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Ignition Probabilities of Wildland Fuels Based on Simulated Lightning Discharges

**Don J. Latham
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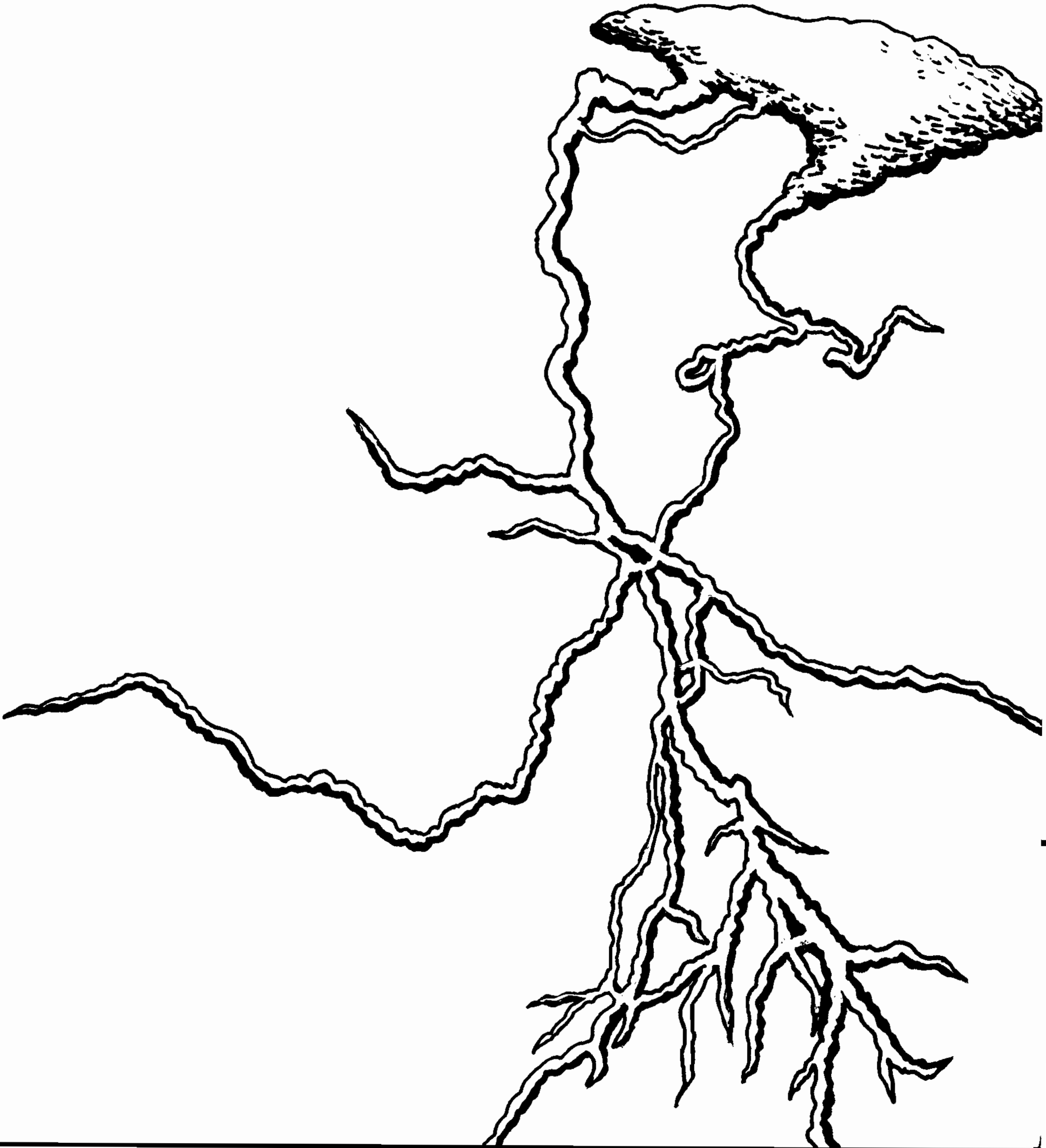

THE AUTHORS

DON J. LATHAM received his bachelor's degree in physics from Pomona College in 1960, his master's in 1964 and Ph.D. in 1967, both in earth science, from the New Mexico Institute of Mining and Technology. From 1968 to 1976 he taught and did research in atmospheric electricity in the Rosenstiel School of Marine and Atmospheric Science, University of Miami. In 1976 he joined the Intermountain Research Station's Intermountain Fire Sciences Laboratory in Missoula, MT, as a research meteorologist/physicist.

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RESEARCH SUMMARY

Fine fuel samples from Northwestern forest areas were subjected to an electric arc discharge that simulated the lightning continuing current. The important fuel state parameters and the ignition probabilities were determined using logistic regression.

The ignition probabilities for duff from short-needled conifer species were found to depend almost entirely on the depth of the fuel bed. In the case of litter and duff from long-needled species, ignition probabilities depend mostly on the ovendry fuel moisture.

Ignition probabilities also depend on the duration of the arc only, with current flow and diameter having no detectable effect. Because the continuing current durations can be fit well by a Weibull distribution for both positive and negative discharges to ground, the probabilities conditional on the current duration can be converted to marginal probabilities per discharge. The necessary integrations were done and the results are presented.

Marginal ignition probabilities are given in four forms. Tables give the probabilities for selected values of the independent variables. Graphs of the probabilities are also shown. Equations based on curve fits to the tabulated values accompany the graphs. Finally, a FORTRAN program that uses a rapid integration scheme to give the probabilities is included in subroutine form. All these products are valid only over the range of values for the independent variables as specified in the paper.

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INTRODUCTION

Land management agencies are now using lightning location equipment in fire management operations. Some implications of this technology were set forth by Latham (1979), including the steps necessary to accomplish the location and timing of lightning-caused fires. One of these steps is assessing the probability that lightning discharge to ground will ignite fuels.

A previous investigation of ignition probability (Fuquay and others 1979) used an energy argument in which the available energy density in the lightning continuing current was compared to the fuel's heat of ignition as used in fire models. The authors concluded that further investigation was needed to improve the accuracy of the ignition probability algorithm.

