was chosen chiefly because of its close proximity to Ottawa and most important, its organizational structure was such that a central computer operation was feasible and potentially useful. All weather data are collected and analysed at the Maniwaki center. All fires are immediately reported to the center and the center has complete control of all detection and initial attack dispatches for the Outaouais Region. A high degree of central planning and control of the fire organization is essential for this computerized system to be useful.

Immediately we established a dense network of 24 lightning counters (slides 11 - 14). (Last slide is map of counters). Each of these locations also collected weather data necessary for fire danger index calculations. The lightning counters were read each morning at 8 a.m. and these data were forwarded to the Maniwaki center for the morning fire prediction update.

A computer communications terminal was installed at the Maniwaki center and was connected by telephone line to a large computer at Toronto, 350 miles away. It should be pointed out that any TELEX or TWX unit in North America was capable of accessing the Toronto computer. Indeed, the TWX units at the Maniwaki headquarters were occasionally used when problems developed in the more sophisticated system. (Slides 15, 16.)

Five separate computer programs could be used by the Maniwaki center. The update program was the most important of these. It carried out the task of updating, to the current time, the fire occurrence forecast in each grid cell. It was also possible to forecast fire occurrence up to 36 hours ahead with this program. The procedure for updating a fire forecast is given in the following Vugraphs (1 - 12).

Input required for fire occurrence forecasting can be divided into two parts. Part one deals with grid data, historical fire occurrence and public detection data. These include:

(a) Number of rows and columns in the grid, size of the cell, and the number of weather stations.

(b) The number of the weather station nearest each cell in the grid.

(c) The average number of man-caused fires that occurred in the past (say during the previous 5 to 10 fire seasons) per Fine Fuel Moisture Code class day for each cell in the grid.

(d) This week-day variation in man-caused fire occurrence expressed in percentage terms of the average.

(e) The ratio of the total number of public detections to the total number of fires burning each hour (of the 24 hour day) for each weather station area.

(f) A subjective rating for each cell representing the "urgency" or need for early detection of fires. This rating incorporates values at risk, fuel type, potential damage, and the fire control resource situation.

Part two of the input requirements deals with information that must be given to the computer at the time of each update. These include part of all of the following:

(a) The previous noon's fine fuel moisture and duff moisture index for each weather station.

(b) The next noon's forecasted fine fuel and duff moisture indexes.

(c) The visibility at each weather station (for the period of the update).

(d) The forecasted index values (and previous noon's index values when appropriate) must be changed as frequently as major deviations from the forecast (or actual measurements occur. This is necessary to keep the fire predictions current.

(e) The time and location (in terms of cell number) of each publicly reported fire must be logged into the system.

(f) Each patrol route and their detected fires must be logged into the system.

(g) Estimated thunderstorm occurrence times and corresponding sensor counts from each weather station.

All inputs must be logged into the system before the system's "clock" passes the time of the event. It should be noted that, for 1975, fire control agencies with the fire weather index package running on the same computer can link the two together. In this case the weather program will supply the fire occurrence package with the appropriate current and forecasted indexes -- thus avoiding the need to log in a large number of weather indexes. Output available after a fire occurrence forecast run includes:

(a) The current time, day of week, date and month plus the time, date and month of the previous update.

(b) A matrix of numbers representing the expected number of fires (multiplied by 1000) in each cell at the "current" time.

(c) The expected total number of fires "currently" burning and the expected total number of fires to be reported by the public.

(d) The chance that not one or more public reports should have been (or will be) made between the last update time and the time of the "current" update time.

(e) The chance of there being 0, 1, 3, --- or fewer fires currently burning.

(f) The "urgency" rating (in 4 categories) for each cell for the current time.

(g) The sum of the urgencies for all cells.

Vugraphs 13 & 14 contain examples of this output.

This output is available from the computer usually within 15 minutes of the updating time. It is held in the computer memory until the next update run so that other field stations or headquarters can see the current fire occurrence situations. In addition to the above output, the complete fire occurrence, urgency and separate weather index files created on the last update may be viewed at any time.

Three other programs were associated with program Update. A program called "Create" is used to initialize the fire occurrence forecast at the beginning of each season or at any other time that a major failure occurs. It is capable of reinitializing all or any part of the fire occurrence forecast and weather file. Program "Backup" enables the user to immediately recover from an update that had been based on erroneous data. Program "LIST" was available during the 1974 season to enable a user to view the latest fire forecast and weather data file being held in the computer. This program will not be necessary in the 1975 version because of an improved file structure system.

Program "Patrol" is the sequential routing program that determines the optimal routes for from 1 to 12 patrols in terms of maximizing the number of potential fire detections or maximizing the sum of the urgency values along each patrol route. A route is chosen in a manner such that no other route will result in a higher cumulated sum of cell values.

For input this package requires:

(a) The criterion (Fire Occurrence or Urgency sum maximization).

(b) The starting and ending airport cells for each patrol.

(c) The speed and duration of each patrol.

Each computer calculated route is given in terms of a sequence of cell numbers that can be readily transferred to a map. Along with each route the expected number of detections is given plus the chance of that patrol detecting both no fires and one or more fires (Vugraphs 15 & 16).

Unfortunately, this package assumes that each patrol is dispatched sequentially. That is, the route for patrol number one is calculated first. The route for patrol number 2 is calculated after taking into account the likely effectiveness of patrol number 1. Patrol route number n is calculated after the previous n-1 routes have been used to adjust the likely fire occurrence forecast or urgency. The program produces reasonable patrol routes only when one aircraft is dispatched from an airport at a given time. A major error occurs when two or more aircraft are dispatched from the same airport at the same time.

In addition to this program, two new patrol programs will be available for the Outaouais region during the 1975 season. The first of these programs evaluates a list of fixed patrol routes. As many routes can be incorporated as desired. Also, the program is structured so that 3 levels of intensities of coverage can be handled. The routes of each intensity level are pre-programmed into the system. Each new route is evaluated in terms of either the current fire occurrence forecast or urgency forecast. For input, all that is required is the intensity level (A, B, or C) and whether or not the evaluation is to be done on the fire forecast or urgency matrix. Output takes the form of a list of patrol route labels and their expected rewards. In addition, the total expected reward is calculated for all patrols in the chosen intensity level (Vugraph 17).

The second new patrol program available for 1975 determines simultaneously the optimal routes for two air patrols. These can be from the same airport or two separate airports. This program overcomes the major objection of the sequential planning program used during the 1974 season. Its limitation is that only two routes can be determined. The computer time required for 3 or more routes currently is prohibitive.

For input this program requires the home airports for each aircraft. These can be the same airport but unlike the sequential program, both aircraft must return to their home airport(s). Each flight is assumed to be 2.5 hours in length at a speed of 130 mph.

Output from this program is similar to the sequential program.

Summary of 1974 Results in the Outaouais Region

Throughout the 1974 season weaknesses were identified in the system and improvements added where possible. Some of these included:

(a) Adjusting the aircraft and public detection capability as the moisture content of the fine fuel varied.

(b) Treating visibility on a per weather station area basis rather than on a region basis.

(c) Adjusting the man-caused occurrence rates for cells associated with new berry picking areas.

(d) Improving the input error detection capability.

Vugraphs 18, 19, and 20 compare on a daily basis the computer fire forecasts and the actual fire occurrences. On the average, the update package was used three times a day and on some days as many as six updates were made.

Based on the 1974 experience another set of changes have been made to the system for 1975.

(a) A complete revision of the storage file structure.

(b) The inclusion of a natural extinguishing factor during wet weather.

(c) The addition of an urgency criterion.

(d) The addition of a day-of-the-week variation in man-caused fire occurrence.

(e) Two new patrol routing programs.

