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1988 Revisions to the 1978 National Fire-Danger Rating System

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Abstract.--The 1978 National Fire-Danger Rating System does not work well in the humid environment of the Eastern United States. System modifications to correct problems and their operational impact on System users are described. A new set of 20 fuel models is defined and compared graphically with the 1978 fuel models. Technical documentation of System changes is provided.

Keywords: Fire potential, fire, wild-land fire, fuel, moisture, weather.

INTRODUCTION

The 1978 National Fire-Danger Rating (NFDR) System (Deeming and others 1977) has been used without modification since it was implemented. During the last 10 years some deficiencies in performance in the Eastern United States have become apparent. These deficiencies were outlined at a National Fire-Danger Rating Workshop held at Harper's Ferry, WV (Gale and others 1986). Workshop participants included a cross section of researchers and State and Federal users. The consensus was that research should find and implement solutions to system shortcomings as quickly as possible. Accordingly, long-term research issues were shelved, as were some management issues that were identified.

The research priorities addressed here were:

- Improve the capability of the NFDRS to respond to drought in humid environments.
- Provide system flexibility to reflect greening and curing of live fuels.
- Correct the problem of overrating fire danger in the autumn.
- Correct the problem of overrating fire danger after rainfall.
- Adjust the fuel models to better predict fire danger in humid climates.

This publication describes the reasons these problems exist, and documents the modifications made to correct them. Each problem and solution is described, then operational impacts on users and System options are discussed. Fuel model descriptions and technical documentation are provided in the Appendixes.

In revising the System, certain constraints were accepted:

- The revisions should be collapsible back to the original (1978) NFDRS to minimize complications for western users, who were not seeking System changes.
- The mechanism for reflecting drought should utilize a currently available and relatively simple index that does not require observation of new weather parameters.
- Basic research to develop a new live fuel moisture model could not be performed in time to be used in this System revision.
- The revisions should expand user capabilities and user responsibilities to influence the System.

In this paper, the version of the NFDRS implemented in 1978 is referred to as the "1978 NFDRS." This revision of the 1978 NFDRS is referred to as the "1988 NFDRS." The 1978 NFDRS is fully documented (Bradshaw and others 1983), so its technical concepts will not be repeated here.

The 1988 NFDRS revisions required development of a new set of 20 fuel models, but the 20 fuel models developed for the 1978 NFDRS also remain available for use. Selection of the 1978 fuel model set disables most of the 1988 NFDRS revisions, while selection of the 1988 fuel model set enables them.

PROBLEMS AND SOLUTIONS

Response to Drought

The 1978 NFDRS relies largely upon 1,000-hour timelag fuel moisture to express the effects of normal annual drying and wetting cycles. This is accomplished directly through the effect of changes in 1,000-hour moisture on Energy Release Component (ERC) and Burning Index (BI) calculations and indirectly through the algorithm in which 1,000-hour moisture is used to calculate live herbaceous and woody fuel moistures. This concept works well in relatively arid climates that have low minimum relative humidities, and limited humidity recovery at night. However, in humid environments such as the Eastern United States, the daily minimum relative humidity in summer is normally greater than 40 percent, and the maximum at night is normally at least 80 percent. Such high humidities prevent the 1,000-hour fuel moisture from decreasing below about 15 percent, even during extended droughts. For example, typical 1,000-hour and live woody fuel moistures computed with the 1978 NFDRS are compared in figure 1 for a dry environment in California and a humid environment in Georgia. Even though 1986 was a severe drought year in Georgia, the 1,000-hour and live woody fuel moistures remained relatively high.

It is not suggested that the theory behind these calculations is incorrect; in fact, the theory is supported by studies (Blackmarr and Flanner 1968; Lindenmuth and Davis 1970; Reifsnyder 1961) showing that foliar moistures typically attain lower values in arid than in humid environments. Therefore no attempt was made to modify current theory; rather, a drought index (Keetch and Byram 1968) was implemented in the 1988 NFDRS and used to modify the amount of dead fuel available for consumption.

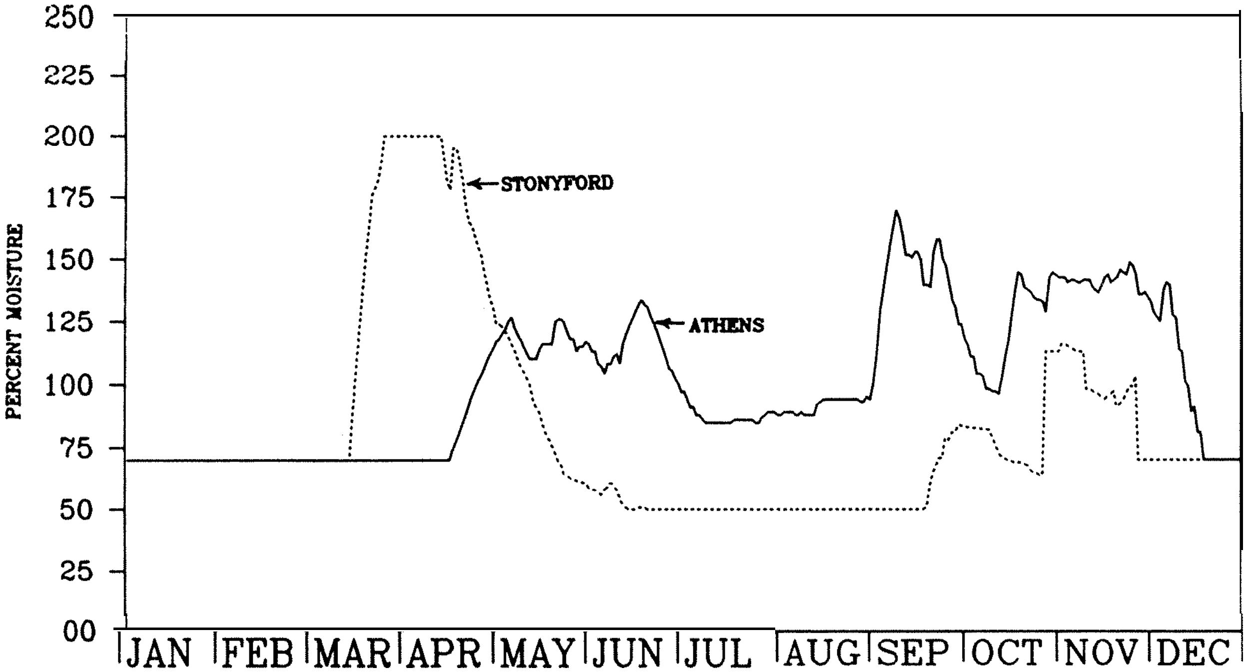
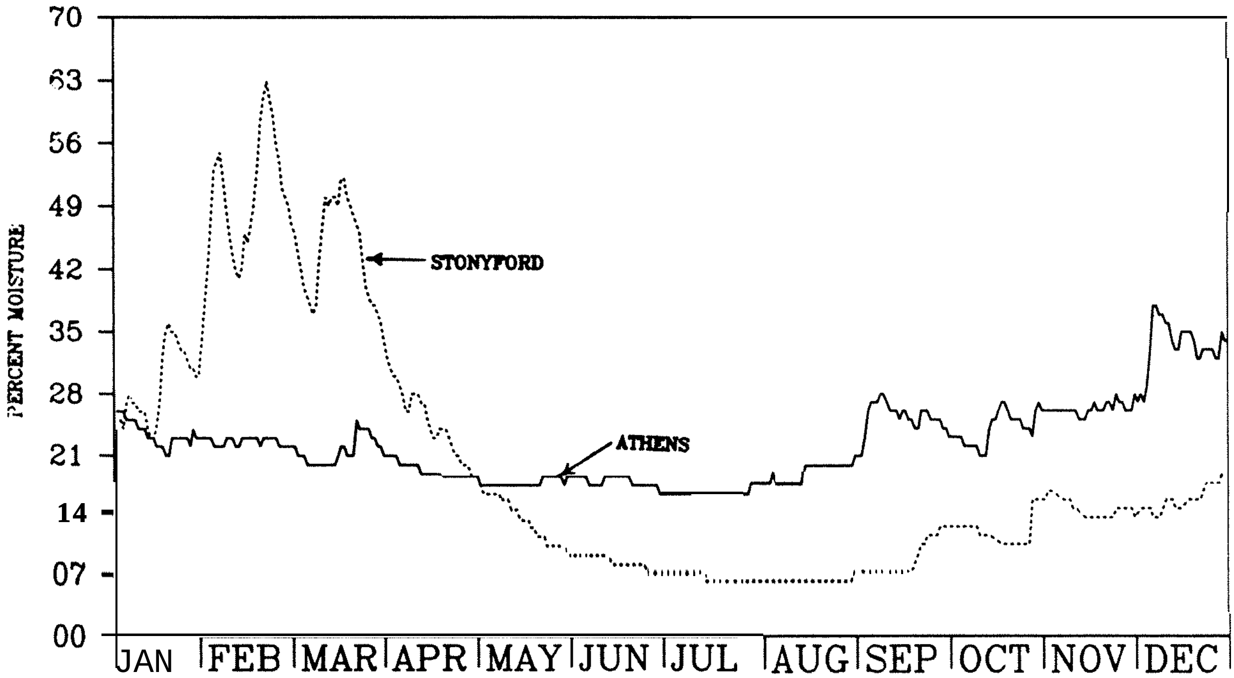


Figure 1.--**1,000-hour timelag** (above) and live woody fuel moisture (below) **comparisons** for a relatively dry western environment (Stonyford Ranger Station in California) and a humid eastern environment (Athens, GA) in **1986**. A generally high relative humidity prevents low **1,000-hour** fuel moistures in the humid environment.



The Keetch-Byram Drought Index (KBDI) is well known in the Southeastern United States and has also been used to some extent in the Northeast. Its purpose is to estimate deep drying of litter and duff. It is assumed that, as deep drying occurs, additional fuel becomes available for consumption within the flaming front of a fire.

The 1978 NFDR fuel models had no reservoir of additional fuel that could be used to simulate increased fuel availability as drought progressed. Therefore, they were modified to include a potential dead fuel load that can be added to the fuel model as a function of the KBDI. The functional relationship is shown in figure 2. The total dead load increases above a threshold KBDI value of 100, which signals that drought has progressed beyond the "zero or incipient" stage (Keetch and Byram 1968). The added fuel is distributed in proportion to the predrought dead fuel loads, with depth increased to preserve the packing ratio. The total potential dead load increase is not realized until the KBDI reaches 800.

Figure 3 presents the KBDI at Athens, GA, for 1986, and the lo-hour timelag fuel load to illustrate the adding of dead fuel to the model when the KBDI exceeds 100. The concept of drought adding available fuel is similarly extended to other dead fuel classes in a fuel model.

Although this added drought response capability was developed to alleviate eastern problems with the 1978 NFDRS, it could also prove helpful in the Western United States. It can be disabled by selecting the 1978 NFDRS fuel model set however.

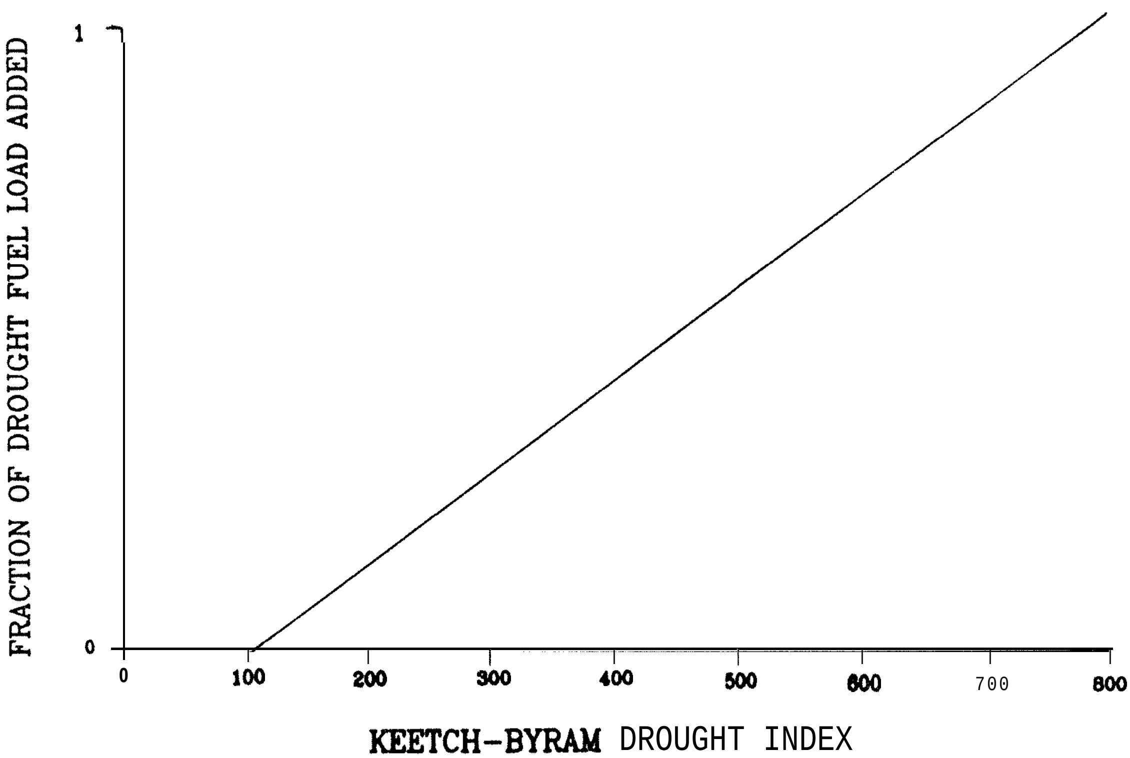


Figure 2.--Functional relationship of fuel load addition due to drought. as defined by the Keetch-Byram Drought Index.