The details of that further investigation are contained in a series of papers. The first paper (Latham 1987) describes the equipment needed to do the testing. The second (Latham 1989) reports the details of the electric arc as an energy source as it was used in the experiments. The third and present publication describes the ignition experiments and the results. This publication also formats the results for application and discusses probability of ignition for lightning continuing currents. The report provides tables, curves, formulas, and algorithms for implementation of the ignition probabilities together with suggestions for use.

DATA AND ANALYSIS

The electric arc source was used to penetrate 1,666 fuel beds with a dc arc discharge. The current and duration of the discharge were varied, as were the fuel bed composition, depth, packing ratio, and moisture. For each fuel bed, the result of ignition or no ignition was recorded. The fuel types used in the analysis were ponderosa pine litter, punky wood (both in chunks and fine powder), peat moss (commercial samples), Douglas-fir duff, lodgepole pine duff, and high-altitude mixed species (primarily Engelmann spruce) duff.

The dependent variable has only two values (1 = ignition or 0 = no ignition), so a logistic regression model was used to estimate the probability of ignition. The logistic model gives a number between 0 and 1, which is appropriate since we are estimating a probability. The maximum likelihood estimates for model parameters were obtained from the SAS procedure CATMOD. The models were constructed from the original observations rather than by grouping the data.

One step in the investigation was determining which independent variables to include in the models. The statistic used for these tests was minus twice the maximized log likelihood (Efron 1978). When candidate variables are added one at a time, the difference in log likelihoods has a chi-square distribution with 1 degree of freedom.

After the models were estimated, a chi-square type statistic, *Cg*, was used to evaluate how well the models fit (Lemeshow and Hosmer 1982). The statistic is calculated from a table of observed and expected values and has a distribution closely approximated by a chi-square distribution with 8 degrees of freedom. Test results by fuel type are shown in table 1. A *p*-value greater than 0.10 indicates that the model fits the data well.

Two important results were apparent from the analyses. The primary result was that the most important of the variables associated with the discharge was its duration. We checked this carefully, because of our original conjecture that the energy density would be important.

Table 1—Evaluation of the fit of logistic regression equations to the ignition data. *Cg* and *p*-value are explained in the text

Fuel	Sample size	*Cg*	*p*-value
Ponderosa pine litter	722	8.61	0.38
Punky wood (rotten, chunky)	136	4.01	.86
Punky wood powder (4.8 cm deep)	105	4.43	.82
Punky wood powder (2.4 cm deep)	70	2.75	.95
Lodgepole pine (duff)	90	6.81	.56
Douglas-fir (duff)	117	1.62	.99
Engelmann spruce (duff)	160	11.86	.16
Peat moss (commercial)	266	3.11	.93

The fact that the duration alone can characterize the discharge for ignition is very significant. It is the one variable associated with the continuing current discharge that is relatively easy to measure in the field (as opposed to the current or the diameter). Second, we found that the moisture content (for moistures less than 40 percent) plays a very small role in the ignition of duff from short-needled species; the depth of the bed is more influential.

LOGISTIC REGRESSION COEFFICIENTS

We broke the coefficients of the exponential in the logistic regression for each fuel type into two parts for convenience in later processing. One coefficient (B) multiplies the duration of the arc discharge, and the other (A) contains the coefficients and variables that are specific to the fuel, such as fuel moisture, bed depth, bulk density, and so on. These coefficients are used to determine the probability of ignition using the equation:

$$\mathrm{pci}(A,B,t) = 1/(1 + \exp(-A - Bt)) \tag{1}$$

where the experimentally determined coefficients are given in table 2. These values are used with equation (1) to generate conditional ignition probabilities when the duration of a continuing current event and fuel parameters are known.

Present lightning location systems do not measure the duration of the continuing current. In fact, they do not even identify those lightning discharges that have a continuing current component. This situation can be partly corrected. We do have a number of measurements, at least for northwestern storms, for the duration of continuing currents from both negative and positive discharges to ground. These measurements can be combined with the conditional probabilities to give a probability per lightning event.

MARGINAL IGNITION PROBABILITY

What we want to know is the probability of an ignition, given the occurrence of an electrical discharge in the fuel, that is, the marginal probability of ignition with respect to discharge duration. We can now estimate conditional ignition probability, given the duration of the discharge and the fuel state, from equation (1) and table 2. If we know the probability distribution for continuing current duration, we can find the marginal probability of ignition by multiplying the two probabilities and adding them up over all durations.

We have determined that the continuing current probability is best fit by the Weibull (see appendix A) distribution (Kappenman 1988):

$$\mathrm{p}(t,n,s) = \left(\frac{n}{s}\right)\left(\frac{t}{s}\right)^{n-1} \exp\left[-\left({}^{t}/s\right)^{n}\right] \tag{2}$$

where t is the duration (msec) and the values of n and s are 1.6 and 207.8 for negative discharges, and 2.3 and 69.3 for positive discharges.

The adding-up is done by the integral:

$$\mathrm{pi}(n,s,A,B) = \int_{0}^{\infty} \mathrm{p}(t,n,s)\ \mathrm{pci}(A,B,t)dt \tag{3}$$

that must be solved by a numerical integration. We performed the integrations necessary and obtained marginal probability distributions as given in table 3 and appendix B. The simple equations of table 3 result from a "best fit" approach starting with simple functions.

We have also developed a FORTRAN algorithm (appendix C) for the marginal probability. This algorithm performs the integration necessary to obtain the marginal distribution as presented above. The integration is a 6-point Gaussian quadrature using Laguerre polynomials. The results check within 2 to 3 percent of the Romberg quadrature used to calculate the values of appendix B. This precision, considering the other uncertainties in application of the algorithms, is entirely adequate.