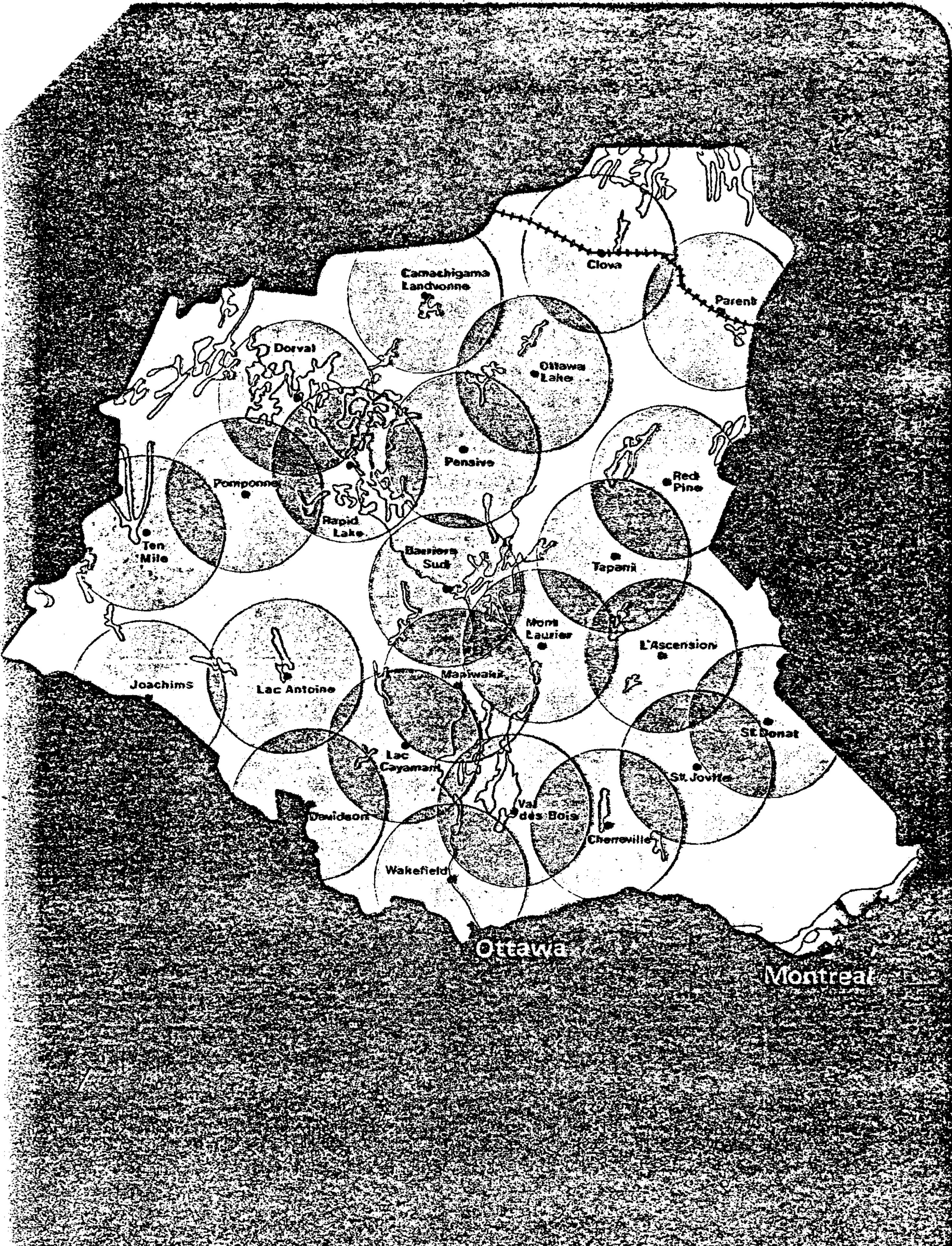
(f) A computerized fire weather package has been directly linked to the weather file.

The estimated monthly cost of running the system was $1500. This includes $300 per month for communications terminal rental, $100 per month for communications line rental, $800 computer cost and $300 per month for a part-time operator.

Although this computer package was developed for aiding in detection planning, it became clear last season that its main use was for fire occurrence forecasting. Detection was of secondary interest. The fire occurrence forecast package provides a means to integrate and summarize a vast amount of weather data, historical fire occurrence data, recent detection activity, and current fire reports into a useful format for fire control decision makers.

In the future, if fire control agencies are to make use of this system and many other similar decision-assisting tools now under development, they must begin now to build up some expertise in the computing field. An experienced programmer with fire control knowledge is required to set up and maintain this system.

#1


Camachigama
Landvonne
Clova
Parent
Dorval
Ottawa
Lake
Pensive
Pomponne
Rapid
Lake
Red
Pine
Ten
Mile
Barriere
Sud
Tapani
Mont
Laurier
L'Ascension
Maniwaki
Joachims
Lac Antoine
St Donat
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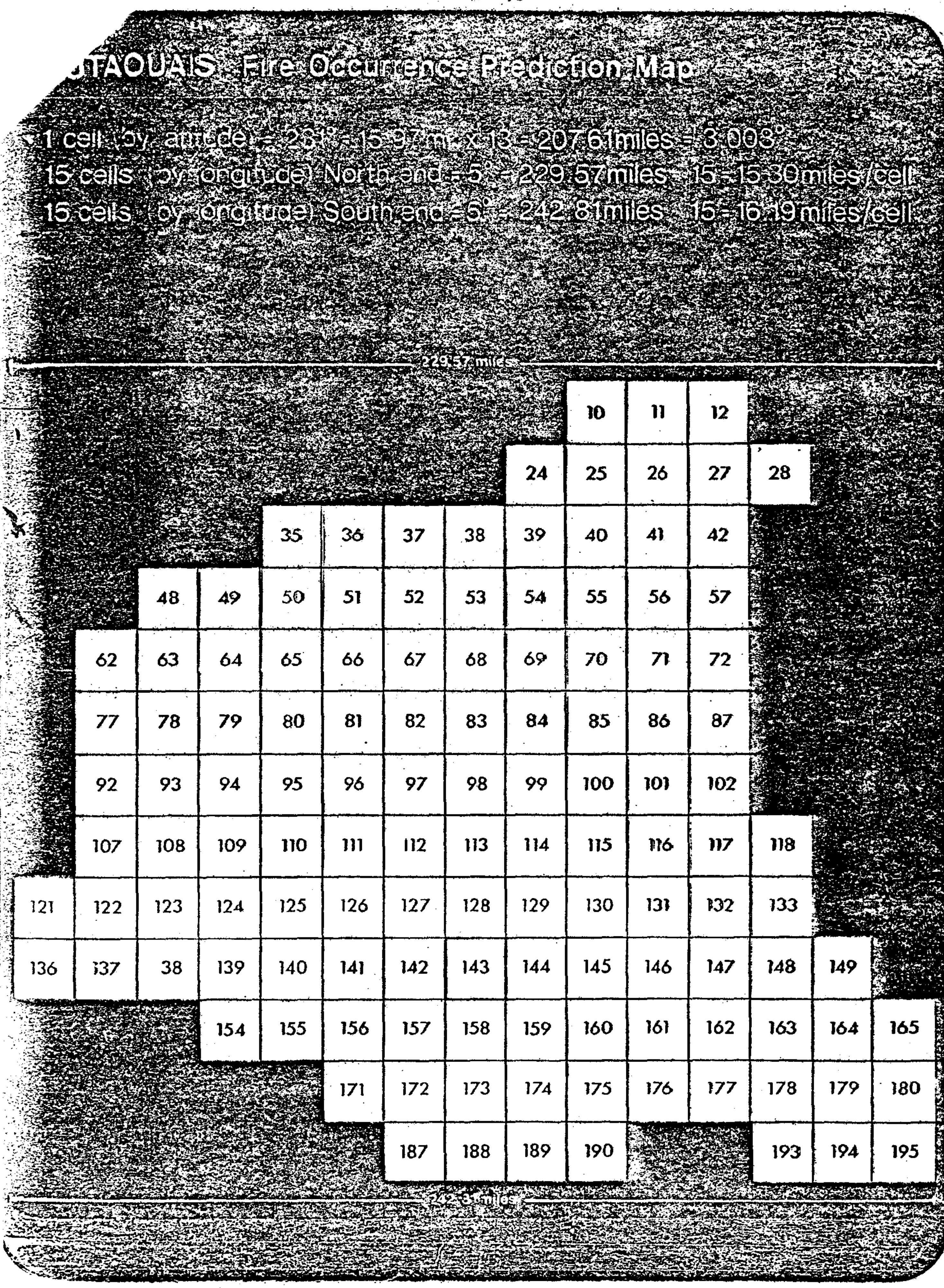
Cayamant
St. Jovite
Davidson
Val
des Bois
Chenreville
Wakefield
Ottawa
Montreal