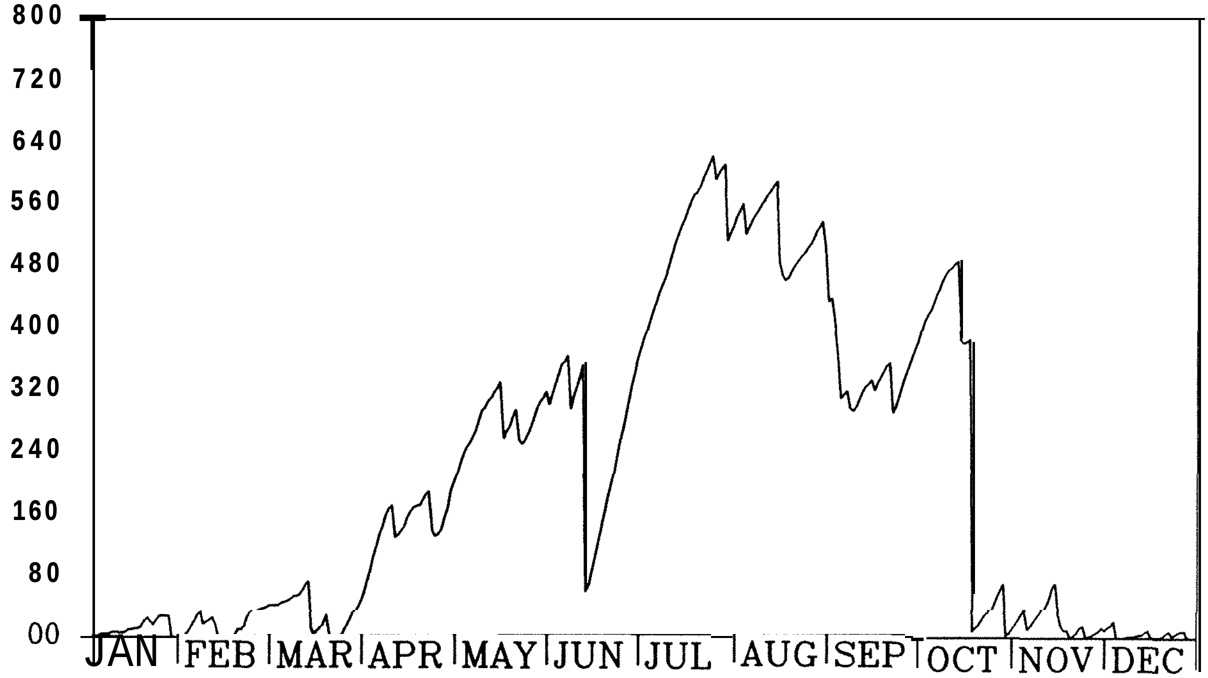
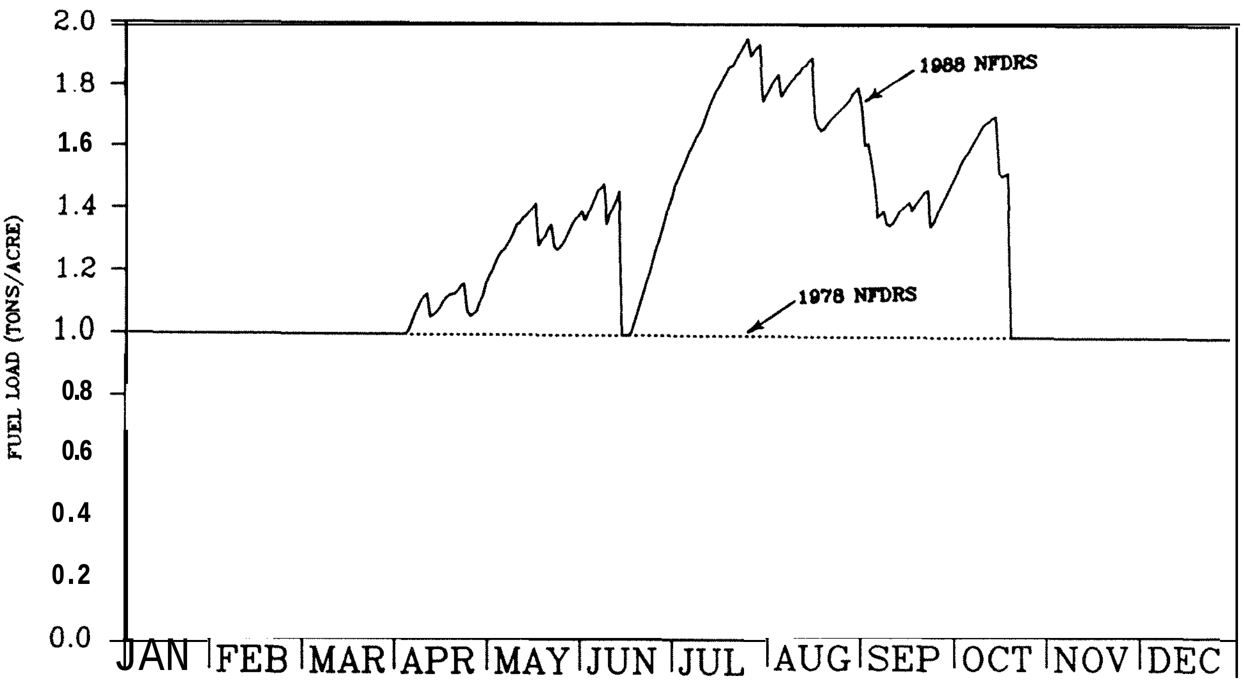


Figure 3.--As the Keetch-Byram Drought Index fluctuates above 100 (above), lo-hour fuel loading in the 1988 NPDRS changes. while that for the 1978 NPDRS is constant (below). Values are for 1986 in Athens, GA (model C).



Greening and Curing Flexibility

Fundamental changes in the 1978 NFDRS model for live fuel moisture (Burgan 1979) may be required. Because it was obvious such changes could not be implemented in time for this effort, they are left for future research.

In the 1978 NFDRS, users of the AFFIRMS System (Helfman and others 1980) could signal the start of greening at any time. Whereas the simulated greening process was relatively gradual, the time over which it was assumed to occur was fixed by the climate class assigned to the weather station, and automatically controlled by AFFIRMS.

Curing in the autumn was not assumed to be gradual. The user could simulate the autumn transition from summer to winter only by entering an AFFIRMS command to indicate that vegetation had frozen. The change in calculated moistures of live herbaceous and woody fuels to dormant-season values was instantaneous. The actual fall curing process is gradual.

Differences between the AFFIRMS System, used for current daily operation of the 1978 NFDRS, and the FIRDAT program of FIREFAMILY (Main and others 1982), used for historical data analysis, caused another problem. Historical analyses of fire danger produced by FIRDAT did not use greening and curing dates entered by the AFFIRMS user. The historical fire-danger profile often differed from conditions during a particular fire season, and fire planning was adversely affected.

The 1988 NFDRS requires users to enter greenness factors that express actual greening and curing of both live herbaceous and live woody vegetation. Greenness factors values are entered separately for live herbaceous and woody vegetation and included as part of each day's weather record. This feature permits the user to control each greenness factor independently, and inclusion of greenness factors in the daily weather record solves the problem of matching historical fire-danger profiles with the actual conditions.

Greenness factors represent your visual estimate of the current general greenness of herbs and grasses, and shrubs, compared with their maximum greenness. The greenness factors range from 0 to 20, where 0 represents fully cured herbaceous plants or dormant shrubs, and 20 represents a condition in which the herbs and/or shrubs are as green as they ever get. Intermediate values represent intermediate greenness. A factor of 10 indicates that the herbs or shrubs are about half as green as they ever get. The greenness factors are independent of climate class; that is, they range from 0 to 20 for all climate classes.

As the herbs and shrubs green in the spring, increasingly larger greenness factors are entered for each. Because herbs and grasses may green at different times or rates than shrubs, the herbaceous and live woody greenness factors do not have to be the same. In addition, it is not necessary to increase the greenness factors by one each day. If greening is proceeding slowly, the same values may be entered for several days. If greening is rapid, the greenness factors may be increased more than one per day. The curing process is handled similarly. That is, the greenness factors for herbs and shrubs are decreased gradually as curing progresses.

The greenness factors for herbs and shrubs also provide a mechanism for reflecting the effect of summer droughts. If a drought becomes so severe that herbs and grasses begin to cure and shrub leaves wilt, the herb and live woody greenness factors can be reduced appropriately. If the drought is later broken, the greenness factors can be increased again to reflect increased moisture. However, the user should make such changes gradually to reflect what is actually occurring in the fuel type.

The user must determine the greenness factors to enter for herbs and shrubs. This is an example of added system flexibility resulting in added user responsibility. Greenness factors must be entered by all system users, regardless of whether they use the 1978 or the 1988 NFDRS fuel model set. Guidelines for adjusting greenness factors are provided in the section titled "Operational Considerations."

Figure 4 illustrates the effect of varying the woody greenness factor. In this figure, live woody (shrub) moisture calculated with the 1978 NFDRS is compared with calculated values from the 1988 NFDRS. Greening was started at the same time in each case. The 1988 NFDRS strongly reflects the effect of summer drying on live woody moistures. This effect was produced by reducing the live woody greenness factor during the dry periods, then increasing it after significant precipitation occurred.

The difference in fall curing can also be seen. The 1978 NFDRS decreased the live woody moisture to the dormant period minimum of 70 percent for climate class 3, on the day a freeze occurred. But with the 1988 NFDRS, the live woody fuel moisture was gradually decreased to this value as the user slowly reduced the live woody greenness factor to 0.

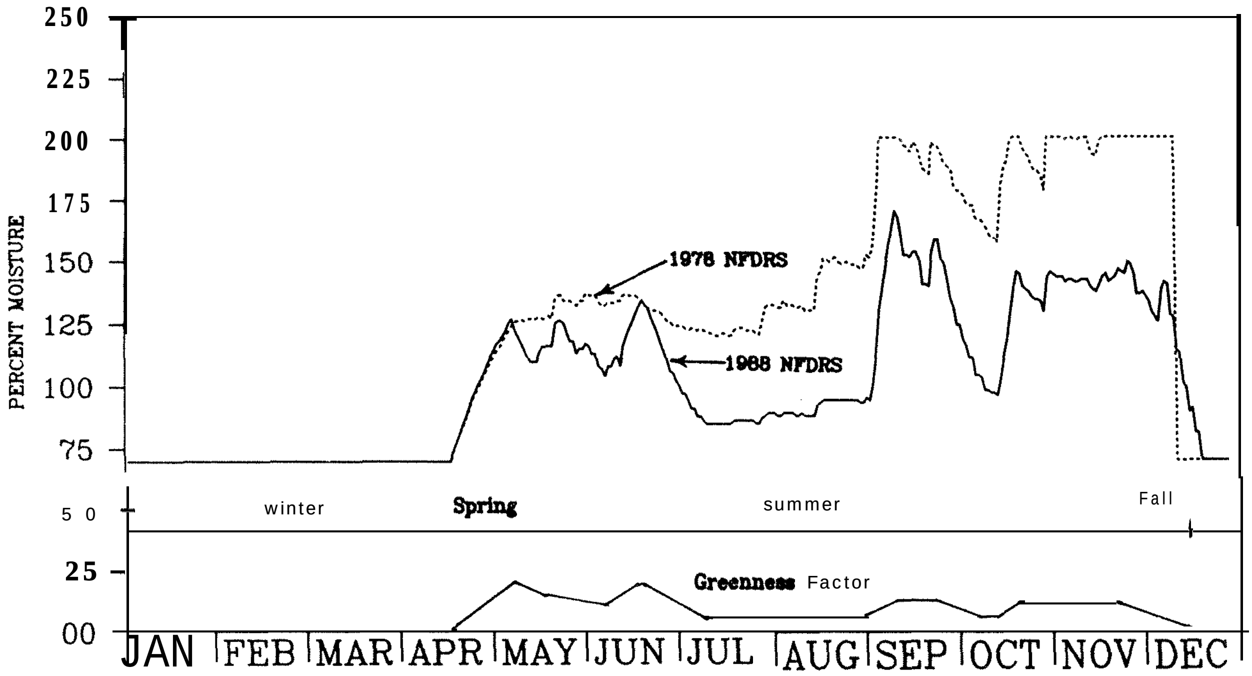


Figure 4.--An example of improved capability to calculate reduced live fuel moisture through use of reduced greenness factor values in the 1988 NPDRS. as compared with live fuel moisture calculations from the 1978 NPDRS. The Y-axis scale references both percent moisture and greenness factor. Values are for 1986 in Athens. GA.

Overrating Fire Danger in the Autumn

A primary reason the 1978 NFDRS overrated autumn fire danger is its poor ability to simulate fall curing. Herbs and shrubs may cure at different times, and the shrubs may be deciduous. Neither of these circumstances can be recognized within the 1978 NFDRS; the vegetation is assumed to cure immediately when a freeze occurs. The result of this assumption is an instantaneous increase in fire danger, due to the sudden reduction of live fuel moistures to their dormant season minimums. The greenness factors in the 1988 NFDRS permit simulation of gradual fall curing, resulting in a gradual increase of autumn fire danger.

In addition, the live woody fuel load can be defined as deciduous or evergreen. Deciduous models allow simulation of leaf fall by permitting load transfers between the live woody class and the fine dead fuel class as a function of the greenness factor for live woody vegetation. This is an extension of the concept in the 1978 NFDRS that live herbaceous fuel load can be transferred between the live and dead categories. When the live woody greenness factor is 0, all the live woody load is transferred to the fine dead fuel class. When it is 20, the live woody load is at its full assigned value for the fuel model, and the fine dead fuel load is correspondingly reduced.