Table 2—Coefficients for the probability distributions of Equation (2). *Mf* is the fuel moisture in percentage of dry weight, δ is the duff depth in cm, and ρb is the bulk density in g/cm^3

Fuel	A	B
Ponderosa pine litter	0.97 – 0.19*Mf*	0.012
Punky wood (rotten, chunky)	–0.59 – 0.15*Mf*	.005
Punky wood powder (4.8 cm deep)	1.2 – 0.12*Mf*	.002
Punky wood powder (2.4 cm deep)	0.13 – 0.05*Mf*	.005
Lodgepole pine (duff)	–5.6 + 0.68δ	.007
Douglas-fir (duff)	–7.1 + 1.4δ	.006
Engelmann spruce (duff)	0.79 – 0.081*Mf* – 8.5ρb	.011
Peat moss (commercial)	0.42 – 0.12*Mf*	.005

Table 3—Equations approximating the curves of figs. 3 through 10. *Mf* is the fuel moisture in percentage of dry weight and δ is the bed depth in cm. These equations are valid only within the specified ranges

Fuel	pineg	pipos
Ponderosa pine litter	$1.04\exp(-0.054Mf)$	$0.92\exp(-0.087Mf)$
Punky wood (rotten, chunky)	$0.59\exp(-0.094Mf)$	$0.44\exp(-0.11Mf)$
Punky wood powder (4.8 cm deep)	$0.9\exp(-0.056Mf)$	$0.86\exp(-0.06Mf)$
Punky wood powder (2.4 cm deep)	$0.73-0.011Mf$	$0.6-0.11Mf$
Lodgepole pine (duff)	$(1+\exp(3.84-0.6\delta))^{-1}$	$(1+\exp(5.13-0.68\delta))^{-1}$
Douglas-fir (duff)	$(1+\exp(5.48-1.28\delta))^{-1}$	$(1+\exp(6.69-1.39\delta))^{-1}$
Engelmann spruce (duff)	$0.8-0.014Mf$	$0.62\exp(-0.05Mf)$
Peat moss (commercial)	$0.84\exp(-0.06Mf)$	$0.71\exp(-0.07Mf)$

Note: Range of validity is 0 to 40 percent for *Mf* and 0 to 10 cm for δ. Do not use outside this range.

SUGGESTIONS FOR USE

Ignition probabilities have a wide range of uses, from preseason planning to dispatch of fire suppression forces. Specific applications are: daily fire-danger rating, preattack (short-range) planning, prepositioning of fire-fighting forces, and dispatch of fire-spotting flights. These uses of ignition probability depend on the available knowledge about the variables involved in the calculations. Generally, the farther from real-time the application is, the poorer the knowledge about the fuel variables.

For all applications that are not real-time, the marginal probability distributions should be used with area lightning statistics. If the duration of discharge is not known, but the type of discharge is (as in a real-time application using lightning location systems), the marginal probabilities given in appendixes B and C should be applied. The simple formulas in table 3 may be used for this purpose as well.

When applying tabulated, graphed, or simple formula approximations, the probabilities given are per continuing current. Almost all positive discharges have a continuing current. The probabilities for positive discharges thus do not need to be corrected, and may be used as is per positive event. Negative discharges to ground do not all have continuing currents. In fact, only about one in five do. When using the probabilities pneg, then, a correction must be applied; that is, a multiplier of 0.2. The FORTRAN program of appendix C has this correction built in, so if the program is checked against the tables (as it should be when implemented), the negative probabilities will seem to be too small.

Application of the distributions to species other than those that we studied is possible according to the suggestions of table 4. These are based on Agriculture Handbook 519 (Little 1978) and consultation with Dr. J. K. Brown of the Intermountain Fire Sciences Laboratory. In addition, we feel that short grasses will behave much the same as the loose, low-organic-content peat moss that we used in the experiments, and tall grasses, such as sawgrass, will behave as ponderosa pine litter, because the ignition will take place in the clumps of dead grass rather than in the standing dead spears. If species are not mentioned in table 4, we suggest that consideration of cover type be the guide.

Because of species/cover type dependence, the primary use of probabilities will eventually be in a geographic information system (GIS). In such use, a calculation for each discharge may not be necessary. Marginal ignition probabilities can be calculated in advance of storms. To do this, of course, one needs the relative number of positive and negative strikes. (About one positive for about every 50 negatives.) Indeed, for several species, the ignition probability is nearly static, because these depend primarily on duff depth. The ignition probabilities can be displayed, perhaps in color, and the discharges superimposed on them. The resulting display would be projected ignitions, not surviving fires. In order to determine survivability, rain and projected fire growth models should be connected to ignitions. A learning program operating in the GIS should be possible to improve the usefulness of the ignition probabilities and survival potential. More specific application of ignition probabilities depends on identification of continuing currents and measurement of their duration in lightning locating systems.

Table 4—Application of fuels studied to other species

Studied fuels				
Ponderosa pine	**Lodgepole pine**	**Douglas-fir**	**Engelmann spruce**	**Peat (commercial)**
Longleaf pine	Eastern white pine	Bald cypress	Spruce-fir	All grasses
Slash pine	Limber pine	All spruce (except Engelmann)	All hemlock	Eastern tamarack (peat)
Loblolly pine	Tamarack	Giant sequoia	Subalpine fir	Black spruce (peat)
Pond pine	Jack pine	Eastern hemlock	Pacific silver fir	Other peat
Pitch pine	Virginia pine	All cedars and juniper	Grand fir	All mosses
Shortleaf pine	Sand pine		Noble fir	
Red pine	Spruce pine		California red fir	
Monterey pine	Pinyons			
Sugar pine	White fir			
Jeffrey pine	Redwood			
Digger pine	Western white pine			
Knobcone pine	Bristlecone pine			

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APPENDIX A: WEIBULL DISTRIBUTIONS FOR LIGHTNING CURRENTS

Continuing current duration distributions are well fit by the Weibull distribution:

$$p(t,n,s) := \left[\frac{n}{s}\right]\cdot\left[\frac{t}{s}\right]^{n-1}\cdot e^{-\left[\frac{t}{s}\right]^{n}} \qquad (1)$$

where t is time, n is the shape parameter, and s the scale parameter.

The Weibull distribution is the statistic of choice for systems in which failure of the whole is contingent on failure of a part or parts of the whole. The probability of failure of the whole increases with time according to the value of n. Previously, the distribution of continuing currents was fit by a lognormal distribution. We found the Weibull to be a more satisfactory fit.

The distributions for negative and positive lightning strokes to ground (based on data from 141 negative strokes and 54 positive strokes) are found from equation (1) with the values:

$$\text{pneg} := p\left[\tau,1.6,207.8\right] \qquad \text{ppos} := p\left[\tau,2.3,\ 69.3\right] \qquad (2)$$

where τ is duration in msec, pneg is the probability of occurrence of a negative continuing current of duration τ, and ppos is the probability of occurrence of a positive continuing current of duration τ. The results of this exercise are given in table 5 and figures 1 and 2.