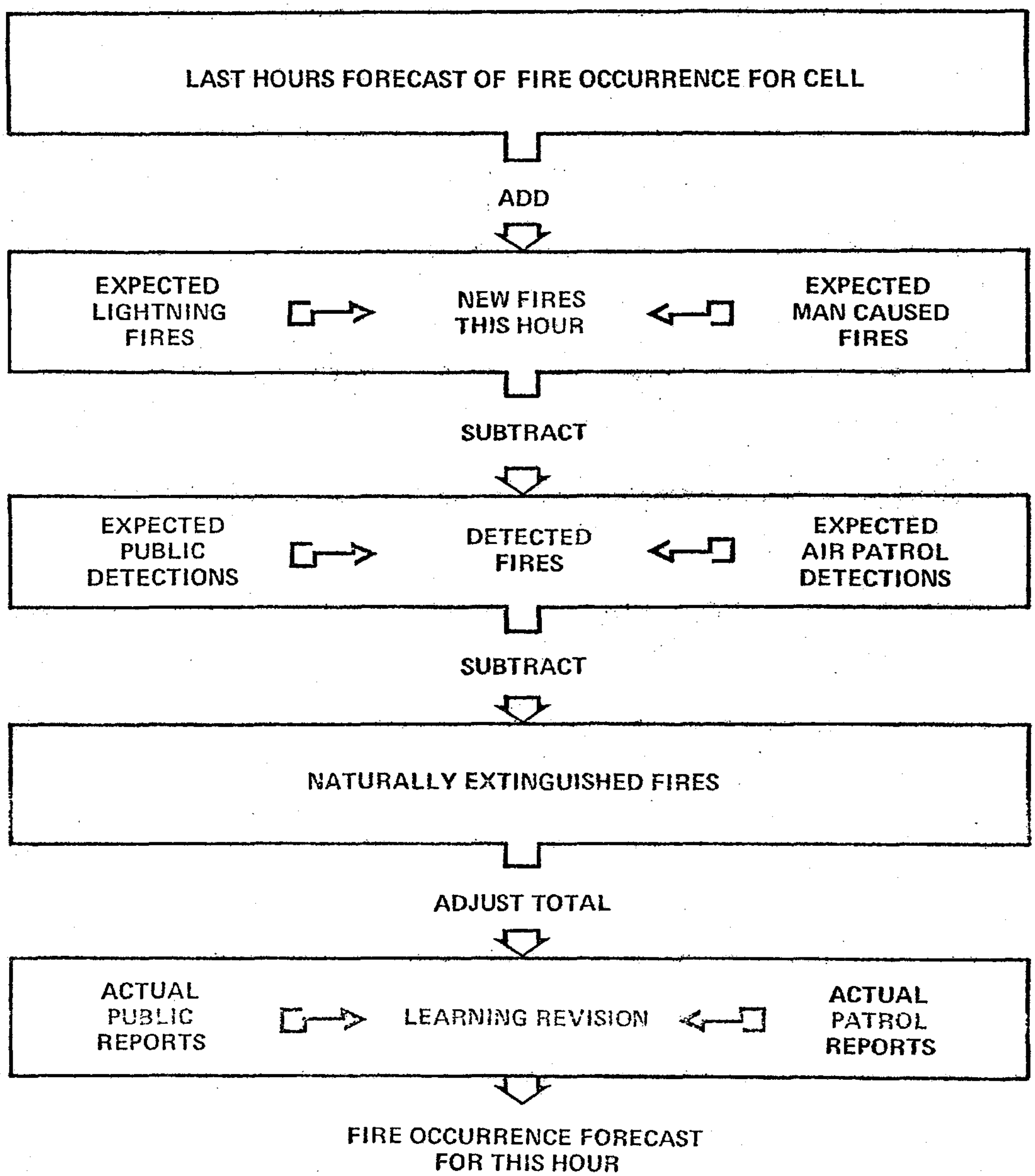
2



OUTAOUAIS Fire Occurrence Prediction Map
1 cell (by latitude) = .231° = 15.97 mi x 13 = 207.61miles = 3.008°
15 cells (by longitude) North end = 5° = 229.57miles ÷ 15 = 15.30miles/cell
15 cells (by longitude) South end = 5° = 242.81miles ÷ 15 = 16.19miles/cell
229.57 miles
10 11 12
24 25 26 27 28
35 36 37 38 39 40 41 42
48 49 50 51 52 53 54 55 56 57
62 63 64 65 66 67 68 69 70 71 72
77 78 79 80 81 82 83 84 85 86 87
92 93 94 95 96 97 98 99 100 101 102
107 108 109 110 111 112 113 114 115 116 117 118
121 122 123 124 125 126 127 128 129 130 131 132 133
136 137 38 139 140 141 142 143 144 145 146 147 148 149
154 155 156 157 158 159 160 161 162 163 164 165
171 172 173 174 175 176 177 178 179 180
187 188 189 190 193 194 195
242.81 miles