Figure 5 illustrates the difference between fuel loading profiles for the 1978 NFDRS and the 1988 NFDRS with the deciduous option selected. The live woody load is constant at 0.5 ton per acre for the 1978 NFDRS model C, while it fluctuates from 0.0 to its maximum value of 0.8 ton per acre for the revised model C. These load changes occur as the live woody greenness factor is changed during the year.

The 1988 System transfers fuel from the live woody and herbaceous classes, as well as the drought fuel class, into the fine dead class during a summer dry period. By comparison, the 1978 NFDRS shows only a slight transfer of fuel into the fine dead fuel class during summer for two reasons: (1) the live woody load is held constant, and (2) high calculated herbaceous moistures permitted little herbaceous load transfer into the fine dead fuel class during the July-August dry period.

The 1988 NFDRS offers the capability to select between an evergreen and a deciduous live woody fuel load. The evergreen mode should be selected if the live shrubs are not deciduous, or if you do not want to permit this fuel load transfer for some other reason. Selection of the 1978 NFDRS fuel model set eliminates the option of indicating whether or not the live woody vegetation is deciduous.

Overrating Fire Danger After Rainfall

The 1978 NFDRS can overrate fire danger after rainfall, especially if strong winds or low humidities occur after a frontal passage. The Spread Component (SC), Ignition Component, and Burning Index rise rapidly with increasing windspeed, and low calculated fine dead fuel moistures associated with low relative humidity. Fine dead fuels are defined as any dead plant material less than one-fourth inch thick.

If fuel moisture sticks are not used, fine dead fuel moisture calculation in the 1978 NFDRS is unaffected by precipitation, unless it is occurring at observation time. If lo-hour timelag fuel moisture sticks are used, they provide a 20-percent influence on the fine dead fuel moisture. The remainder

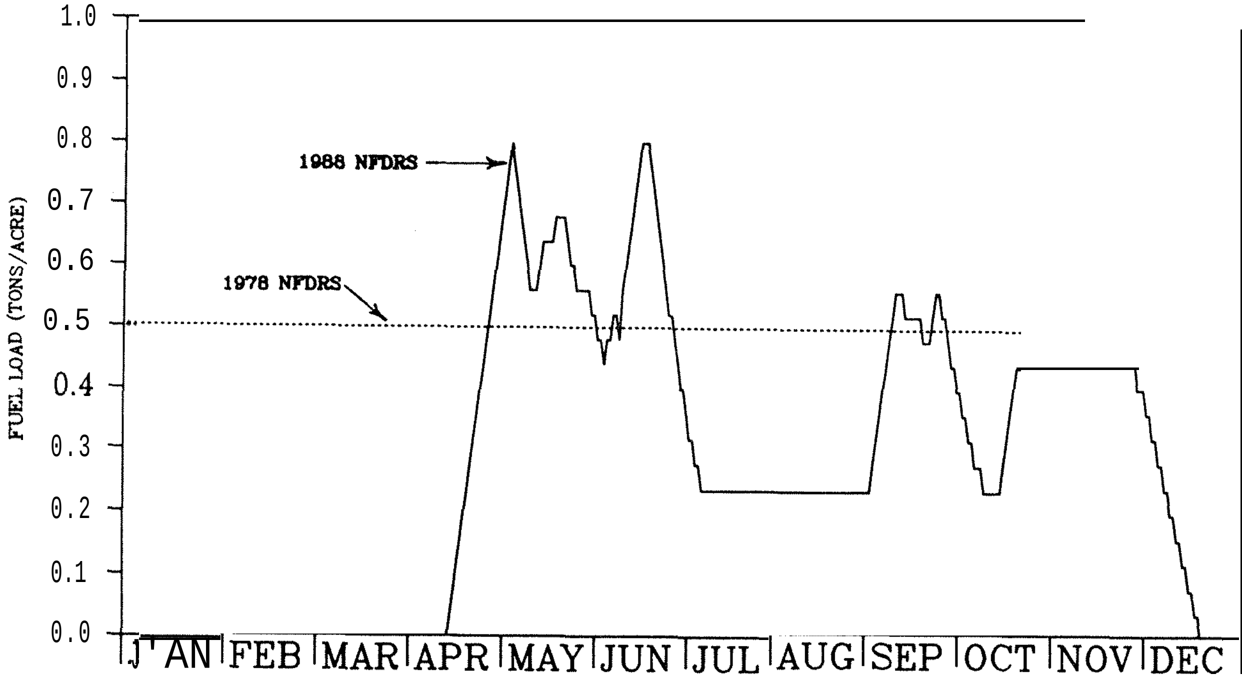
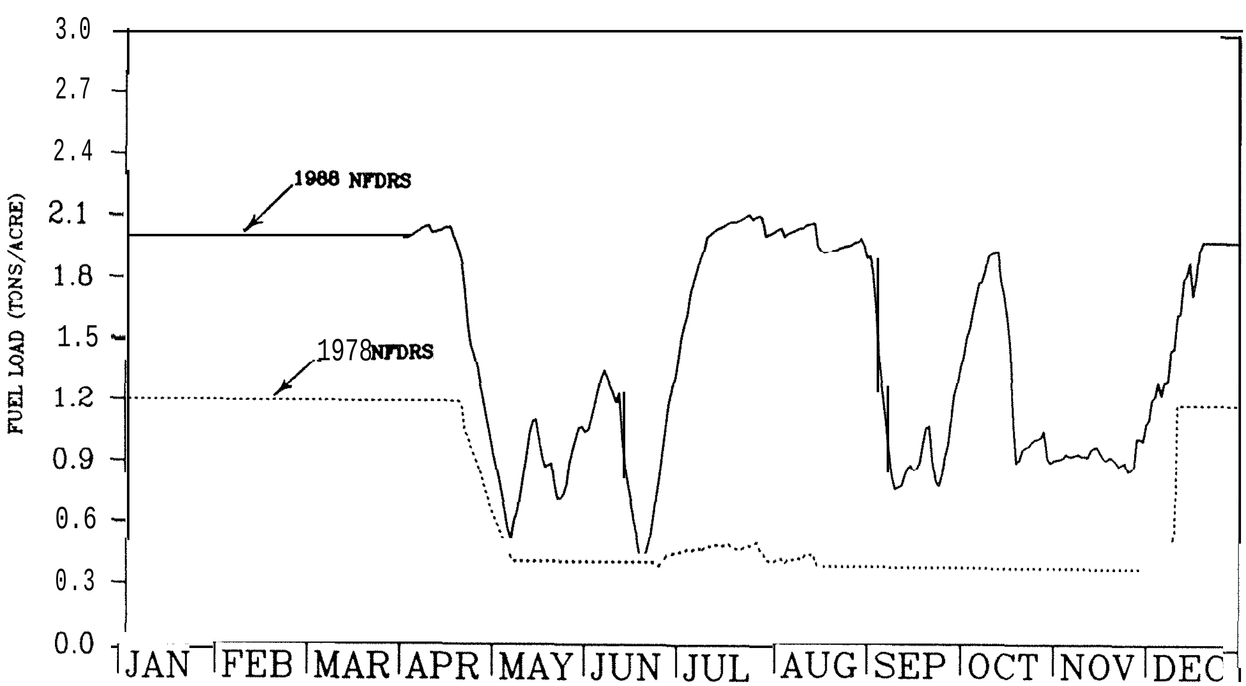


Figure 5.--Live woody (above) and fine dead (below) fuel load profiles **from** model C for the **1978** NPDRS and the **1988** NPDRS during a drought year **(1986)** in Athens, GA. The live woody load was declared deciduous.



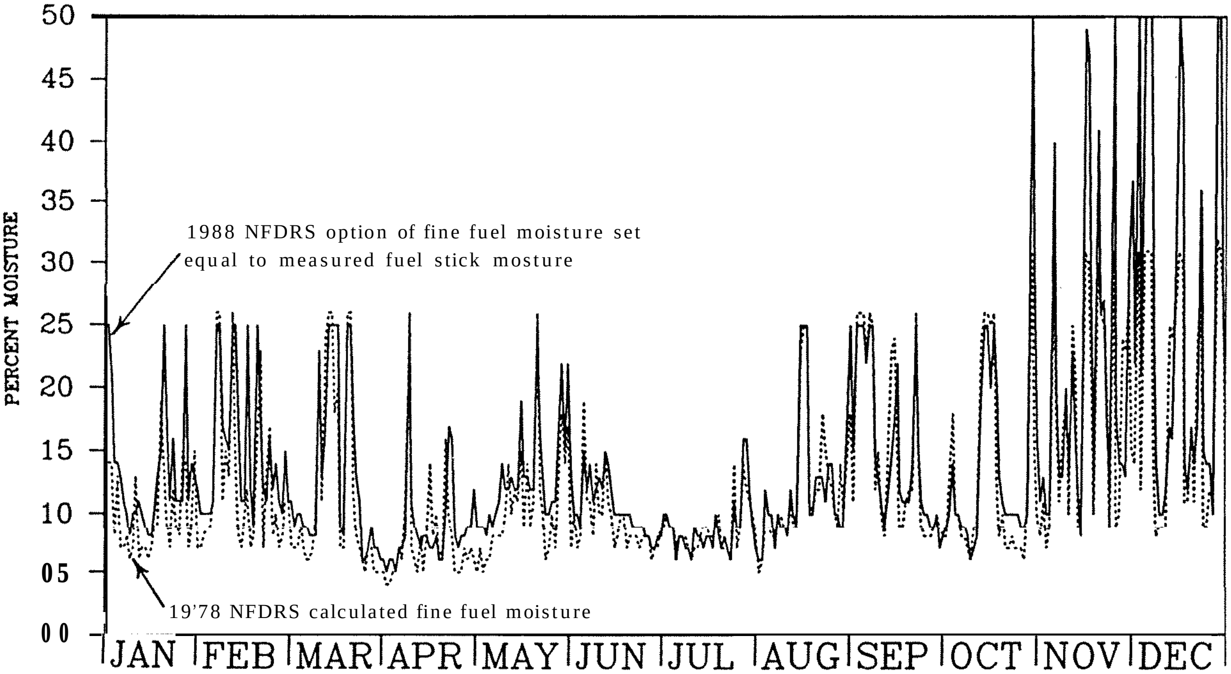
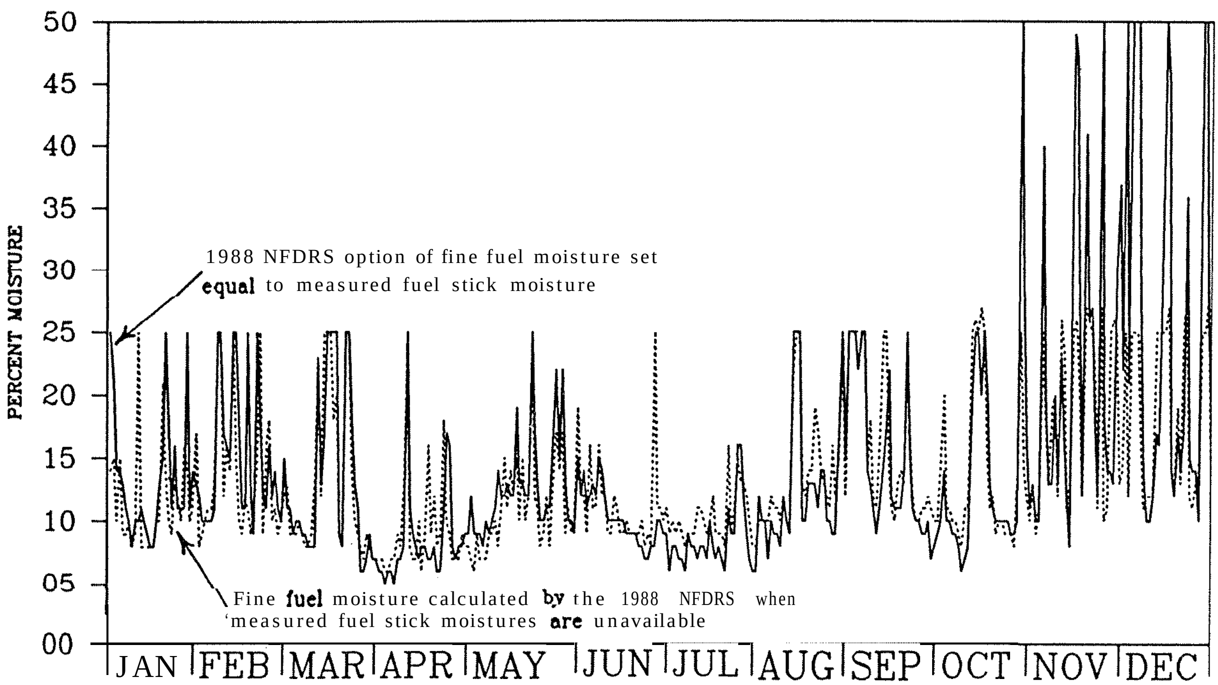


Figure 6.--Differences between fine-fuel moisture determined by weighing fuel sticks and Pine-fuel moisture estimated by the 1978 NPDRS (above) and the 1988 NPDRS (below). Values are for 1986 in Athens, GA.



of the calculation is a function of current dry-bulb temperature and relative humidity. Experience has shown that both methods produce fine dead fuel moisture values that are too low. In addition, recent research (Anderson 1985) has shown that few fine dead fuels actually have a l-hour timelag as has been thought in the past. Rather, their response time, while variable, is closer to 10 hours.

The 1988 NFDRS provides an option to set the fine dead fuel moisture equal to the lo-hour timelag fuel stick moisture. The effect of choosing this option is shown in figure 6. In general, this revision produces higher fine dead fuel moistures and much more response to rainfall events. Whether or not this option is selected, use of fuel moisture sticks and entry of measured values is strongly recommended. When fuel moisture sticks are not used in the 1988 NFDRS, the fine dead fuel moisture is calculated as a function of 100-hour timelag fuel moisture, and observed dry-bulb temperature and relative humidity. Use of the 100-hour timelag fuel moisture provides a mechanism for including the effect of precipitation events that do not occur at observation time.