Table 5—Values of the Weibull distribution for continuing currents. Pneg for negative discharges to ground, and ppos for positive discharges to ground. τ is the continuing current duration in msec

	Weibull distributions	
τ	**pneg(X1000)**	**ppos(X100)**
0	0	0
10	1.237	0.265
20	1.846	.623
30	2.304	.966
40	2.667	1.225
50	2.957	1.354
60	3.186	1.342
70	3.363	1.208
80	3.495	.995
90	3.586	.752
100	3.640	.523
110	3.662	.335
120	3.656	.198
130	3.624	.107
140	3.570	.054
150	3.497	.025
160	3.408	.010
170	3.305	.004
180	3.191	.001
190	3.068	
200	2.938	
210	2.802	
220	2.664	
230	2.524	
240	2.383	
250	2.243	
260	2.105	
270	1.970	
280	1.838	
290	1.710	
300	1.587	
310	1.469	
320	1.357	
330	1.249	
340	1.148	
350	1.052	
360	.963	
370	.878	
380	.800	
390	.727	
400	.659	
410	.596	
420	.538	
430	.485	
440	.436	
450	.391	
460	.351	
470	.314	
480	.280	
490	.249	

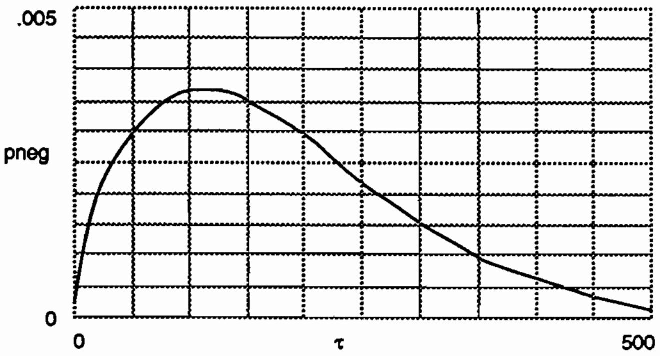


Figure 1—A plot of the Weibull probability distribution (pneg) for negative discharges to ground. is the duration in msec.

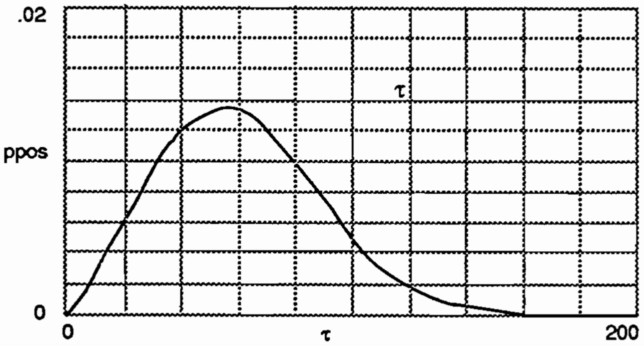
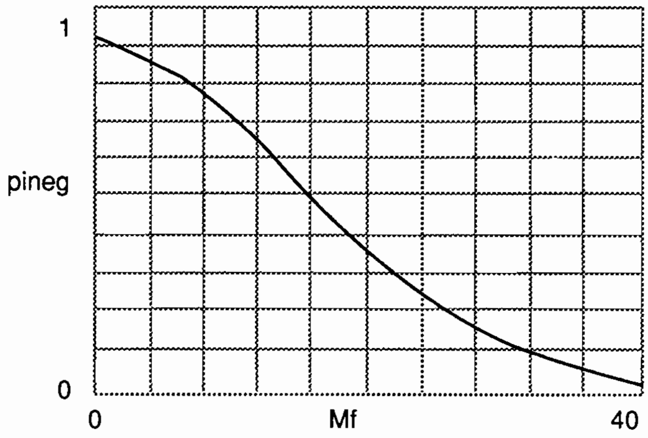


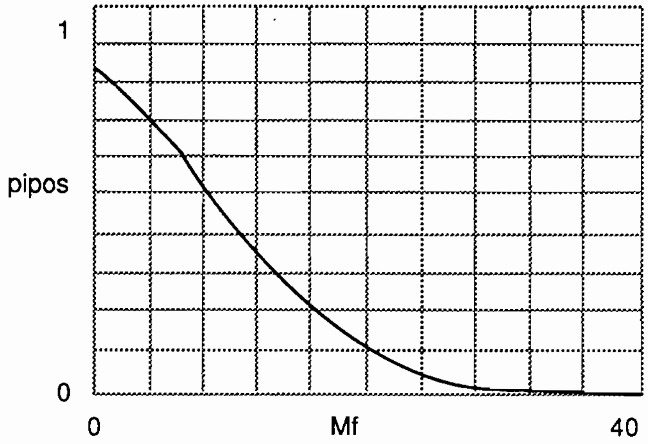
Figure 2—A plot of the Weibull distribution (ppos) for positive discharges to ground. τ is the duration in msec.

APPENDIX B: GRAPHS, TABLES, AND SIMPLE EQUATIONS FOR MARGINAL IGNITION PROBABILITIES



Mf	pineg
0	0.925
4	0.864
8	0.77
12	0.646
16	0.507
20	0.372
24	0.256
28	0.166
32	0.102
36	0.059
40	0.032

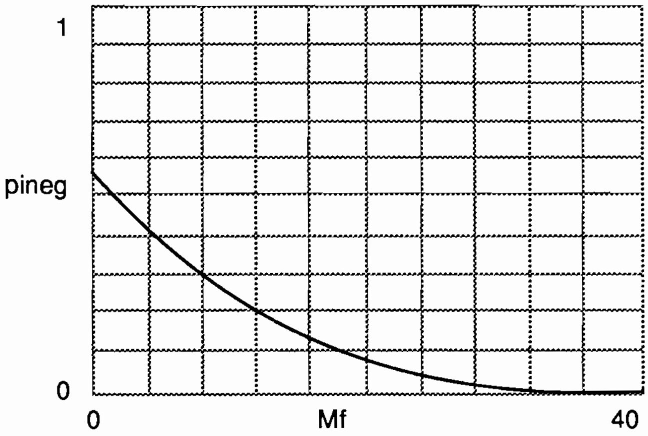
$$\text{pineg} = 1.04 \exp(-0.054\text{Mf})$$