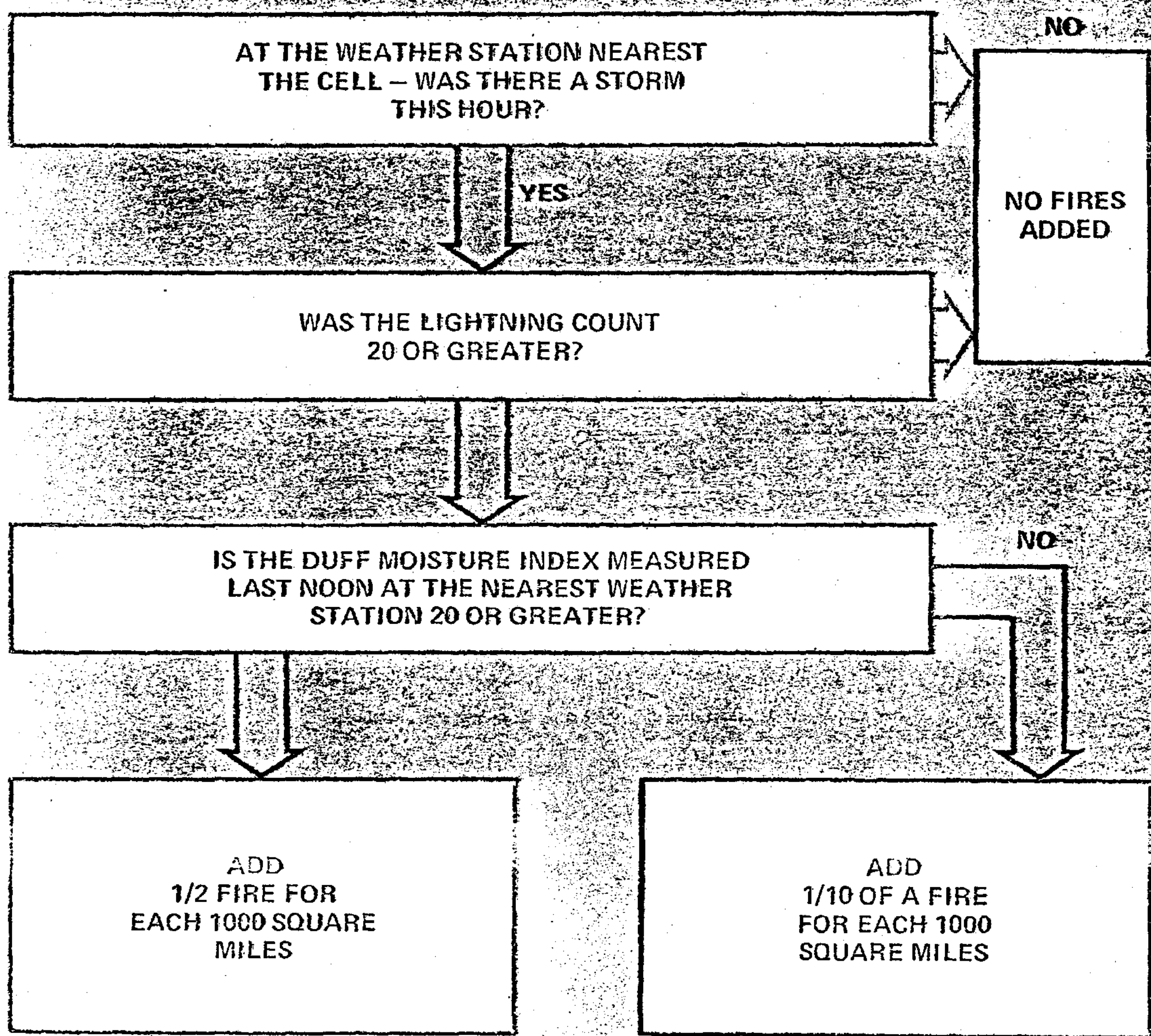
#3

HOURLY PREDICTION OF FIRE OCCURRENCE FOR A GIVEN CELL



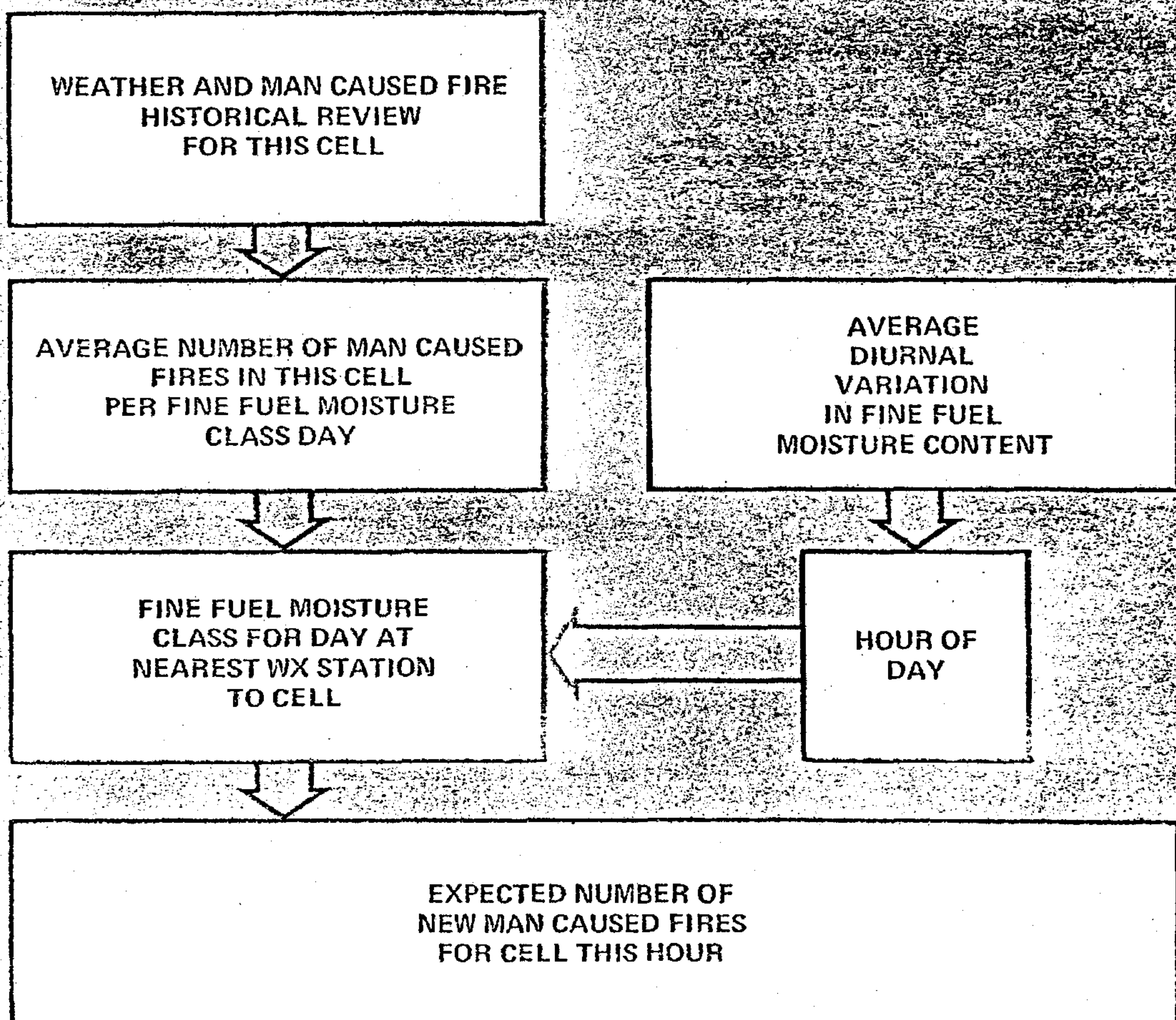
#4

HOURLY PREDICTION OF LIGHTNING FIRES IN A CELL



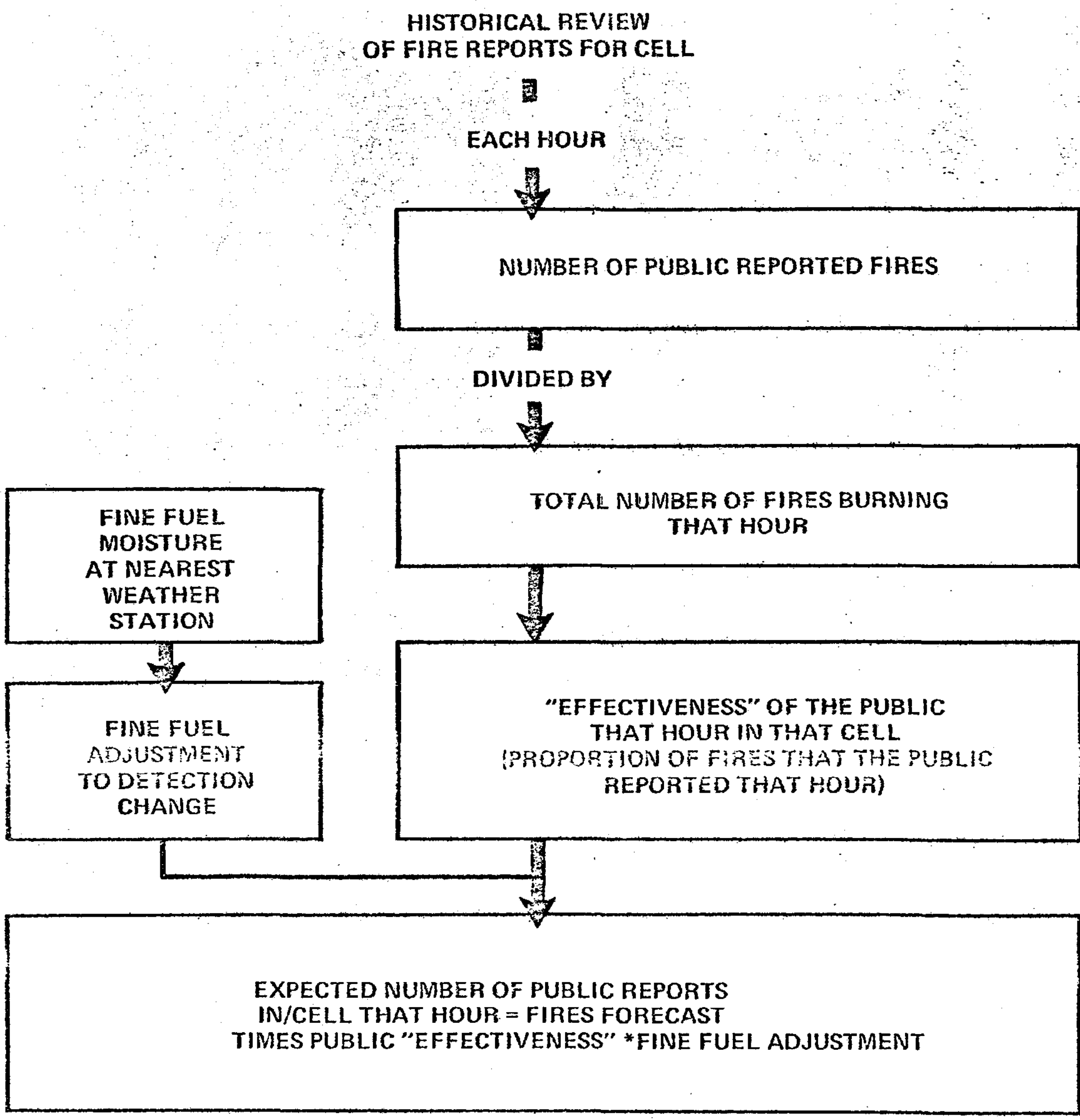
#5

HOURLY PREDICTION OF MAN-CAUSED FIRES IN A CELL

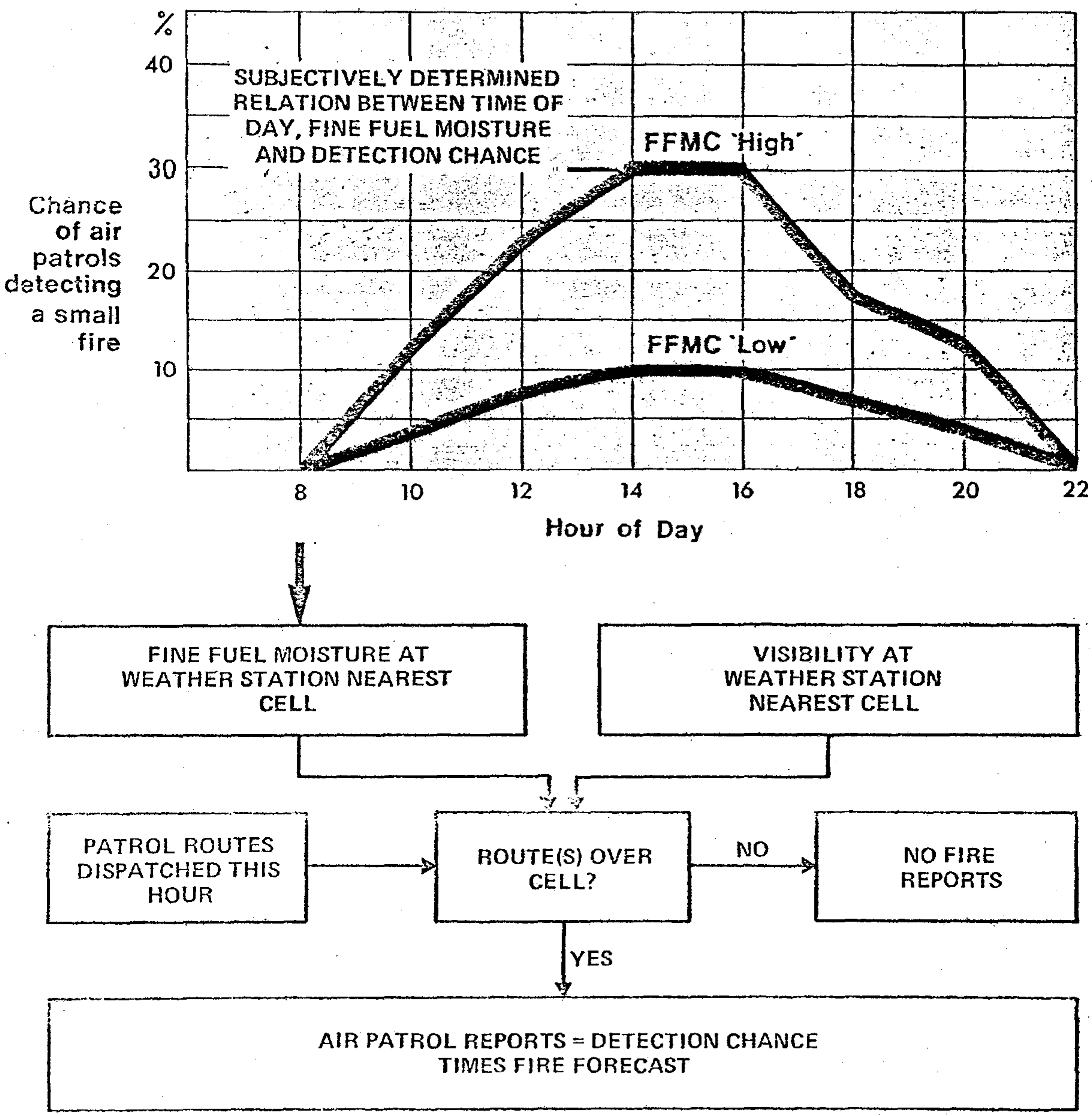


#6

HOURLY PREDICTION OF PUBLIC FIRE REPORTS IN A CELL

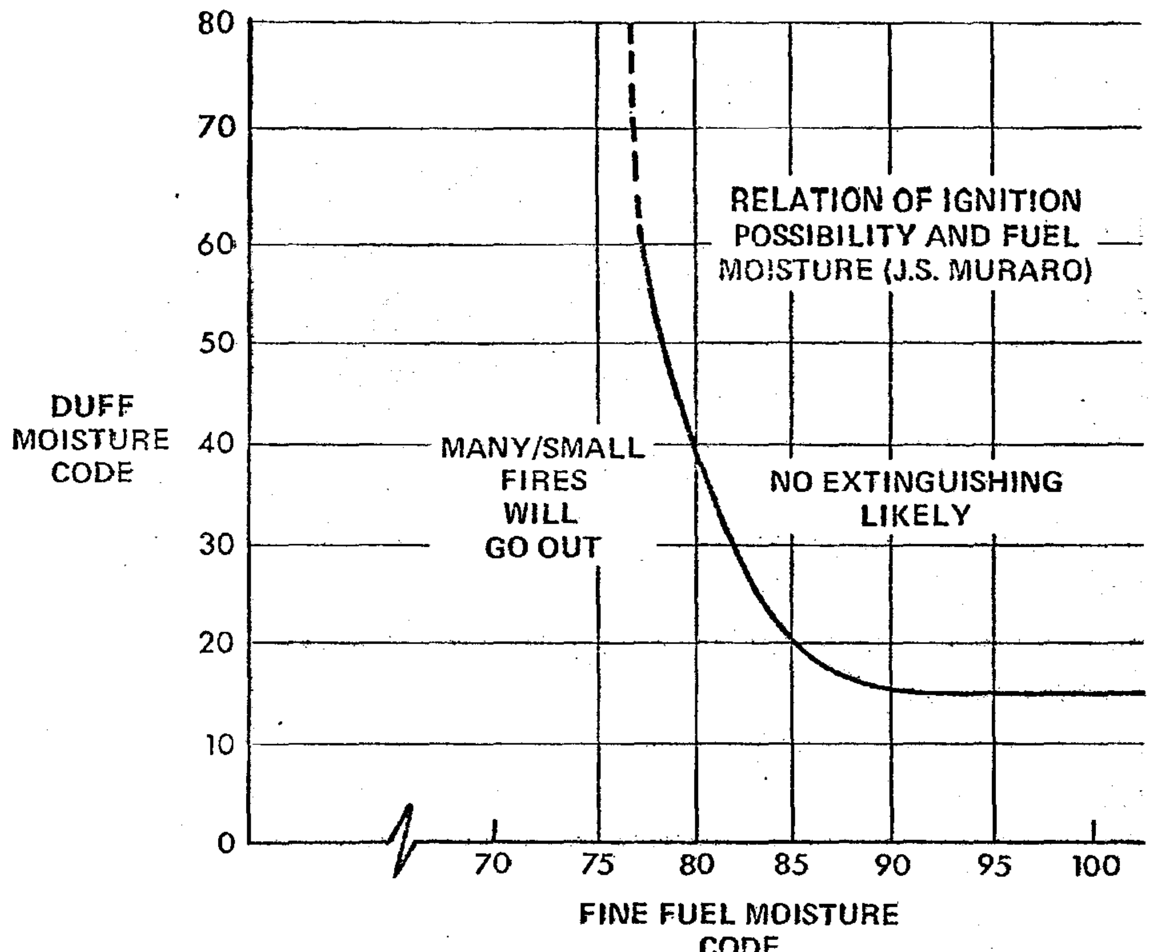