If the user chooses the 1988 NFDRS fuel models but does not want to set fine dead fuel moisture equal to lo-hour timelag fuel moisture, the 1988 NFDRS still does so on the day of and day following a precipitation event of more than 0.1 inch to reduce the problem of overrating fire danger after rain. Otherwise the fine dead fuel moisture calculation is not affected.

Fire danger can also be overrated after a rain if strong winds persist after frontal passage. The 1978 NFDRS uses an adjustment factor that depends on the fuel model to reduce windspeeds measured at the standard height of 20 feet above surrounding vegetation to midflame level. Subsequent research (Albini and Baughman 1979) indicates that wind adjustment factors for closed stands such as hardwood or hardwood/conifer forests in the East should be about 0.2 during the summer and about 0.5 during the winter. The 1988 NFDRS revision provides a variable windspeed adjustment factor for fuel types that have deciduous live woody fuel. The windspeed is reduced most during the summer or whenever the shrubs are fully green, least when the shrubs have lost their leaves, and an intermediate amount at intermediate greenness levels. These conditions are indicated by user entry of a greenness factor for live woody fuels. The windspeed adjustment factor remains constant for fuel models whose live woody fuel load is declared evergreen (nondeciduous) or for models that do not have a live woody fuel load.

The 1988 field tests indicated that with only the above revisions fire danger was still often overrated on the day of and day following precipitation. Therefore, the wind adjustment factor is now multiplied by 0.3 on those two days only. This correction reduces the sensitivity of the 1988 NFDRS to wind until the dead fuels have had at least 1 day of drying.

Figure 7 illustrates the effect of this change for fuel model C. Choice of the 1978 NFDRS fuel models eliminates the above-described changes to the windspeed adjustment factor.

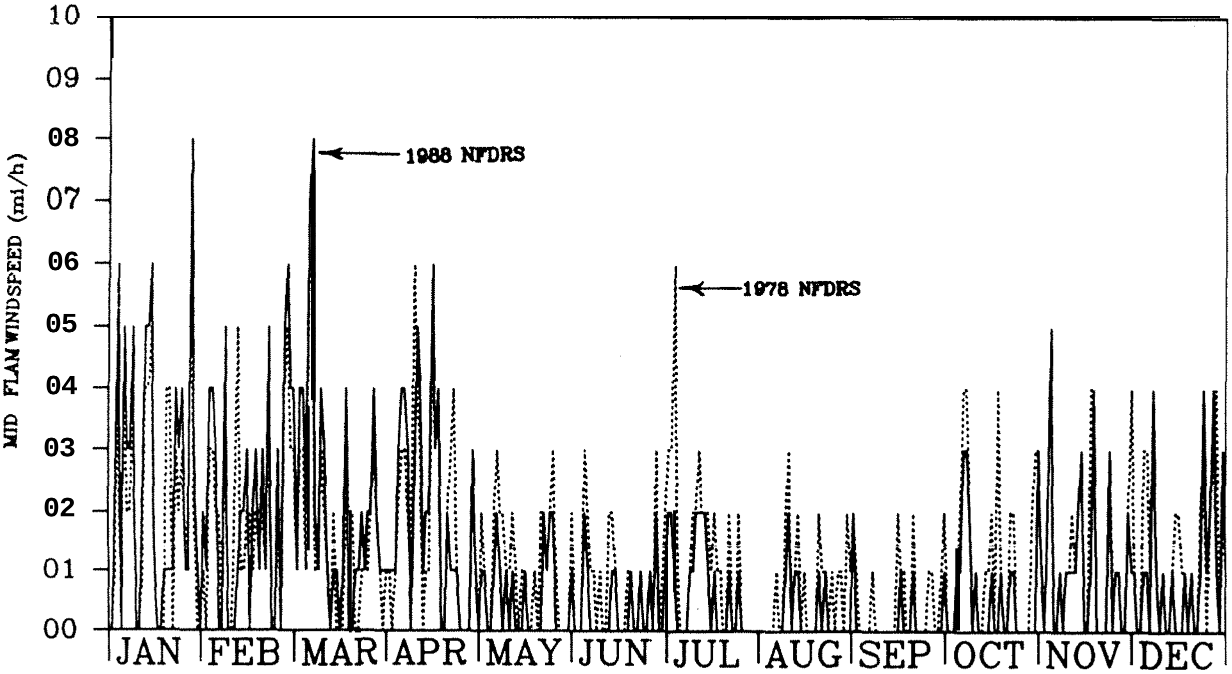


Figure 7.--For some fuel models. the variable wind adjustment factor of the 1988 NPDRS tends to produce higher windspeeds than the 1978 NPDRS during the winter and lower windspeeds in the summer. Values are from model C for 1986 in Athens, GA.

Revised Fuel Models

The changes described required modification of all 20 1978 NFDRS fuel models. A second set of 20 fuel models was created. In some cases, fuel loads were changed to improve the seasonal response, but the major changes involved adding a minimum and maximum wind adjustment factor and a reservoir of dead fuel to improve the drought response. The user can choose which set of fuel models to use: the original 1978 NFDRS models or the 1988 revision of those models. Both the 1978 and 1988 NFDRS fuel models are listed in appendix A. As noted previously, the fuel model set chosen determines whether the system revisions are implemented.

System Response Comparison

SC, ERC, and BI profiles for the 1986 fire season at Athens, GA (fig. 8) illustrate the combined effects of the revisions. Values of SC are reduced during the January-April dormant season, but slightly increased during a midsummer and early fall drought. For this example, fine dead fuel moisture was set equal to the measured fuel stick moisture. This usually results in higher fine dead fuel moisture values than are obtained through the standard 1978 NFDRS calculations. Because the SC is strongly affected by fine dead fuel moisture, the effect is to produce a general reduction in SC throughout the year, with the effect being greatest during the cool, moist period of winter and early spring. During the May-June period, the 1988 system SC is near 0 for the additional reason that the 20-foot windspeeds undergo their greatest adjustment to midflame level windspeeds when the vegetation is in full leaf. A small effect of drought on the SC can be seen during the July-August and October periods when deep drying increased the amount of available fuel.

The ERC (fig. 8) is slightly higher for the 1988 NFDRS than for the 1978 NFDRS during the spring because the live woody load was designated to be deciduous, and was thus transferred to the fine dead fuel class during the dormant season. The most dramatic difference, however, occurs during the summer drought, when the ERC is significantly increased for the 1988 System. This increase reflects a combination of both increased dead fuel load due to deep drying, and coincidental reduction of live fuel moistures, simulated through reduction of greenness factors to help reflect the severity of the drought. Greenness factors were added to the historical weather data for the Stonyford, CA, and Athens, GA, weather stations, after consultation with local fire managers. The FIREFAMILY programs have been restructured to use greenness factors as they become available in new weather records, or to process older data without them.

The BI (fig. 8) is a function of both the ERC and the SC. Thus, it is most effective in illustrating the combined effects of all the System revisions. Winter and early spring BI values are reduced primarily by letting fine dead fuel moisture equal measured fuel stick moisture. Summer drought is better reflected through a combination of increasing dead fuel availability and reducing live fuel moisture. The fire danger increases slower in late November and December, as a result of a more gradual simulation of the fall curing process.

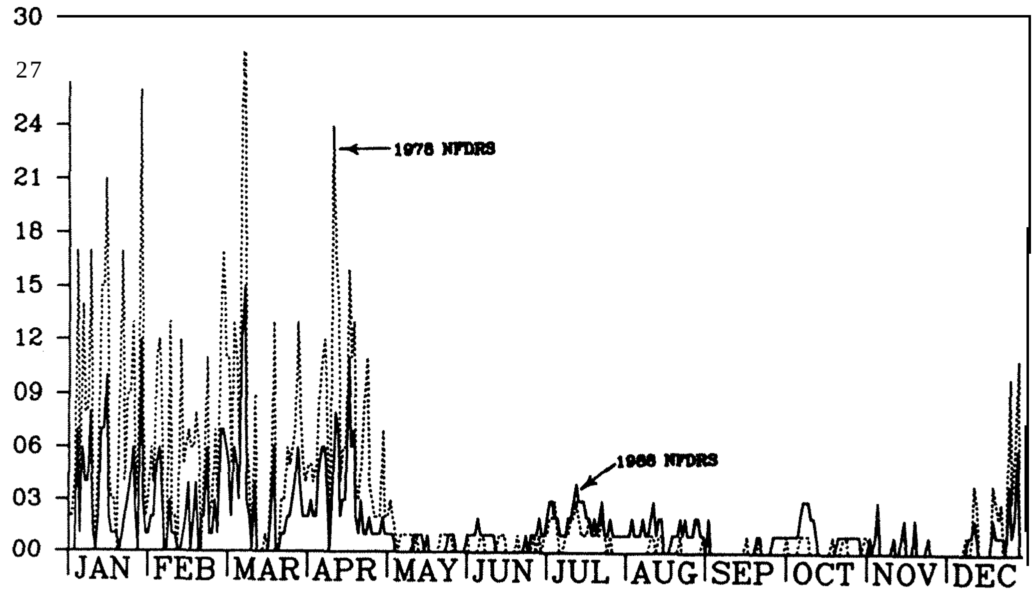
OPERATIONAL CONSIDERATIONS

Impacts on All Users

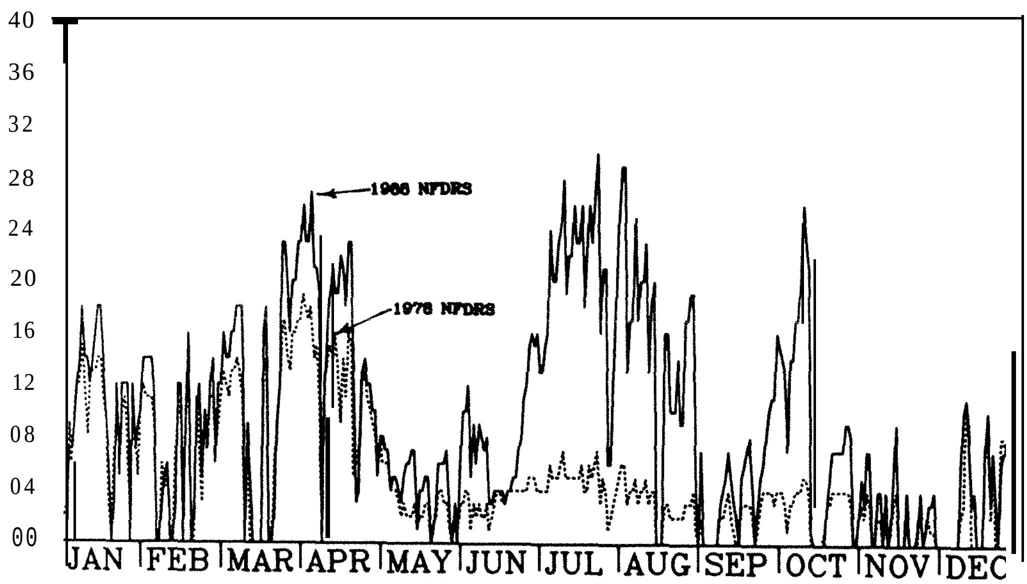
The revisions to the 1978 NFDRS have been structured to enable fire managers to use the System nearly unchanged or to select those modifications that address specific local problems. The exceptions are mandatory entry of greenness factors for live herbaceous and woody fuels, and addition of the KBDI. First, let us consider the impacts this revision will have on all users of the NFDRS.

The KBDI computation requires entry of average annual precipitation amount at your weather station to the station catalog. This includes both rainfall and the water equivalent of snowfall. If you do not take weather all year, or do not know what this value is, a reliable estimate can be obtained from the nearest National Weather Service Office. The KBDI computation also requires daily entries of precipitation amount.

At the beginning of the fire season, you need to enter a starting KBDI value. Normally, this value would be near 0 because winter rainfall or snow melt have recharged soil moisture. However, this inquiry provides an opportunity to enter an estimated value if significant drying occurs before you activate the weather station and begin calculating the KBDI. In such instances, use table 1 to make your best estimate. It indicates the number of rainless days to reach KBDI values of 100, 200, 300, or 400 for various mean annual precipitation amounts and at various average maximum daily dry-bulb temperatures. Obviously, this table can only serve as a rough guide to a reasonable starting KBDI value. It is preferable to begin calculations after a significantly wet period, when soils are fully charged with moisture.



Pfgure 8.--Cumulative effects of the 1988 NPDRS revisions on Spread Component (top), Energy Release Component (middle). and Burning Index (bottom). for the 1.978 NPDRS and the revised NPDRS. Values are from model C for 1986 in Athens, GA.