Mf	pipos
0	0.842
4	0.716
8	0.545
12	0.364
16	0.214
20	0.114
24	0.057
28	0.028
32	0.013
36	0.006
40	0.003

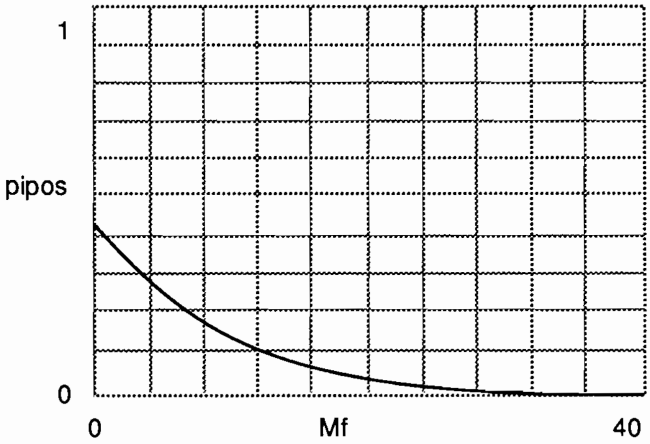
$$\text{pipos} = 0.92 \exp(-0.087\text{Mf})$$

Figure 3—Marginal ignition probabilities for ponderosa pine litter. Pineg is the probability of ignition for negative discharges, pipos for positive discharges. Tabular values and simplified equations are given for convenience.



Mf	pineg
0	0.571
4	0.433
8	0.305
12	0.201
16	0.125
20	0.074
24	0.043
28	0.024
32	0.014
36	0.007
40	0.004

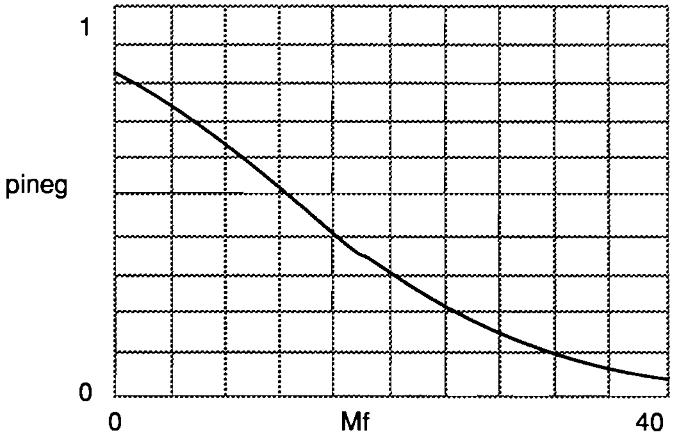
$$\text{pineg} = 0.595 \exp(-0.094\text{Mf})$$



Mf	pipos
0	0.43
4	0.293
8	0.186
12	0.112
16	0.065
20	0.037
24	0.02
28	0.011
32	0.006
36	0.003
40	0.002

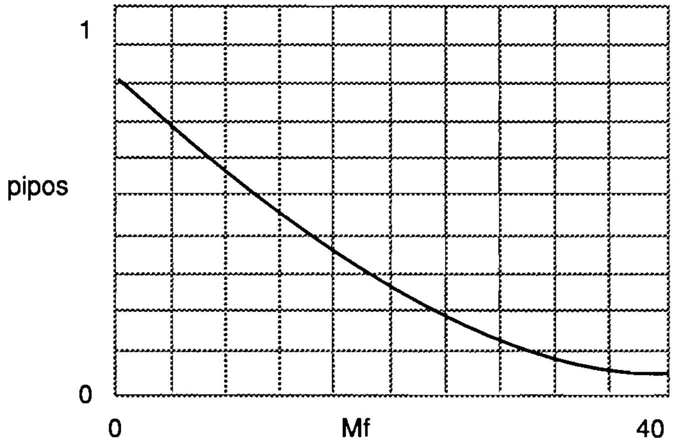
$$\text{pipos} = 0.439 \exp(-0.114\text{Mf})$$

Figure 4—Marginal ignition probabilities for rotten, chunky punky wood. Pineg is the probability of ignition for negative discharges, pipos for positive discharges. Tabular values and simplified equations are given for convenience.



Mf	pineg
0	0.821
4	0.742
8	0.643
12	0.529
16	0.412
20	0.304
24	0.214
28	0.144
32	0.095
36	0.061
40	0.039

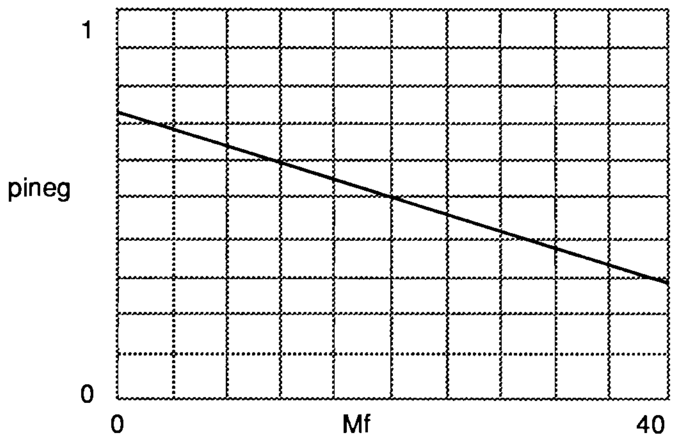
$$\text{pineg} = 0.9\ \exp(-0.056\text{Mf})$$



Mf	pipos
0	0.79
4	0.699
8	0.59
12	0.471
16	0.355
20	0.254
24	0.174
28	0.116
32	0.075
36	0.048
40	0.03

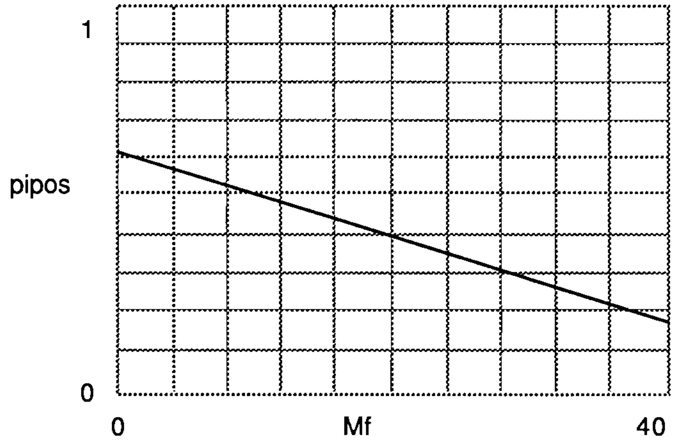
$$\text{pipos} = 0.86\ \exp(-0.061\text{Mf})$$

Figure 5—Marginal ignition probabilities for powdered punky wood, depth 4.8 cm. Pineg is the probability of ignition for negative discharges, pipos for positive discharges. Tabular values and simplified equations are given for convenience.