HOURLY PREDICTION OF EXPECTED AIR PATROL DETECTIONS



#8

PREDICTION OF NATURALLY EXTINGUISHED FIRES IN A CELL



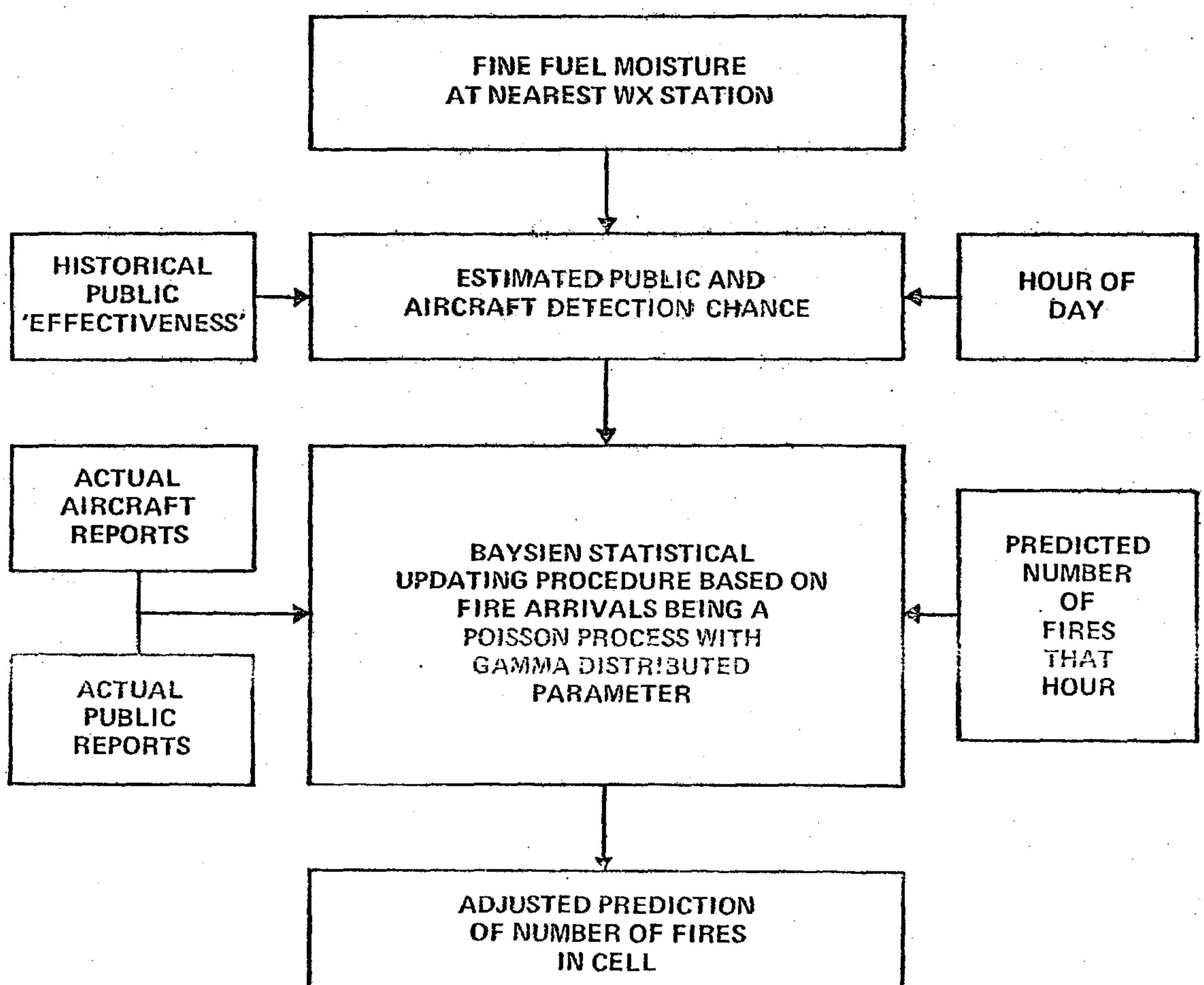
DUFF MOISTURE CODE AND FINE FUEL MOISTURE CODE FROM WX STATION NEAREST THE CELL

DOES FUEL MOISTURE STATE FALL ABOVE OR BELOW CURVE

~~YES~~ ABOVE → NO FIRES ARE REMOVED

~~YES~~ BELOW → 75% OF FIRES IN CELL ARE REMOVED EACH DAY = 3.125% PER HOUR (THIS VALUE IS SUBJECTIVELY SET)