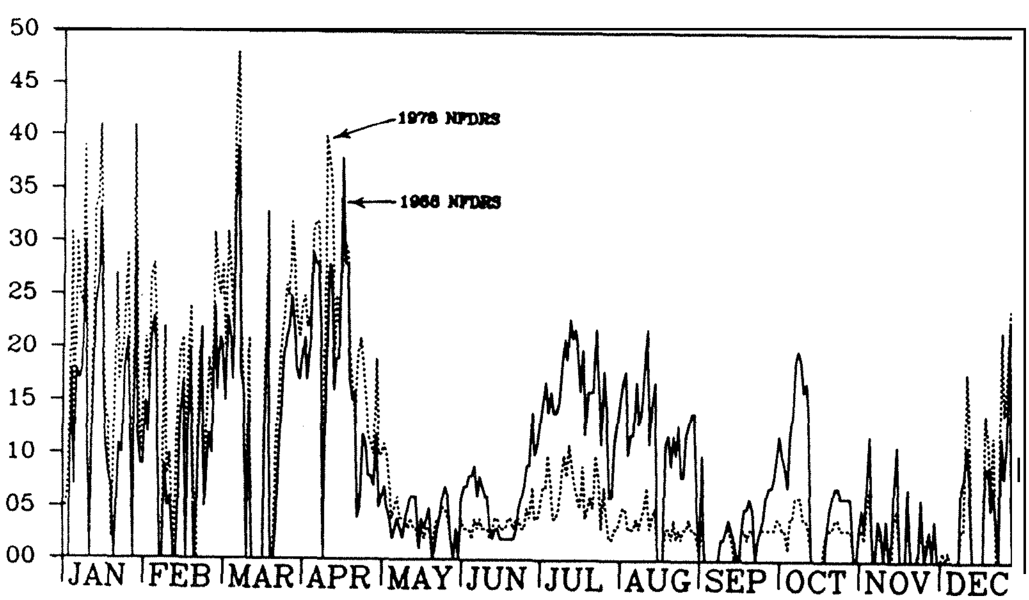


Table 1.--Rainless days required to reach various KBDI values

Mean annual precip. (inches)	Average daily maximum dry-bulb temperature 60 °F				70 °F				80 °F			
	KBDI				KBDI				KBDI			
	100	200	300	400	100	200	300	400	100	200	300	400
10	100	200	300	400	50	100	189	289	27	60	95	145
15	100	200	300	400	49	99	149	238	23	48	81	118
20	100	200	300	400	34	77	127	177	20	41	66	99
25	61	161	261	361	32	55				35	56	82
30	50	105	205	305	25	46	107	157	16	29	41 47	70
35	50	100	160	260	21		88	133	14			59
40	41	91	141	215	19	40	65	97	19	22	35	51
45	34	75	125	175	17	35	57	84	8	19	30	45
50	34	67	112	162	15	31	50	74	7	15	27	39
55	27	60	95	145	13	28	45	66	6	13	24	35
60	25	54	88	131	12	25	41	59			22	32
65	23	48	81	118	11	23	37	54	6	12	20	29
70	20	45	74	107	10	21	34	50	5	11	18	27
75	20	43	69	102	9	20	32	47	5	11	17	25
80	19	40	65	97	9	19	30	44		10	16	24

Use of greenness factors requires entry of the season of year as part of the daily weather record. This may seem a trite entry, but proper implementation of the greenness factors was impossible without it. The following tabulation provides guidelines for both season and greenness factor entries.

Season	Guideline
Winter	Enter winter only when herbs are cured; and shrubs are dormant. Enter both herb and woody greenness factors as 0 (zero).
Spring	Enter spring from the time either the herbs or shrubs first begin a new season's growth until the herbs complete their spring growth flush. If the shrubs begin to green but the herbs are still cured, continue to enter a greenness factor of 0 for the herbs until they too begin to green, then start increasing it. Gradually increase the live woody greenness factor as the shrub growth flush increases. Follow similar reasoning if the herbs and grasses green before the shrubs.
Summer	Enter summer from the time the herb growth flush is completed until the shrubs begin to show signs of fall curing. Enter separate values that represent the relative greenness of herbs and shrubs. Often herbs cure during the summer, while shrubs remain quite green. In this case, the herb greenness factor should be reduced to 0, while the woody greenness factor remains at some value intermediate between 1 and 20.

Fall — Enter fall from the time deciduous shrubs begin to lose their leaves, or evergreen shrubs begin to enter dormancy, until the shrubs and herbs are fully dormant. As fall progresses, gradually reduce the greenness factors for grasses and shrubs if either. is above 0. If grasses are cured, enter the herb greenness factor as 0. When grasses are cured and shrubs are dormant, enter a greenness factor of 0 for both, and cycle the season entry back to winter.

When entering live herbaceous and woody greenness factors, it is important to avoid large changes. It is reasonable to increase or decrease the greenness factors gradually, or to hold them constant for a number of days, but you should not vacillate between increasing and decreasing values over short time periods. Basically, the values should be 0 in the winter and increase from 1 to 20 in the spring. Then, during dry periods, as plants begin to show signs of moisture stress, decrease the herbaceous greenness factor to help reflect obvious curing of grasses or other herbaceous plants, especially annuals. For perennials and shrubs that may not show immediate obvious signs of drying, the following guideline is adapted from work by Johnson (1980) for the Southeastern United States. It is just a guideline and is no substitute for common sense or visual observation of what is actually occurring in the field. With experience, you may want to revise the guideline for your location.

Suggested Greenness Factors During Dry Periods

KBDI value	Greenness factor	KBDI value	Greenness factor
0-200	20	401-420	9
201-220	19	421-440	8
221-240	18	441-460	7
241-260	17	461-480	6
261-280	16	481-500	5
281-300	15	501-520	4
301-320	14	521-540	3
321-340	13	541-560	2
341-360	12	561-580	1
361-380	11	581+	0
381-400	10		

If the KBDI drops suddenly due to significant rainfall, increase the greenness factor gradually, rather than jumping it to a higher value just to follow the above guideline. The vegetation is not likely to green significantly in 1 day.

User Options

The mechanics of new selections in the 1988 NFDRS are provided in revised users manuals for the AFFIRMS, FIREFAMILY, and personal computer NFDRS (Donaldson 1988) programs, or in specific prompts presented during program operation.

Your first choice is between the 1978 and the 1988 NFDRS fuel models. Your selection should be based on whether the 1978 fuel models have served you well in the past. Remember that if you select the 1978 NFDRS fuel models, you still need to enter greenness factors, season, and precipitation amount in your daily weather record. The KBDI will be provided regardless of your choice. If you select the 1988 fuel models, you will need to reanalyze your historical weather data and redefine your manning class breakpoints. Obviously, the 1988 fuel models are going to produce different seasonal fire-danger profiles.

If you use the 1988 NFDRS fuel models, your second choice is whether or not to set the fine dead fuel moisture equal to the observed lo-hour timelag fuel stick moisture. If this option is selected, the fine dead fuel moisture will always equal the lo-hour timelag fuel moisture. If it is not selected, fine dead fuel moisture will equal the lo-hour fuel moisture only on the day of and the day after precipitation. In general, if your fine dead fuels are composed primarily of conifer needles and/or hardwood leaves that have a waxy surface when fresh, select this option. But if your fine fuels are composed primarily of grasses, lichens or other very small nonwaxy fuel particles, do not select this option. Before making this decision, consider whether the 1978 NFDRS has been overrating fire danger in the past.

The last choice is whether or not to define the live woody vegetation as deciduous or evergreen. Broadleaf shrubs that do not lose their leaves are defined as evergreen.

Users who want to minimize the effect of the 1988 NFDRS revisions should:

- Select the 1978 NFDRS fuel models.
- Do not set fine dead fuel moisture equal to lo-hour fuel stick moisture.
- Enter live woody and herbaceous greenness factors as follows:
    - Increase both live herbaceous and woody greenness factors from 0 to 20 during spring greening period (7, 14, 21 or 28 days for climate classes 1, 2, 3, or 4, respectively).
    - Enter the live herbaceous greenness factor as 20 until the calculated herbaceous moisture decreases below 30 percent, or a killing frost occurs, then begin entering 0.
    - Keep entering the live woody greenness factor as 20 until a killing frost occurs, then begin entering 0.
    - Enter 0 for both greenness factors when the grass is cured and the shrubs are dormant.

Your selection of options provided with the 1988 NFDRS can make a significant difference in the seasonal fire-danger profile, depending on the fuel model used. You are encouraged to use the FIRDAT program of FIREFAMILY to examine the effects of different choices for dry, wet, and average fire seasons before making your decisions.

SUMMARY

Field personnel at the Harpers Ferry NFDRS Workshop asked that the utility of the 1978 NFDRS be improved for the humid environment of the Eastern United States and that the modifications be made as soon as possible. Users in the Western United States did not ask for System changes. The revisions described here have been structured to minimize impacts on western users, while permitting modifications that solve eastern problems.

Field testing at several locations in the Eastern United States, California, and Alaska has shown that these revisions effectively deal with the concerns of the eastern users. It must be remembered, however, the NFDRS absolutely requires proper weather station location and maintenance, as well as consistent and accurate observations and data entries. Without strong, competent field support, the National Fire-Danger Rating System can never be expected to produce useful results.

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APPENDIX A: FUEL MODEL DESCRIPTIONS AND SEASONAL PROFILES

1978 NFDRS Fuel Model Descriptions

Fuel model parameters	A	B	C	D	E	F	G	H	I	J	K	L	N	O	P	Q*	R	S	T	U
Load (tons/acre)																				
l-hour dead	0.2	3.5	0.4	2.0	1.5	2.5	2.5	1.5	12.0	7.0	2.5	0.25	1.5	2.0	1.0	2.0	0.5	0.5	1.0	1.5
lo-hour dead	--	4.0	1.0	1.0	0.5	2.0	2.0	1.0	12.0	7.0	2.5	--	1.5	3.0	1.0	2.5	0.5	0.5	0.5	1.5
100-hour dead	--	0.5	--	--	0.25	1.5	5.0	2.0	10.0	6.0	2.0	--	--	3.0	0.5	2.0	o-5	0 . 5	--	1.0
1000-hour dead	--	--	--	--	--	--	12.0	2.0	12.0	5.5	2.5	--	--	2.0	--	1.0	--	0 . 5	--	--
Woody	--	11.5	0.5	3.0	0.5	9.0	0.5	0.5	--	--	--	--	2.0	7.0	0.5	4.0	0.5	0.5	2.5	0.5
Herbaceous	0.3	--	0.8	0.75	0.5	--	0.5	0.5	--	--	--	0.5	--	--	0.5	0.5	0.5	0.5	0.5	0.5
Surface-area-to-volume ratio (1/ft)																				
l-hour dead	3,000	700	2,000	1,250	2,000	700	2.000	2,000	1,500	1,500	1,500	2,000	1,600	1,500	1.750	1,500	1,500	1,500	2,500	1,750
lo-hour dead	--	109	109	109	109	109	109	109	109	109	109	--	109	109	109	109	109	109	109	109
100-hour dead	--	30	30	--	30	30	30	30	30	30	30	--	--	30	30	30	30	30	--	30
1000-hour dead	--	8	--	--	--	--	8	8	8	8	8	--	--	8	--	8	8	8	--	--
Woody	--	1,250	1,500	1,500	1.500	1,250	1,500	1,500	--	--	--	--	1,500	1,500	1,500	1,200	1,500	1,200	1,500	1,500
Herbaceous	3,000	--	2,500	1.500	2,000	--	2,000	2,000	--	--	--	2,000	--	1,500	2,000	1,500	2,000	1,500	2,000	2,000
Heat content (all fuels) (Btu/lb)	8,000	9,500	8,000	9,000	8.000	9,500	8.000	8,000	8,000	8,000	8,000	8,000	8,700	9,000	8,000	8,000	8.000	8.000	8,000	8,000
Moisture of Extinction (%)																				
Dead	15	15	20	30	25	15	25	20	25	25	25	15	25	30	30	25	25	25	15	20
Fuel Bed Depth (ft)	0.8	4.5	0.75	2.0	0.4	4.5	1.0	0.3	2.0	1.3	0.6	1.0	3.0	4.0	0.4	3.0	0.25	0.4	1.25	0.5
Wind adjustment factor	0.6	0.5	0.4	0.4	0.5	0.5	0.4	0.4	0.5	0.5	0.5	0.6	0.6	0.5	0.4	0.4	0.4	0.6	0.6	4
SC_{max}	301	58	32	68	25	24	30	8	65	44	23	178	167	99	14	59	6	17	96	16

*Data for model Q obtained from field measurements by Rod Norum. 1977-1978. On file with: U.S. Department of Agriculture, Forest Service, Pacific Northwest Station, Institute of Northern Forestry, 308 Tanana Dr.. Fairbanks AK 99775-5500.

Fuel model parameters	A	B	C	D	E	F	G	H	I	J	K	L	N	O	P	Q*	R	S	T	U
Load (tons/acre)																				
l-hour dead	0.2	3.5	0.4	2.0	1.0	2.5	2.5	1.5	12.0	7.0	2.5	0.25	1.5	2.0	1.0	2.5	0.5	0.5	1.0	1.5
lo-hour dead	--	4.0	1.0	1.0	0.5	2.0	2.0	1.0	12.0	7.0	2.5	--	1.5	3.0	1.0	5.4	0.5	0.5	0.5	1.5
100-hour dead	--	0.5	--	--	0.25	1.5	5.0	2.0	10.0	6.0	2.0	--	--	3.0	0.5	2.9	0.5	0.5	--	1.0
1000-hour dead	--	--	--	--	--	--	12.0	2.0	12.0	5.5	2.5	--	--	2.0	--	1.0	--	0.5	--	--
Woody	--	11.5	0.8	3.0	1.0	7.0	0.5	0.5	--	--	--	--	2.0	7.0	0.5	3.0	0.5	0.5	2.5	0.5
Herbaceous	0.3	--	0.8	1.0	0.5	1.0	0.5	0.5	--	--	--	0.5	--	--	0.5	1.0	0.5	0.5	0.5	0.5
Drought	0.2	3.5	1.8	1.5	1.5	2.5	5.0	2.0	12.0	7.0	2.5	0.25	2.0	3.5	1.0	3.5	0.5	1.5	1.0	2.0
Surface-area-to-volume ratio (1/ft)																				
l-hour dead	3,000	700	2.000	1,250	2,000	700	2,000	2,000	1,500	1.500	1,500	2,000	1,600	1,500	1.750	3,500	1,500	1,500	2,500	1,750
lo-hour dead	--	109	109	109	109	109	109	109	109	109	109	--	109	109	109	109	109	109	109	109
100-hour dead	--	30	30	--	30	30	30	30	30	30	30	--	--	30	30	30	30	30	--	30
1000-hour dead	--	8	--	--	--	--	8	8	8	8	8	--	--	8	--	8	8	8	--	--
Woody		1,250	1,500	1,500	1.500	1,250	1,500	1,500	--	--	--	--	1,500	1.500	1,500	1.500	1,500	1,200	1,500	1,500
Herbaceous	3,000	--	2,500	1.500	2,000	1,500	2,000	2,000	--	--	--	2.000	--	1,500	2.000	1,500	2.000	1,500	2,000	2,000
Heat content (ail fuels) (Btu/lb)	8,000	9,500	8,000	9,000	8,000	9,500	8,000	8,000	8,000	8,000	8,000	8,000	8,700	9,000	8,000	8,000	8,000	8,000	8,000	8,000
Moisture of extinction (%)																				
Dead	15	15	20	40	25	15	25	20	25	25	25	15	40	30	30	18	25	25	15	20
Fuel bed depth (ft)	0.8	4.5	0.25	2.0	0.4	4.5	1.0	0.3	2.0	1.3	0.6	1.0	3.0	4.0	0.4	2.0	0.25	0.4	1.25	0.5
Minimum wind adjustment factor	0.6	0.5	0.3	0.4	0.3	0.5	0.3	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.3	0.2	0.3	0.6	0.6	0.3
Maximum wind adjustment factor	0.6	0.5	0.5	0.4	0.5	0.5	0.3	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.3	0.3	0.5	0.6	0.6	0.3
SC_{max}	301	58	32	68	25	24	30	8	65	44	23	178	167	99	14	59	6	17	96	16

*Data for model Q obtained from field measurements by Rod Norum. 1977-1978. On file with: U.S. Department of Agriculture, Forest Service, Pacific Northwest Station, Institute of Northern Forestry, 308 Tanana Dr., Fairbanks AK 99775-5500.