Mf	pineg
0	0.723
4	0.684
8	0.642
12	0.598
16	0.553
20	0.507
24	0.461
28	0.415
32	0.371
36	0.329
40	0.29

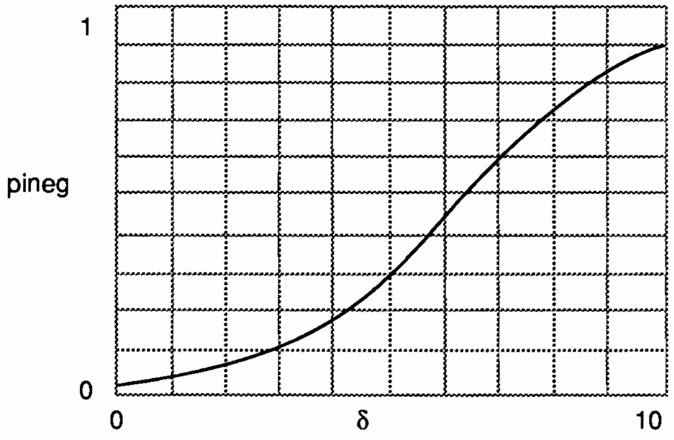
$$\text{pineg} = 0.73 - 0.011\text{Mf}$$



Mf	pipos
0	0.607
4	0.559
8	0.509
12	0.46
16	0.411
20	0.364
24	0.319
28	0.277
32	0.239
36	0.205
40	0.174

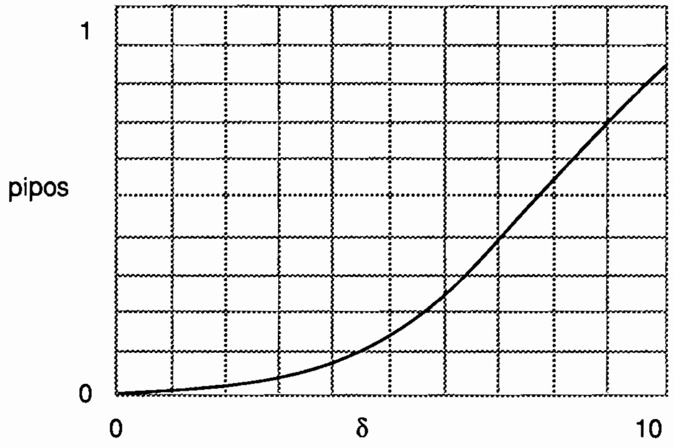
$$\text{pipos} = 0.6 - 0.11\text{Mf}$$

Figure 6—Marginal ignition probabilities for powdered punky wood, 2.4 cm deep. Pineg is the probability of ignition for negative discharges, pipos for positive discharges. Tabular values and simplified equations are given for convenience.



δ	pineg
0	0.019
1	0.036
2	0.066
3	0.117
4	0.195
5	0.305
6	0.442
7	0.59
8	0.725
9	0.83
10	0.902

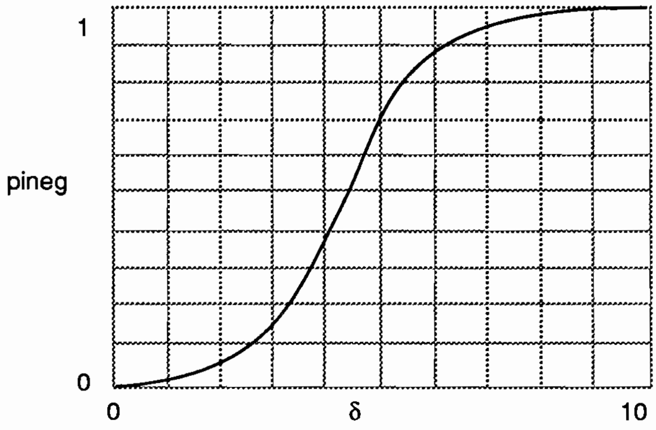
$$\text{pineg} = 1/(1 + \exp(3.84-0.6\delta))$$



δ	pipos
0	0.006
1	0.011
2	0.022
3	0.043
4	0.081
5	0.147
6	0.253
7	0.4
8	0.566
9	0.72
10	0.835

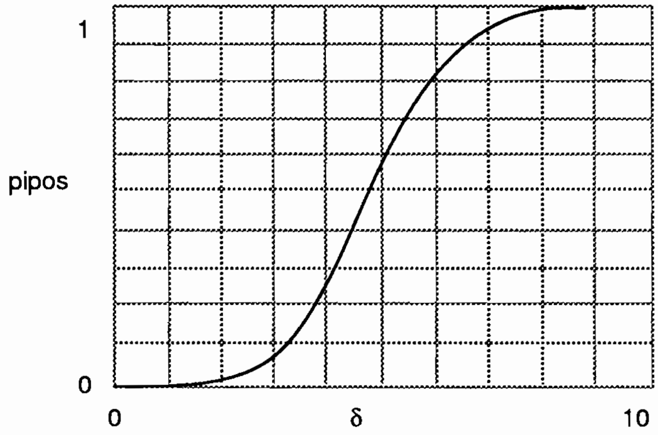
$$\text{pipos} = 1/(1 + \exp(5.13-0.68\delta))$$

Figure 7—Marginal ignition probabilities for lodgepole pine duff. Pineg is the probability of ignition for negative discharges, pipos for positive discharges. Tabular values and simplified equations are given for convenience.