HOURLY LEARNING PROCESS
ADJUSTMENT TO FIRE PREDICTION
FOR THE CELL



CRITERIA FOR URGENCY FOR DETECTION

1) On a cell basis — assign a number from 1 to 5 with 5 being in need of most (early) urgent detection.

2) Assume that one fire is burning (just started) in the cell in a random location.

3) Assume that the burning conditions (Fuel Moisture & wind) is HIGH.

4) In assessing "urgency" consider

    i) values (timber, recreation, political),
    ii) fuel condition,
    iii) potential damage,
    iv) potential suppression costs,
    v) attack difficulty.

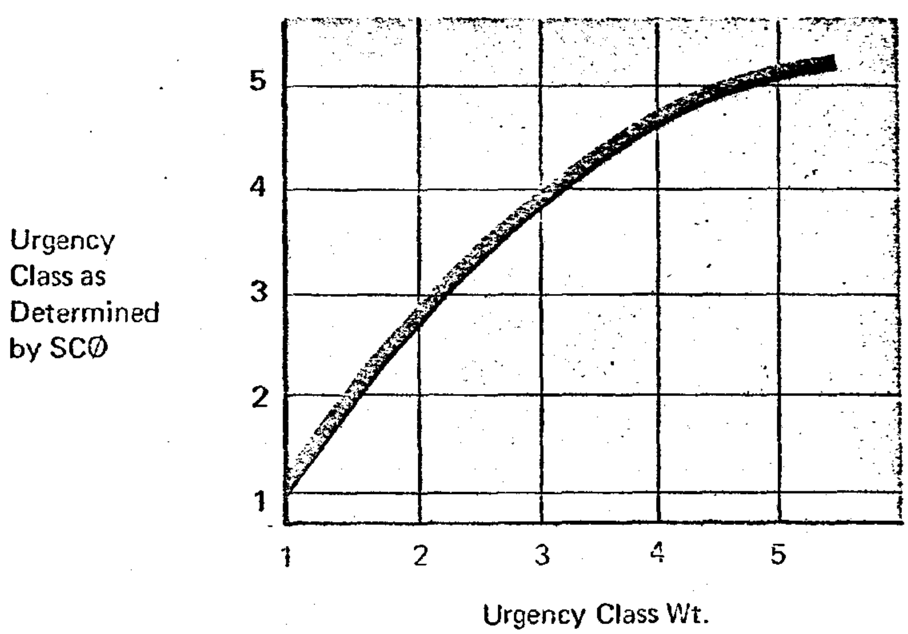
5) These numbers will be used to weight the forecasted numbers of fires in a cell in the following way:

#11

Urgency for Detection in the Cell	=	Predicted Number of Fires	x	Urgency Class Weight	x	Fuel Moisture Rate of Spread Weight

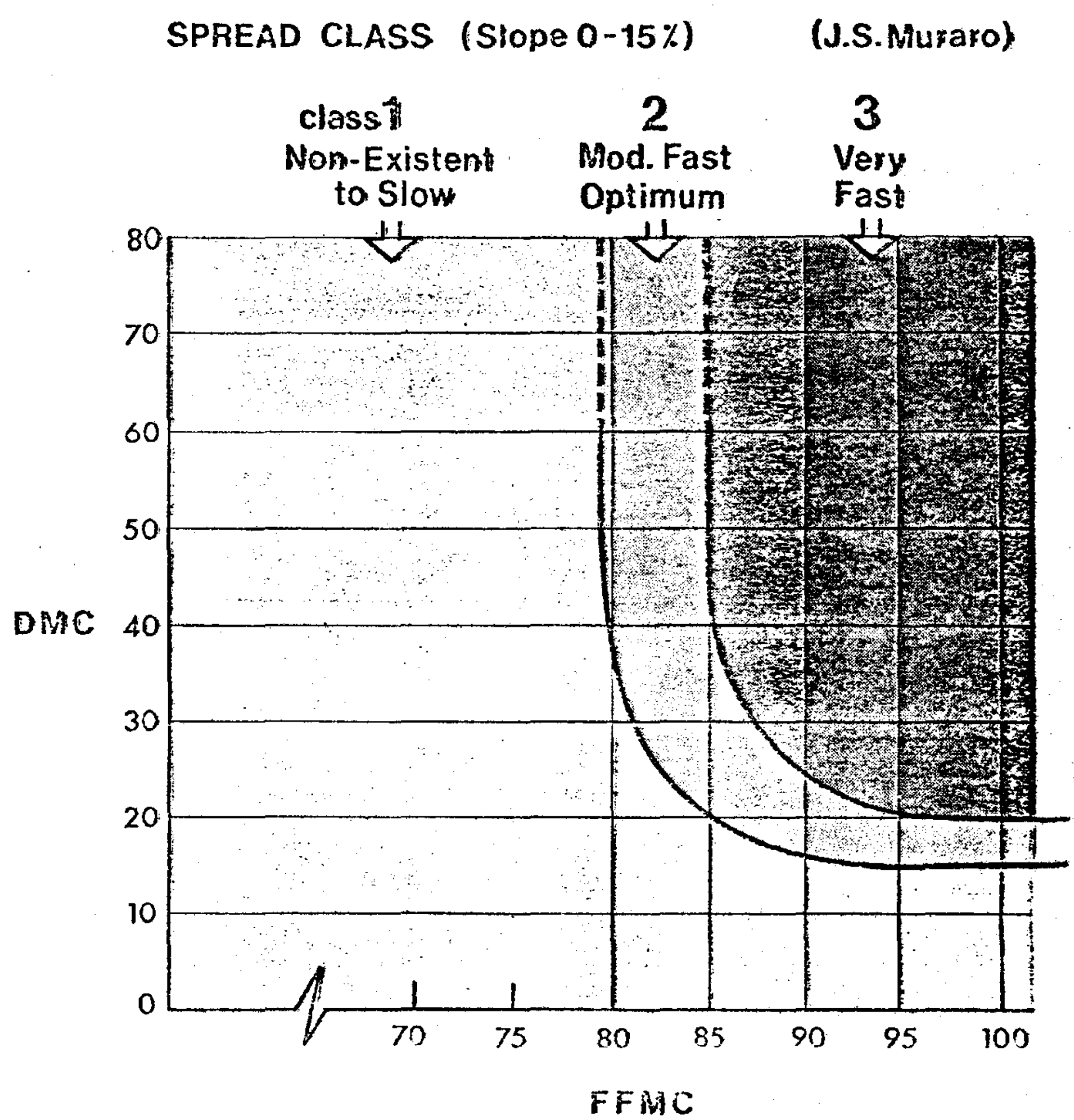
The combined urgency class weight and fuel moisture-wind weight will range from 1 to 25.

6) Determination of Urgency Class Wt.