The following series of graphs for 1986 present seasonal BI comparisons between the 1978 (dotted lines) and 1988 (solid lines) NFDRS fuel models. Stonyford, CA, and Athens, GA, data were used to illustrate the general fire-danger profile that can be expected from each model in subhumid western and humid eastern situations. Obviously all 20 fuel models are not applicable at both Stonyford and Athens. The profiles are meant only to provide the user a convenient first assessment. Proper fuel model selection requires similar work by the user with local weather data.

Because the NFDRS indexes are primarily a function of weather patterns, the 20 fuel models all produce similar profiles for each weather station; however, they are much different between the two weather stations. Note particularly that the BI range varies greatly among the fuel models.

Drought response is produced in part by increased dead fuel availability as duff and litter dry, but it is also significantly affected by the live herbaceous and woody fuel load, the live fuel moistures, and whether or not the live woody component is deciduous. The greatest drought response can be expected from those fuel models that have a relatively high live herbaceous and/or woody load, with the woody load declared deciduous. For example, the drought response of fuel model C, for the Athens data, is largely due to reduction of the greenness factor to about 6 during the driest months. The greater response of model C for Stonyford results from both low live fuel moistures and the addition of most of the 1.8 tons of dead "drought" fuel when the KBDI approached 800. The KBDI profiles are presented for reference.

The following tabulation defines the options selected to produce the 1988 NFDRS profiles.

Fuel model	Fine-dead fuel moisture equal fuel stick moisture	Deciduous or evergreen	Annual or perennial herbaceous
A	No	N/A	Annual
B	Yes	Evergreen	N/A
C	Yes	Deciduous	Perennial
D	Yes	Evergreen	Perennial
E	Yes	Deciduous	Perennial
F	Yes	Evergreen	Perennial
G	Yes	Deciduous	Perennial
H	Yes	Deciduous	Perennial
I	Yes	N/A	N/A
J	Yes	N/A	N/A
K	Yes	N/A	N/A
L	Yes	N/A	Perennial
N	Yes	Evergreen	N/A
O	Yes	Evergreen	N/A
P	Yes	Deciduous	Perennial
Q	Yes	Deciduous	Perennial
R	Yes	Deciduous	Perennial
S	Yes	Evergreen	Perennial
T	Yes	Evergreen	Perennial
U	Yes	Deciduous	Perennial

APPENDIX B: TECHNICAL DOCUMENTATION

Response to Drought

1. Calculate the fraction of predrought dead fuel load for each size class:

$$F_i = W_i/W_d$$

where

F_i = fraction of the dead load in the i^{th} dead fuel size class

W_i = load of the i^{th} dead fuel size class

W_d = total predrought dead fuel load for the fuel model

2. Calculate the packing ratio for the fuel model.

$$R = W_t/D_o$$

where

R = the packing ratio

W_t = total predrought live and dead load for the fuel model

D_o = the predrought fuel bed depth

3. Calculate the total dead fuel load to add per unit increase in the KBDI above 100.

$$U_i = W/(800-100) = W/700$$

where

U_i = unit increase of dead fuel load per unit increase in the KBDI above 100

W = potential total dead fuel load that could be add due to drought

4. Calculate the dead fuel load to be added to each dead fuel class, at the current KBDI value.

$$W_a = (K_c - 100)U_i$$

$$W_j = W_i + F_i W_a$$

where

W_a = total dead fuel load to be added at the current level of drought

K_c = today's KBDI

W_j =-drought-induced load of the j^{th} dead fuel class

5. Calculate the depth required to preserve the predrought packing ratio

$$D_d = (W_{ld} - W_{1,000})/R$$

where

D_d = fuel bed depth at the current level of drought

W_{ld} = total live and dead load at the current level of drought

$W_{1,000}$ = the 1,000-hour dead fuel load

From this point on, the algorithms that calculate SC and ERC are used unchanged.

Effect of Greenness Factor on Live Fuel Moisture Calculations

Season of the year, as entered by the user, defines which of the following live fuel moisture calculation procedures is followed.

1. **Winter.** Live herbaceous and woody moistures are set to their minimums. Greenness factor values are 0.

$$M_h = M_{fd}$$

$$M_w = M_{cm}$$

where

M_h = live herbaceous moisture content (percent)

M_{fd} = fine dead fuel moisture (percent)

M_w = live woody fuel moisture (percent)

M_{cm} = dormant-season woody moisture for the weather stations' climate class (50, 60, 70, 80 for climate classes 1, 2, 3, 4)

2. Spring. Live woody and herbaceous fuel moistures are increasing rapidly as greenness factor values increase from 1 to 20.

The equation for live herbaceous moisture calculation is

$$M_h = M_{sp} G_g / 20$$

where

M_h = 1988 NFDRS live herbaceous moisture (percent)

M_{sp} = live herbaceous moisture as calculated in the 1978 NFDRS for spring greening conditions

G_g = current live herbaceous greenness factor

The equation for live woody moisture calculation is

$$M_w = M_{wo} G_w / 20$$

where

M_w = 1988 NFDRS live woody moisture (percent)

M_{wo} = live woody moisture as calculated in the 1978 NFDRS

G_w = current live woody greenness factor

3. summer. Live herbaceous and woody moistures fluctuate in response to drying and wetting cycles. Greenness factor values vary between 0 and 20. Annual herbaceous vegetation should cure sometime during this period.

The equation for live herbaceous moisture calculation is

$$M_h = M_{su} G_g / 20$$

where

M_{su} = live herbaceous moisture as calculated in the 1978 NFDRS, for the growing season, after completion of greening

The equation for live woody moisture calculation is

$$M_w = M_{wo} G_w / 20$$

4. Fall. Live herbaceous and woody moistures are decreasing. Vegetation is entering dormancy.

Calculation for live herbaceous moisture is

$$Mh = M_{su}G_g/20$$

where

M_{su} = live herbaceous moisture as calculated for transition conditions in the 1978 NFDRS.

Calculation for live woody moisture is

$$M_w = M_{wo}G_w/20$$

Dynamic live woody fuel load--In addition to the above changes in live fuel moisture calculations, the revised NFDRS provides the option to define live woody fuel as being either deciduous (dynamic) or evergreen (static). If the evergreen option is selected, the live woody load remains constant at all live woody fuel moistures. If the deciduous option is selected, the live woody load is transferred between the live woody class and the fine dead fuel class as a function of the live woody greenness factor, where:

$$W_{tf} = (1-G_w/20)W_l$$

where

W_{tf} = live woody load to be transferred to the fine dead class

Wl = total live woody load in the fuel model

The fraction of the live woody load not moved to the fine dead fuel class remains in the live woody class.

Variable **wind adjustment factor--** The wind adjustment factor varies seasonally when the live woody vegetation is designated to be deciduous. In this case the wind adjustment factor is set to its maximum value during the winter. This provides the minimum midflame windspeed adjustment. During the spring it decreases, and during the fall it increases, as a function of the woody greenness factor. During the summer it is set to its minimum value. It is held constant all year if the live woody vegetation is designated to be evergreen.

$$W_{rf} = W_{mx} - (W_{mx} - W_{mn})G_w/20$$

where

W_{rf} = wind adjustment factor

W_{mx} = maximum value for the wind adjustment factor

W_{mn} = minimum value for the wind adjustment factor

If more than 0.1 inch of precipitation occurred either on the current or the previous day, the wind adjustment factor is multiplied by 0.3 to reduce the sensitivity of the NFDRS to wind immediately following a rain.

Fine Dead Fuel Moisture

The user has an option of whether or not to set fine dead fuel moisture equal to the measured fuel stick moisture. If this option is not selected, then the fine dead fuel moisture will be equal to the lo-hour timelag fuel moisture only on the day of and the day following precipitation. Standard fuel moisture sticks provide the best method to obtain lo-hour timelag moisture, but if they are not used, the fine dead fuel moisture calculation is modified as follows:

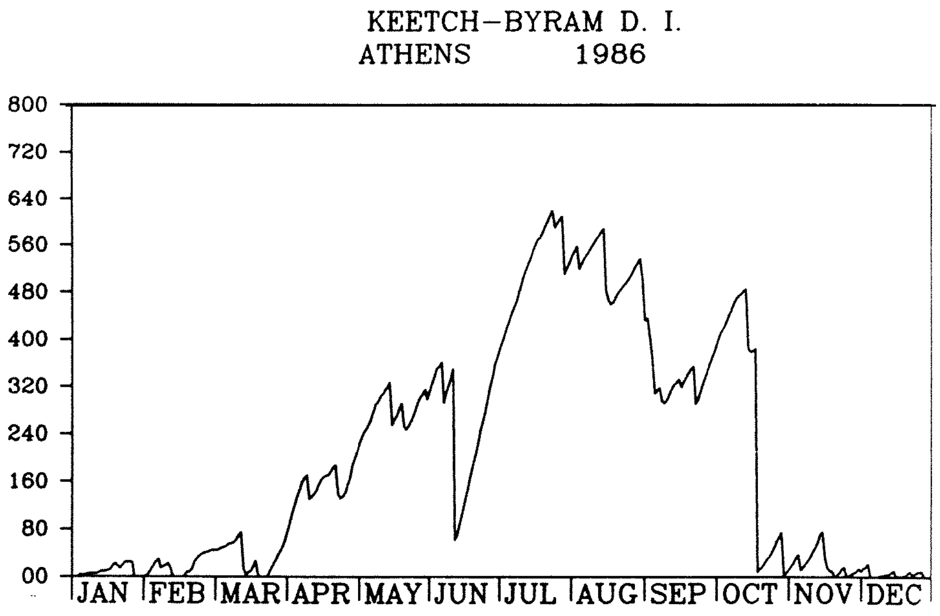
$$M_1 = 1.03E_{mc}0.8 + M_{100}0.2$$

where

MI = fine dead fuel moisture

E_{mc} = equilibrium fuel moisture

M_{100} = 100 hour timelag fuel moisture


KEETCH-BYRAM D. I.
ATHENS 1986
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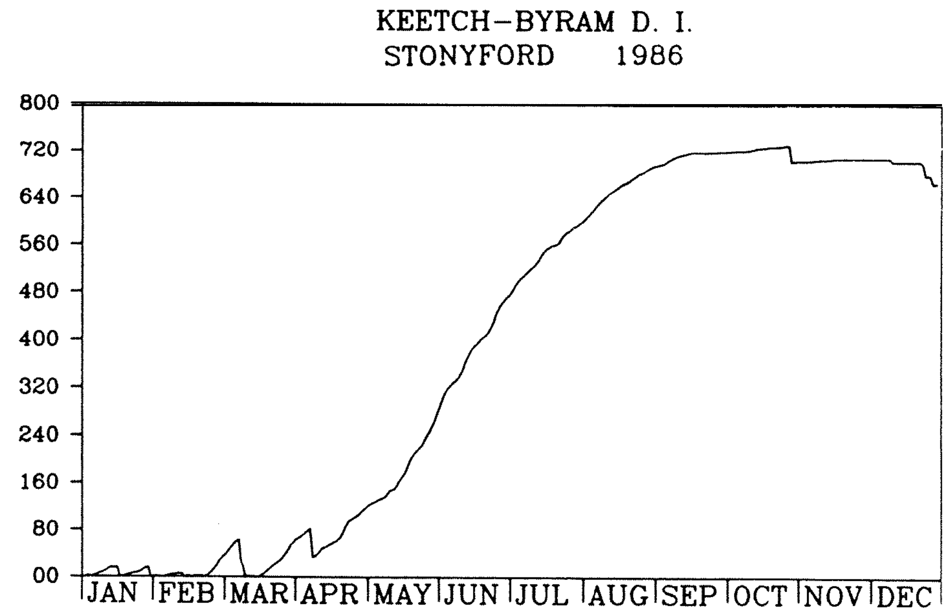
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC


KEETCH-BYRAM D. I.
STONYFORD 1986
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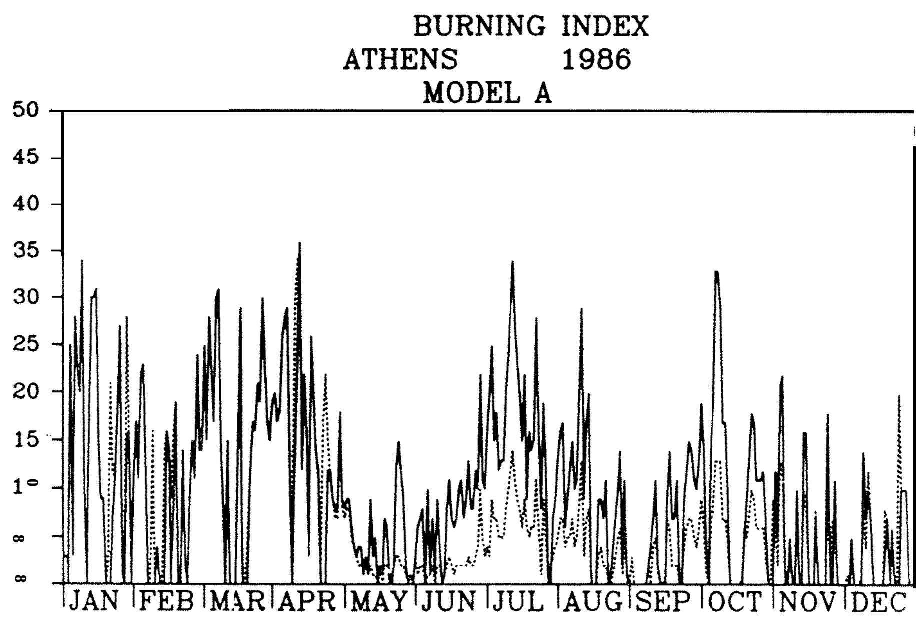
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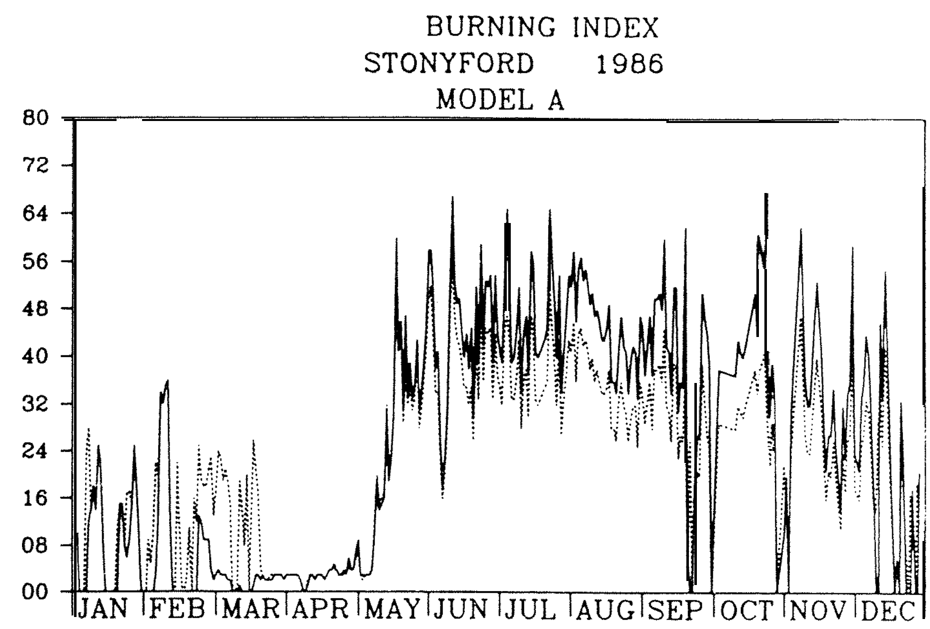
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC


BURNING INDEX
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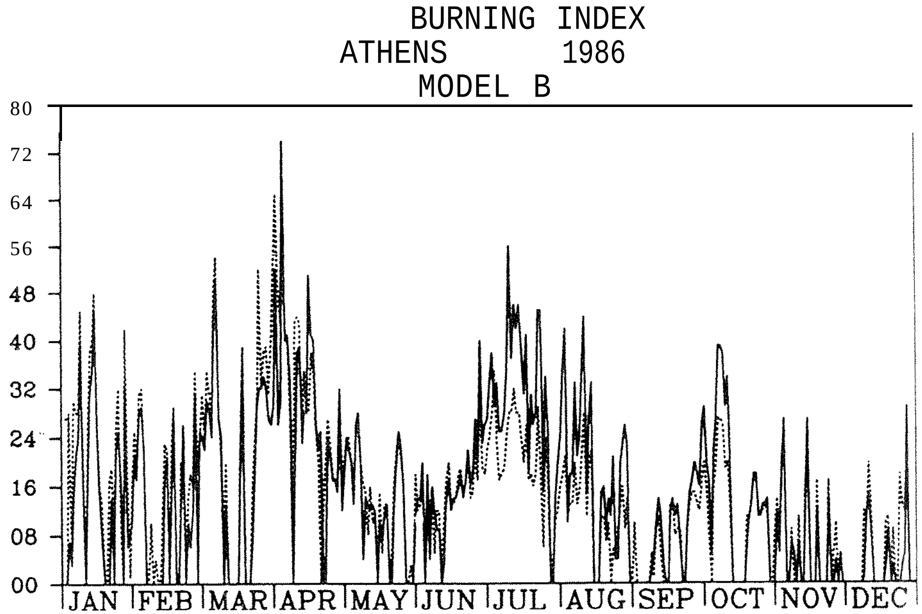
BURNING INDEX
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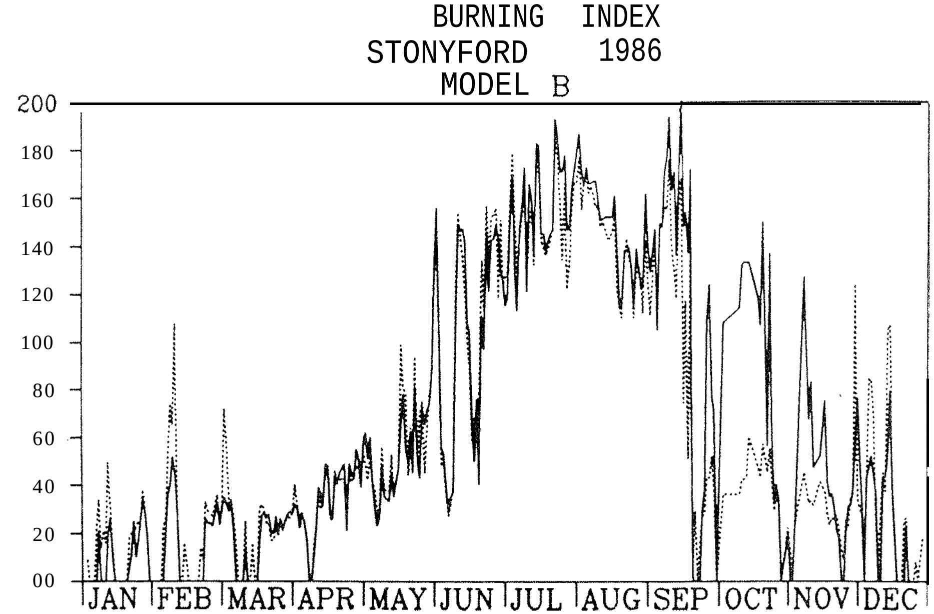
BURNING INDEX
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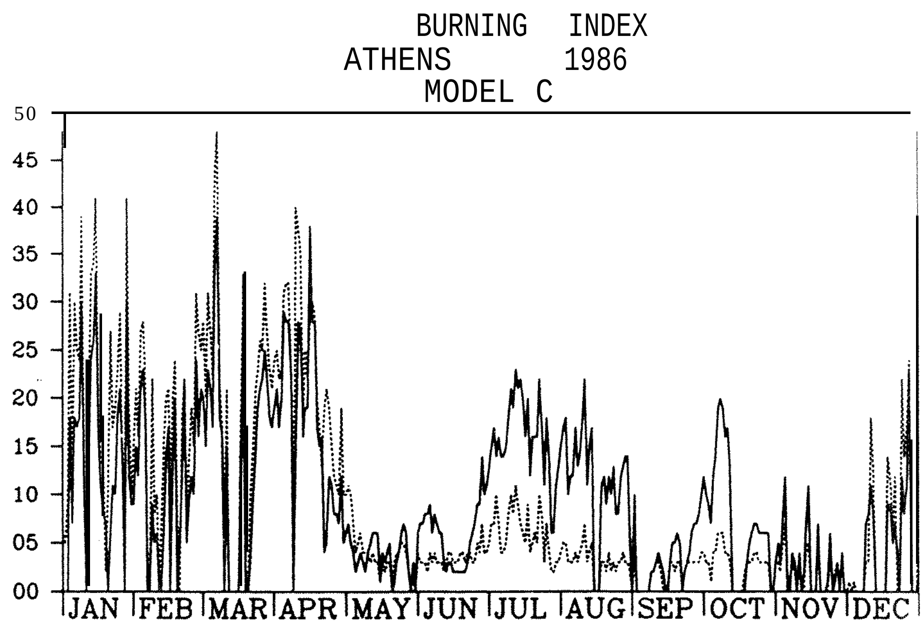
BURNING INDEX
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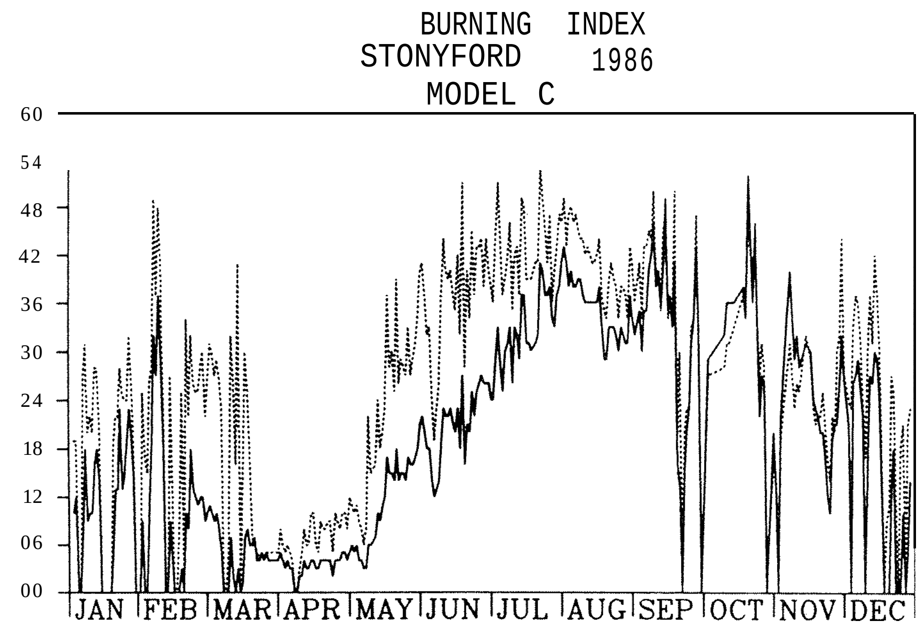
BURNING INDEX
STONYFORD 1986
MODEL C
60
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36
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JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

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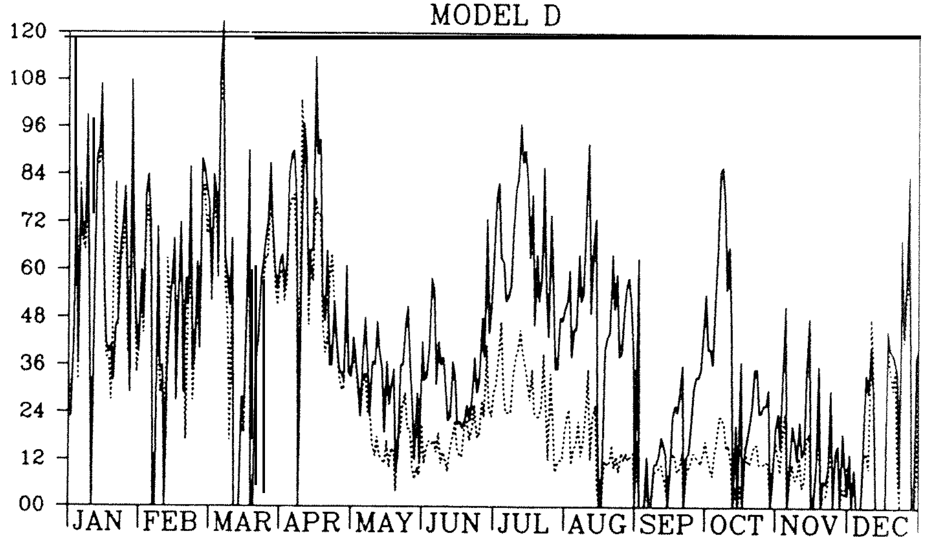
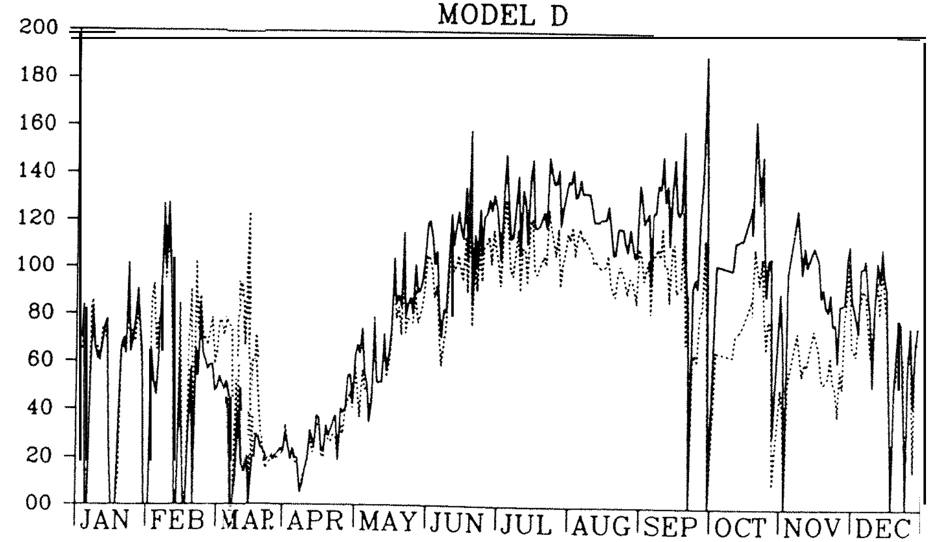
ATHENS 1986
MODEL D