δ	pineg
0	0.003
1	0.013
2	0.049
3	0.162
4	0.406
5	0.709
6	0.9
7	0.969
8	0.989
9	0.994
10	0.995

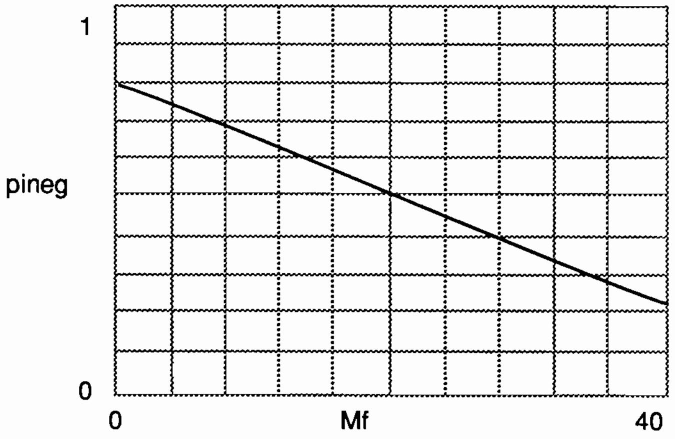
pineg = 1/(1 + exp(5.49–1.28δ))



δ	pipos
0	0.001
1	0.005
2	0.02
3	0.075
4	0.245
5	0.566
6	0.84
7	0.955
8	0.989
9	0.997
10	0.999

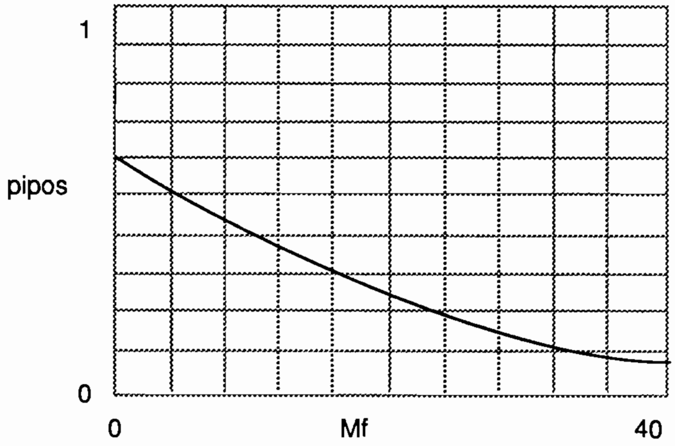
pipos = 1/(1 + exp(6.69–1.39δ))

Figure 8—Marginal ignition probabilities for Douglas-fir duff. Pineg is the probability of ignition for negative discharges, pipos for positive discharges. Tabular values and simplified equations are given for convenience.



Mf	pineg
0	0.79
4	0.741
8	0.687
12	0.628
16	0.567
20	0.505
24	0.444
28	0.386
32	0.33
36	0.279
40	0.233

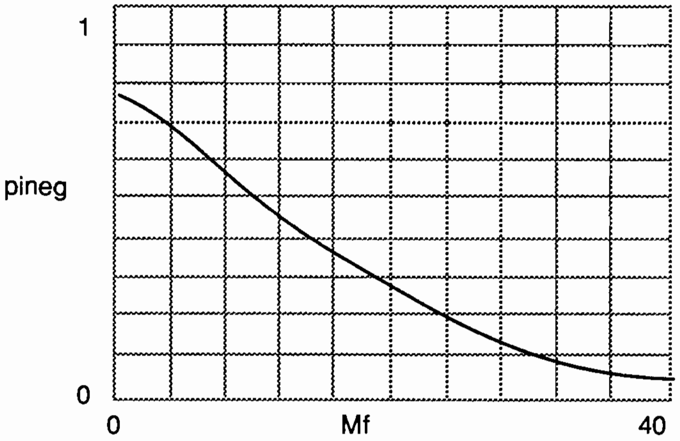
$$\text{pineg} = 0.8 - 0.014\text{Mf}$$



Mf	pipos
0	0.593
4	0.515
8	0.436
12	0.361
16	0.291
20	0.23
24	0.179
28	0.136
32	0.103
36	0.077
40	0.057

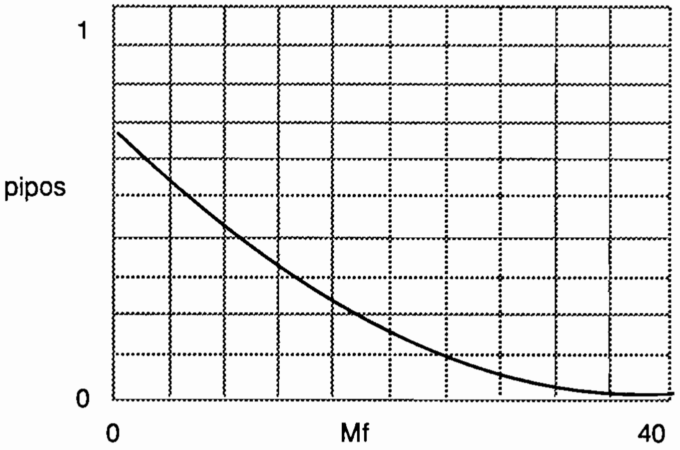
$$\text{pipos} = 0.62\ \exp(-0.051\text{Mf})$$

Figure 9—Marginal ignition probabilities for high-altitude mixed species, primarily Englemann spruce. Pineg is the probability of ignition for negative discharges, pipos for positive discharges. Tabular values and simplified equations are given for convenience.



Mf	pineg
0	0.774
4	0.686
8	0.583
12	0.472
16	0.365
20	0.269
24	0.19
28	0.13
32	0.086
36	0.056
40	0.036

$$\text{pineg} = 0.839 \exp(-0.058\text{Mf})$$



Mf	pipos
0	0.674
4	0.561
8	0.442
12	0.33
16	0.234
20	0.159
24	0.105
28	0.068
32	0.043
36	0.027
40	0.017

$$\text{pipos} = 0.715 \exp(-0.072\text{Mf})$$

Figure 10—Marginal ignition probabilities for commercial peat moss. Pineg is the probability of ignition for negative discharges, pipos for positive discharges. Tabular values and simplified equations are given for convenience.