SCØ Assigned Classes	Weight for Urgency
1	1
2	1.5
3	2
4	3
5	5

7) Determination of Fuel Moisture Weighting Values



Rate of Spread Class	Weighting Factor
1	1
2	2.5
3	5.0

#13

FIRE FORECAST FOR FLAY TIME,DAY AND MONTH 13 25 8 (P

EVIOUS UPDATE TIME DATE AND MONTH 15 24 8

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	2	2	2	2	2	2	2	2	2	19	18	11	2	2	2
2	2	2	2	2	2	2	2	2	63	26	20	11	11	2	2
3	2	2	2	2	61	61	103	56	68	68	92	92	2	2	2
4	2	2	62	104	56	44	50	53	52	58	63	94	2	2	2
5	2	286	56	76	55	53	59	64	60	61	22	31	2	2	2
6	2	286	11	11	59	62	65	63	58	97	20	20	2	2	2
7	2	286	100	11	15	62	68	59	61	108	97	98	2	2	2
8	2	12	12	3	11	57	9	17	11	63	49	32	5	2	2
9	286	12	12	6	6	24	8	15	91	71	46	47	65	2	2
10	27	3	3	6	6	20	24	12	22	41	64	50	52	30	2
11	2	2	2	5	3	10	39	54	49	26	51	37	39	44	6
12	2	2	2	2	2	31	55	72	6	30	55	20	27	5	2
13	2	2	2	2	2	2	4	5	5	4	2	2	20	2	2

25 13 8

53 53 57 62 85 60 62 56 87 65 72 53 57 52 76 73 78 76 75 67 55 35 58 6

80 80 80 80 86 80 80 80 88 80 80 80 80 80 80 80 80 80 80 80 80 80 80 8

8 7 12 13 36 7 30 18 26 22 32 13 15 7 20 21 23 22 25 24 11 15 14 1

8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8

EXPECTED NUMBER OF PULIC DETECTIONS SINCE LAST UPDATE 4.426

CHANCE OF NO PUBLIC REPORTS SINCE LAST UPDATE 1.2

CHANCE OF ONE OR MORE PUBLIC REPORTS 98.8

EXPECTED TOTAL NO OF FIRES CURRENTLY BURNING 5.994

CHANCE OF THERE BEING NO FIRES CURRENTLY BURNING .2%

CHANCE OF THERE BEING 1 OR FEWER FIRES 1.7%

CHANCE OF THERE BEING 2 OR FEWER FIRES 6.2%

CHANCE NF THERE BEING 3 OR FEWER FIRES 15.2%

CHANCE OF THERE BEING 4 OR FEWER FIRES 28.6%

CHNCE OF THERE BEING 5 OR FEWER FIRES 44.7%

CHANCE OF THERE BEING 6 OR FEWER FIRES 60.7%

14

Urgency map produced after thunderstorm

```
PLAY URGENCY MATRIX   TIME 14 DATE 26 MONTH 8

                  L L L
                L L L L L
        L L M L L L L L
    L L L L L L L L L L
  L L L L L L L L L L L
  L H H L L L L L H L L
  L L H H L L L L H H H
  L L M H L M M M M M M L
L L L M M M L L H H M M H
H M M M M M M L L M H M M M
      M M M M M M M M M M M L
          H M M M M M M M L L
            L L L M     M L L

TOTAL OF URGENCIES 26261
```

PATROL 1 DAY 26 HOUR 10 MON 8 EXPECTED DETECTIONS .399

DURATION 3.0 START 143 END 143 SPEED 150.

143-- 128-- 113-- 98-- 97-- 82-- 67-- 52-- 37-- 38-- 53--

68-- 83-- 84-- 85-- 100-- 101-- 116-- 115-- 130-- 131-- 146--

145-- 144-- 129-- 144-- 143--

NUMBER OF FIRES	CHANGE OF DETECTING
0	67.1%

CHANCE OF NOT DETECTING ANY FIRES 67.1%

CHANCE OF DETECTING ONE OR MORE FIRES 32.9%

PATROL 2 DAY 26 HOUR 10 MON 8 EXPECTED DETECTIONS .350

DURATION 3.0 START 65 END 65 SPEED 120.

65-- 80-- 81-- 96-- 97-- 82-- 67-- 52-- 37-- 36-- 51--

66-- 65-- 64-- 63-- 62-- 77-- 92-- 93-- 94-- 95-- 80--

65--

NUMBER OF FIRES	CHANGE OF DETECTING
0	70.5%

CHANCE OF NOT DETECTING ANY FIRES 70.5%

CHANCE OF DETECTING ONE OR MORE FIRES 29.5%

PATROL 1 DAY 31 HOUR 9 MON 7 EXPECTED DETECTIONS .034

DURATION 2.5 START 42 END 42 SPEED 100.

42-- 41-- 40-- 39-- 38-- 53-- 68-- 83-- 84-- 85-- 86--

71-- 56-- 57-- 42--

NUMBER OF FIRES	CHANGE OF DETECTING
0	96.7%

CHANCE OF NOT DETECTING ANY FIRES96.7%

CHANCE OF DETECTING ONE OR MORE FIRES 3.3%

PATROL 2 DAY 31 HOUR 9 MON 7 EXPECTED DETECTIONS .050

DURATION 2.5 START 54 END 54 SPEED 100.

54-- 53-- 68-- 67-- 82-- 97-- 98-- 83-- 84-- 99-- 100--

85-- 70-- 69-- 54--

NUMBER OF FIRES	CHANGE OF DETECTING
0	95.1%

CHANCE OF NOT DETECTING ANY FIRES 95.1%

CHANCE OF DETECTING ONE OR MORE FIRES 4.9%

PATROL 3 DAY 31 HOUR 9 MON 7 EXPECTED DETECTIONS .063

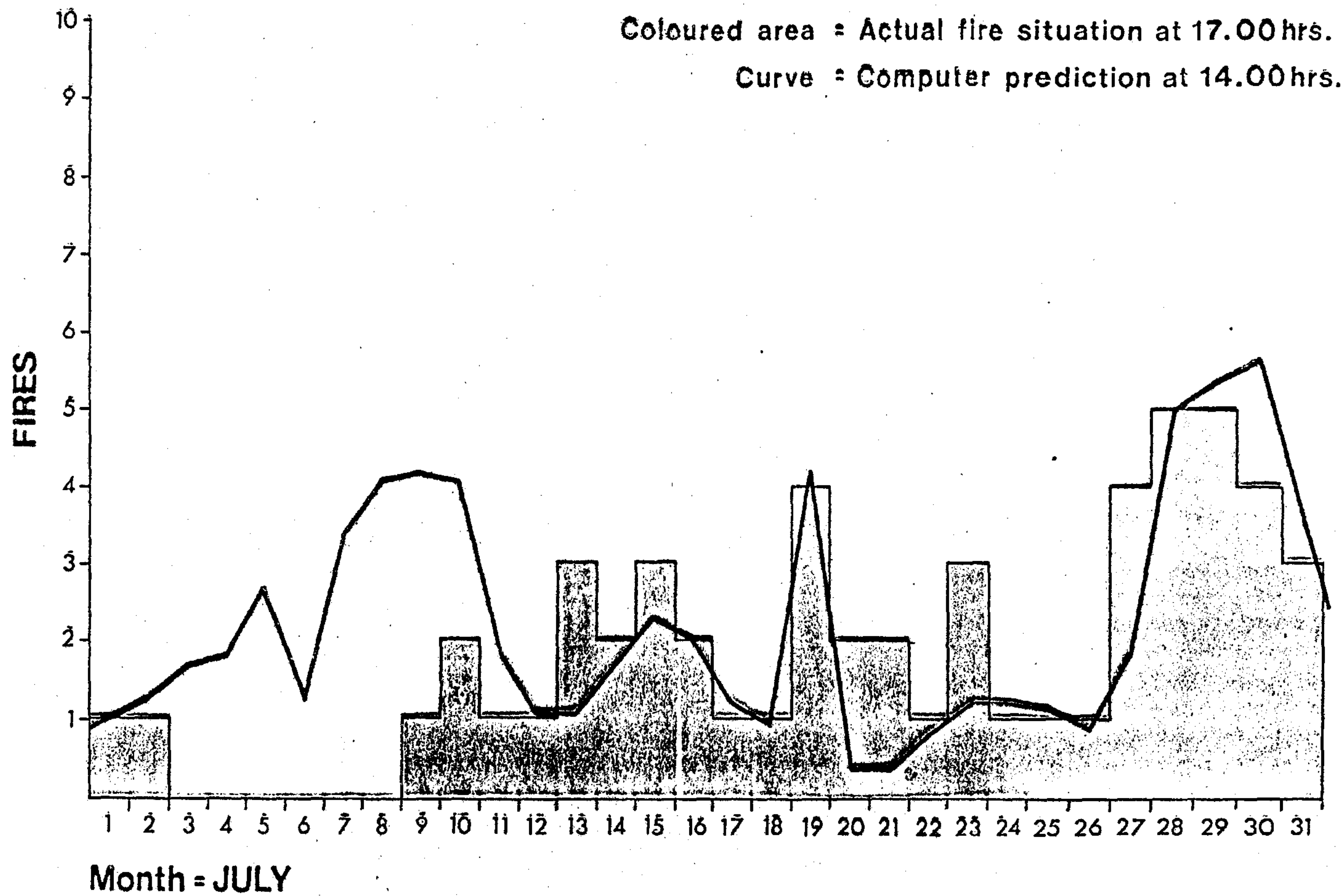
DURATION 2.5 START 65 END 65 SPEED 100.