APPENDIX C: A FORTRAN PROGRAM FOR ELECTRIC ARC IGNITION

```fortran
C ************************************************
C
      SUBROUTINE THOR5 (IFUEL,FM,DEPTH,ISTROKE,PROB)
C
C ***********************************************
C
C TO CALCULATE THE MARGINAL IGNITION PROBABILITY GIVEN A NATURAL ELECTRICAL
C DISCHARGE OF TYPE <STROKE> INTO FUEL TYPE <FUEL> WITH MOISTURE
C <FM> % AND/OR DEPTH <DEPTH> IN CM. NOTE THAT NOT ALL NEGATIVE DISCHARGES
C HAVE A CONTINUING CURRENT!!!
C THE SUBROUTINE USES GAUSSIAN QUADRATURE, WITH THE COEFFICIENTS FOR
C THE LAGUERRE POLYNOMIALS FROM:
C     "HANDBOOK OF MATHEMATICAL FUNCTIONS"
C      M. ABRAMOWITZ AND I. STEGUN, EDS.
C      US GOV'T. PRINTING OFFICE, APS-55 1964
C
C THIS PROGRAM IS A PART OF "IGNITION PROBABILITIES FOR WILDLAND FUELS"
C  BY DON LATHAM AND JOYCE SCHLIETER.
C
C !!!!!!DO NOT ALTER ANY NUMBERS IN THIS SUBROUTINE!!!!!!
C
C ***************************************************************
C
C THE INPUT VARIABLE <FUEL> HAS THE VALUE 1-8 ACCORDING TO:
C         1) PONDEROSA PINE LITTER,
C         2) ROTTEN, CHUNKY, PUNKY WOOD,
C         3) PUNKY WOOD POWDER, DEEP (4.8 CM)
C         4) PUNKY WOOD POWDER, SHALLOW (2.4 CM)
C         5) LODGEPOLE PINE DUFF
C         6) DOUGLAS FIR DUFF
C         7) HIGH ALTITUDE, MIXED, MAINLY ENGLEMANN SPRUCE
C         8) PEAT MOSS (COMMERCIAL)
C
C  OTHER FUELS WILL USE ONE OF THESE AS SURROGATE; CONSULT THE
C  ACCOMPANYING TEXT
C
C  THE INPUT VARIABLE <FM> IS THE FUEL MOISTURE IN %
C  THE INPUT VARIABLE <DEPTH> IS THE DUFF DEPTH IN CM.
C  THE INPUT VARIABLE <STROKE> IS +1 FOR POSITIVE DISCHARGES,
C  -1 FOR NEGATIVE DISCHARGES.
C  THE OUTPUT IS <PROB>, THE PROBABILITY OF IGNITION PER DISCHARGE.
C  AGAIN, NOTE THAT ABOUT 1 IN 5 NEGATIVE DISCHARGES HAS A CONTINUING
C  CURRENT. THIS IS ACCOUNTED FOR IN THIS SUBROUTINE.
C
C ***************************************************************
C
C SETUP AND PARAMETERS
C
      DOUBLE PRECISION WT,XI,AC1,AC2,AC3,AC4,B,SUM,T,Y,FX,S
C
C EVERYTHING DOUBLE PRECISION INTERNALLY
C
      DIMENSION WT(6),XI(6),AC1(8),AC2(8),AC3(8),AC4(8),B(8)
C
C
C
C WEIGHTS FOR ORDER 6 POLYNOMIAL
C
      DATA WT/0.458964673950,0.417000830772,0.113373382074,
     +        1.03991974531E-2,2.61017202815E-4,8.98547906430E-7/
C
```

```
C ZEROES OF ORDER 6 POLYNOMIAL
C
      DATA XI/0.222846604179,1.188932101673,2.992736326059,
     +        5.775143569105,9.837467418383,15.982873980602/
C
C EVERY POSITIVE DISCHARGE HAS A CONTINUING CURRENT, ONLY 1 IN 5
C NEGATIVE DISCHARGES DOES.
C
      DATA CCPERPOS,CCPERNEG /1.,0.2/
C
C ONLY TYPE 7 USES BULK DENSITY; WE USE THE AVERAGE FOR THAT FUEL
C
      DATA RHOB /0.127/
C
C COEFFICIENTS FOR THE FUEL TYPES
C
      DATA AC1,AC2,AC3,AC4,B
     +/     0.97, -0.59, 1.2, 0.13, -5.6, -7.1, 0.79, 0.42,
     +    -0.19, -0.15, -0.12, -0.05, 0.0, 0.0, -0.081, -0.12,
     +    0.0, 0.0, 0.0, 0.0, 0.68, 1.4, 0.0, 0.0,
     +    0.0, 0.0, 0.0, 0.0, 0.0, 0.0, -8.5, 0.0,
     +    0.012, 0.005, 0.002, 0.005, 0.007, 0.006, 0.011, 0.005/
C
C
C THESE ARE THE COEFFICIENTS IN THE WEIBULL DISTRIBUTION FOR CC'S
C
      DATA ETANEG,ETAPOS,SNEG,SPOS /1.6,2.3,207.8,69.3/
C
C DETERMINE DISCHARGE TYPE
C
      IF (ISTROKE.EQ.1) THEN
         ETAM=1./ETAPOS
         S=SPOS
         COEF=CCPERPOS
        ENDIF
      IF (ISTROKE.EQ.-1) THEN
         ETAM=1./ETANEG
         S=SNEG
         COEF=CCPERNEG
      ENDIF
C
C CALCULATE F(X) AT XI AND INTEGRATE
C
      SUM=0.0
      DO 100 I=1,6
      T=S*(XI(I)**ETAM)
      Y=AC1(IFUEL)+AC2(IFUEL)*FM+AC3(IFUEL)*DEPTH+AC4(IFUEL)*RHOB
     +  +B(IFUEL)*T
      FX=1./(1.+DEXP(-Y))
  100 SUM=SUM+WT(I)*FX
      PROB=SUM*COEF
C
C
      RETURN
      END
C
C ************************************************************
C
```

Latham, Don J.; Schlieter, Joyce A. 1989. Ignition probabilities of wildland fuels based on simulated lightning discharges. Res. Pap. INT-411. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 16 p.

Ignition of wildland fine fuels by lightning was simulated with an electric arc discharge in the laboratory. The results showed that fuel parameters such as depth, moisture content, bulk density, and mineral content can be combined with the duration of the simulated continuing current to give ignition probabilities. The fuel state parameters of importance and the ignition probabilities were determined using logistic regression. Graphs, tables, formulas, and a FORTRAN computer program are given for field use.

KEYWORDS: fire ignition, litter, duff, continuing current, logistic regression

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

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