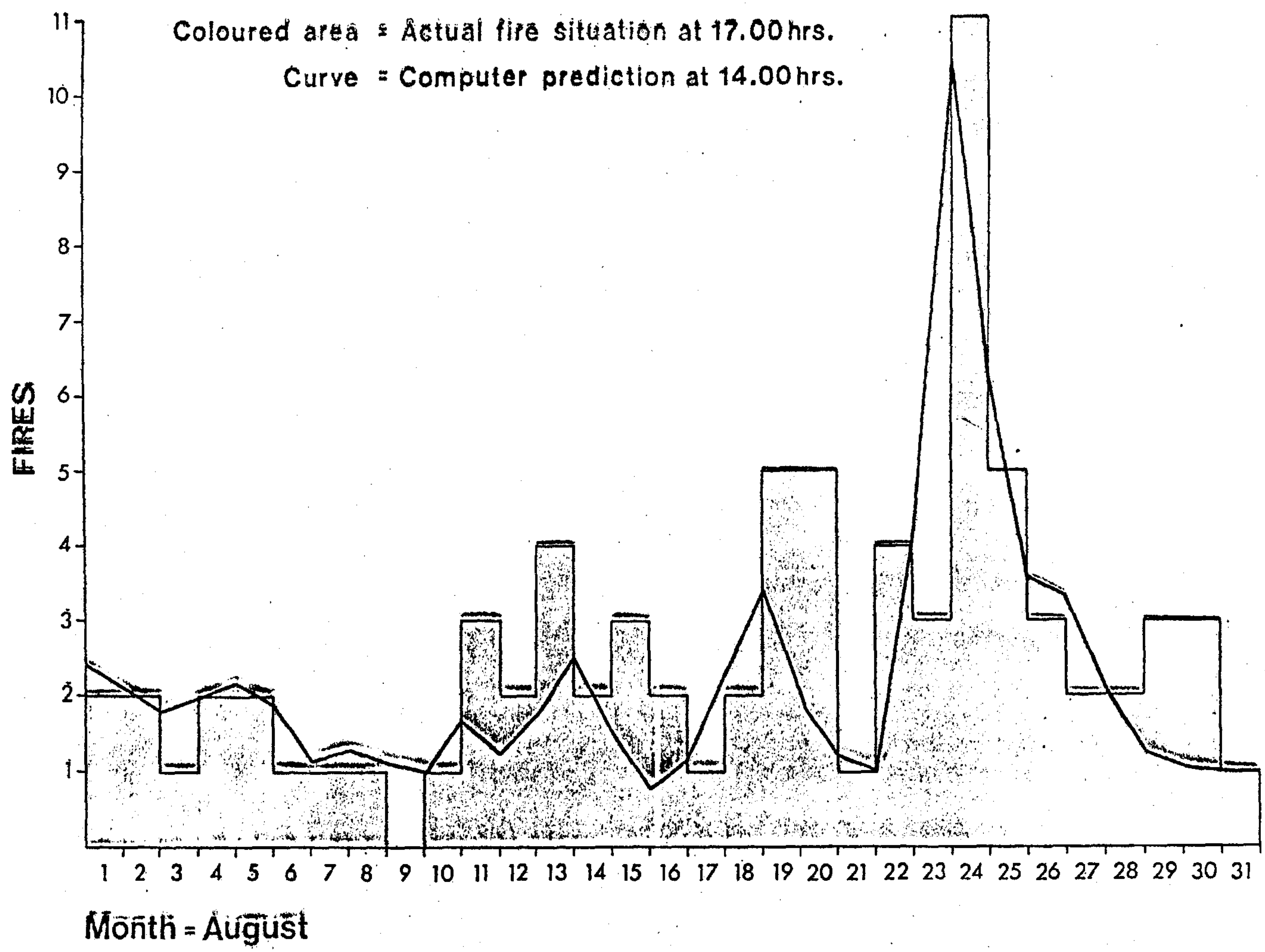
65-- 66-- 67-- 82-- 97-- 96-- 95-- 94-- 79-- 78-- 77--

Example of output from the fixed patrol route program

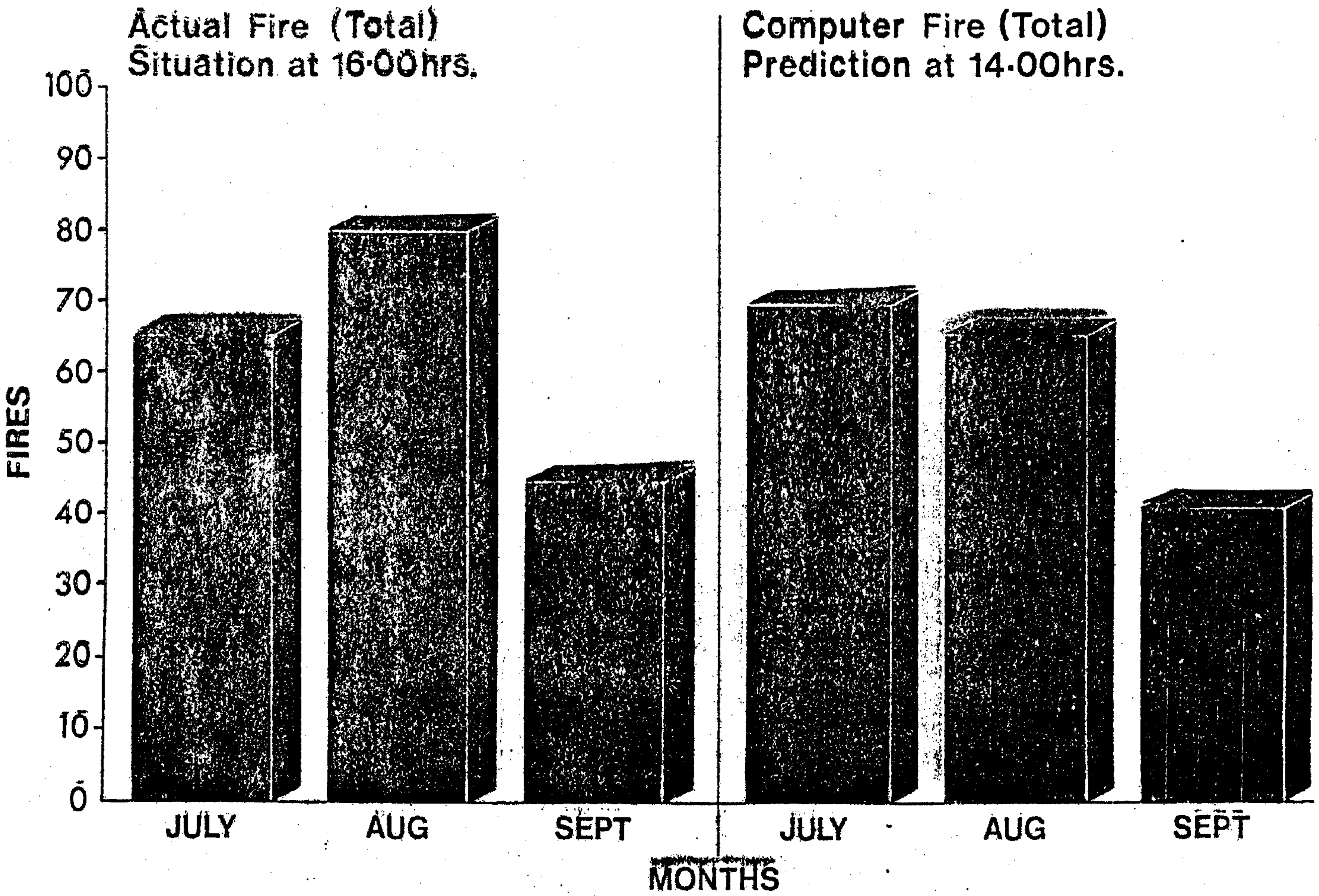
PATROL PLAN A PREDICTED RESULTS FOR HOUR 9 DAY 23 MON 8

PATROL NUMBER	EXPECTED DETECTIONS	***CHANCE OF DETECTING**** NO FIRES	ONE OR MORE FIRES
1	30	97.0	3.0
2	30	97.0	3.0
3	30	97.0	3.0
4	30	97.0	3.0
5	30	97.0	3.0
6	33	96.8	3.2
7	36	96.5	3.5
8	30	97.0	3.0
9	48	95.3	4.7
10	24	97.6	2.4
11	36	96.5	3.5
TOTAL	357	100.0	0.


Coloured area = Actual fire situation at 17.00 hrs.
Curve = Computer prediction at 14.00 hrs.
FIRES
10
9
8
7
6
5
4
3
2
1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Month = JULY


Coloured area = Actual fire situation at 17.00 hrs.
Curve = Computer prediction at 14.00 hrs.
FIRES
11
10
9
8
7
6
5
4
3
2
1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Month = August

#19



Actual Fire (Total)
Situation at 16·00hrs.
Computer Fire (Total)
Prediction at 14·00hrs.
FIRES
100
90
80
70
60
50
40
30
20
10
0
JULY
AUG
SEPT
JULY
AUG
SEPT
MONTHS

#20