BURNING INDEX
STONYFORD 1986
MODEL D



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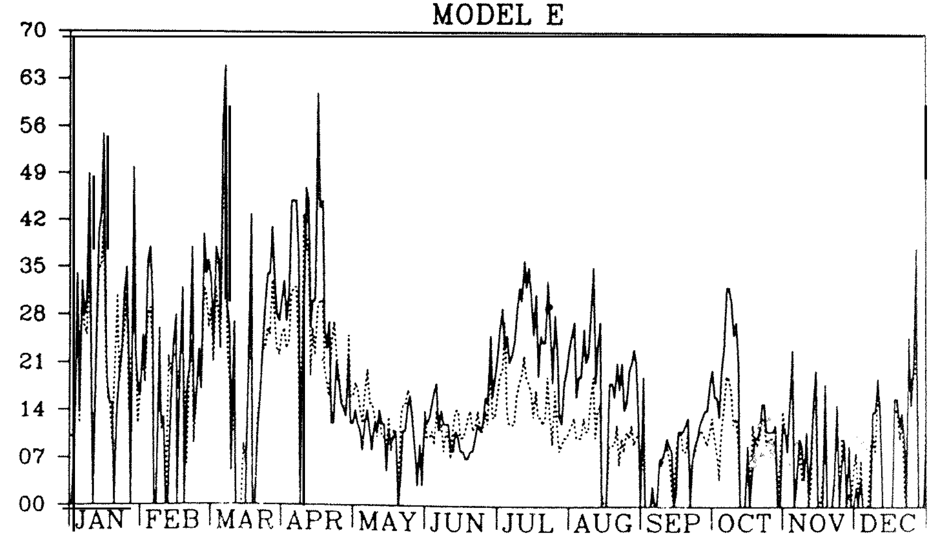
ATHENS 1986
MODEL E



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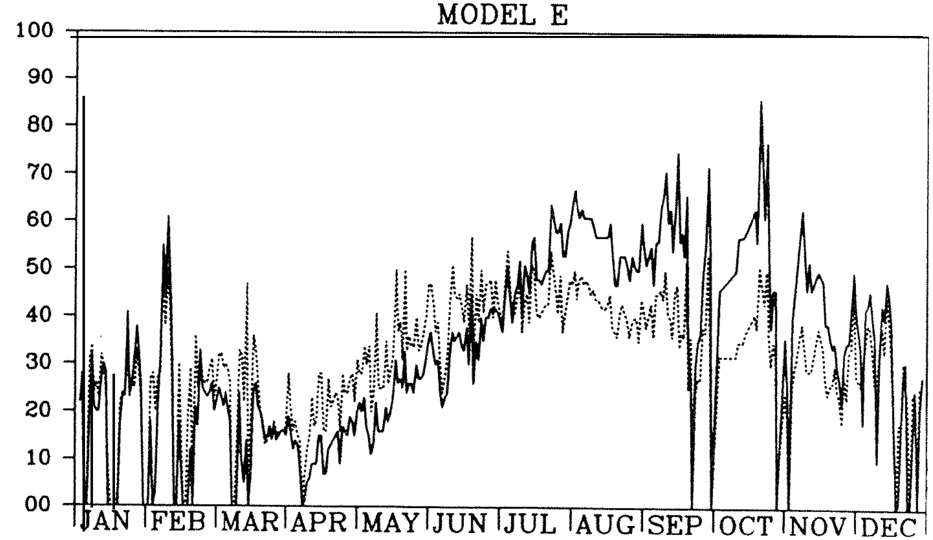
MODEL E



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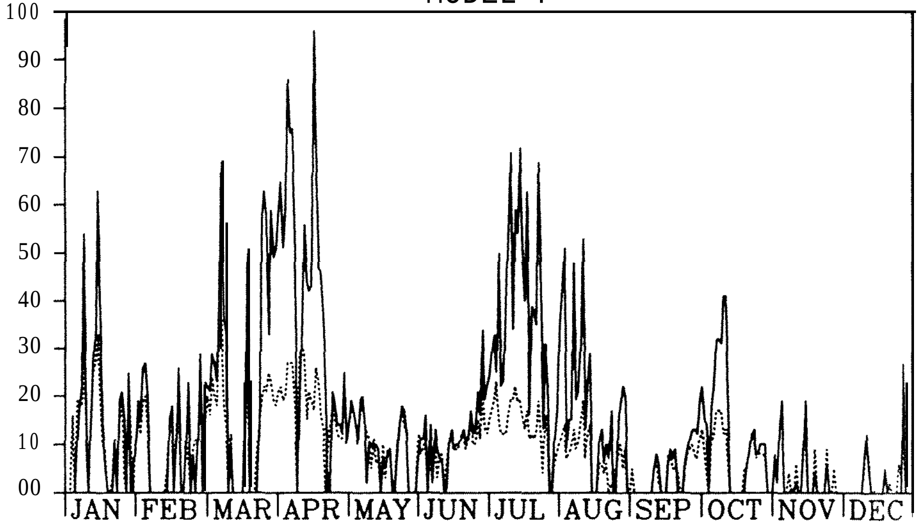
ATHENS 1986
MODEL F



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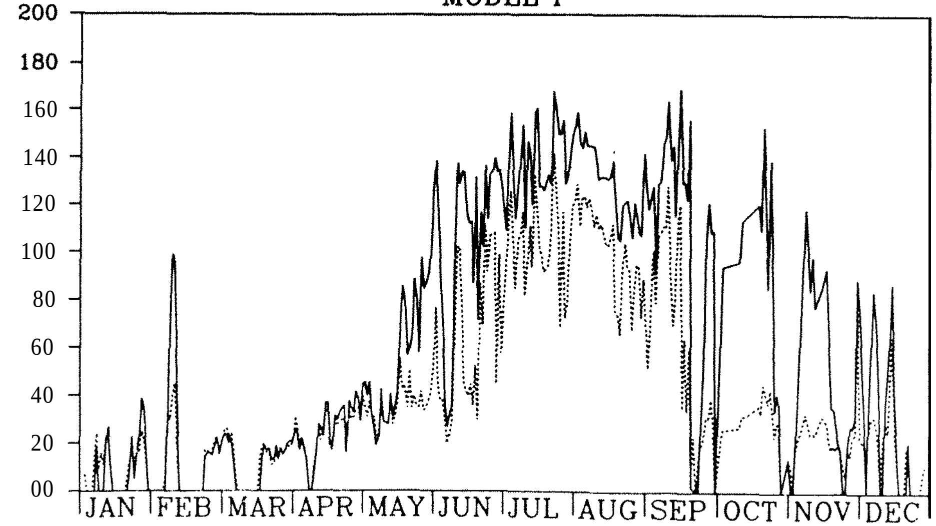
STONYFORD 1986
MODEL F



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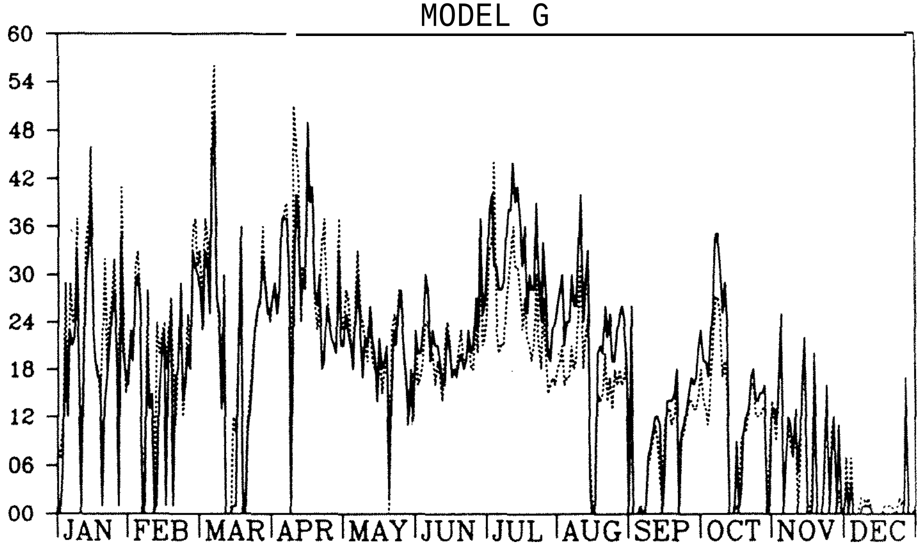
ATHENS 1986
MODEL G



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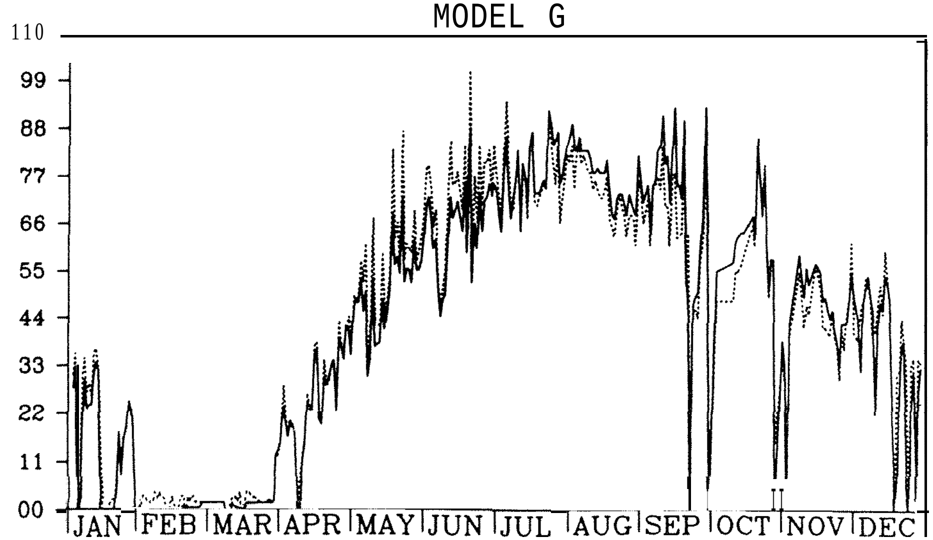
STONYFORD 1986
MODEL G



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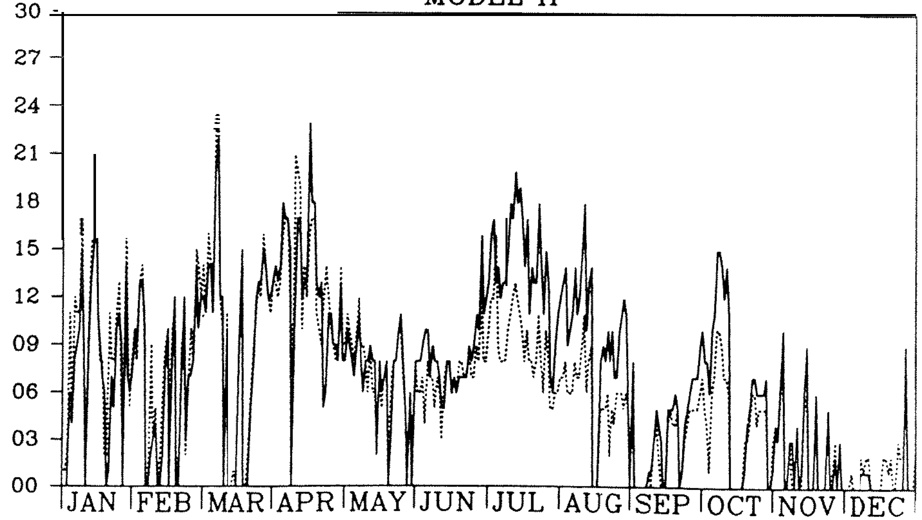
ATHENS 1986
MODEL H



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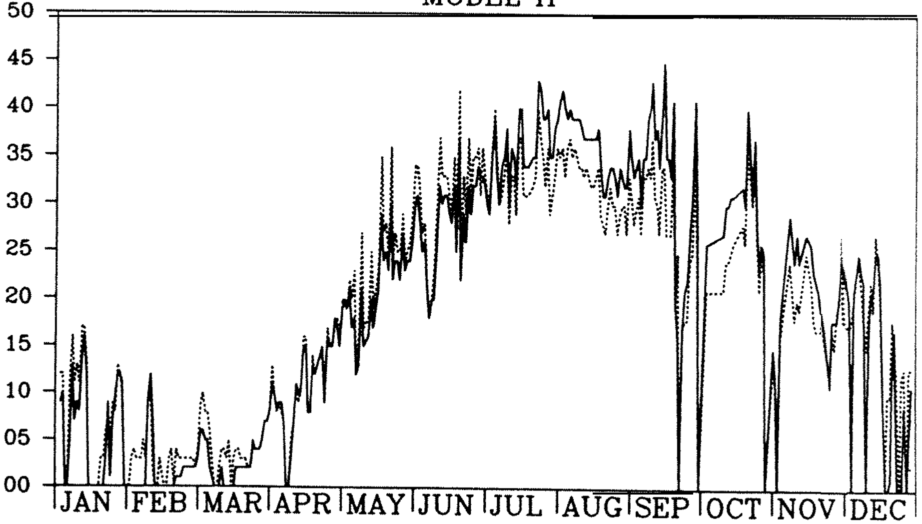
MODEL H



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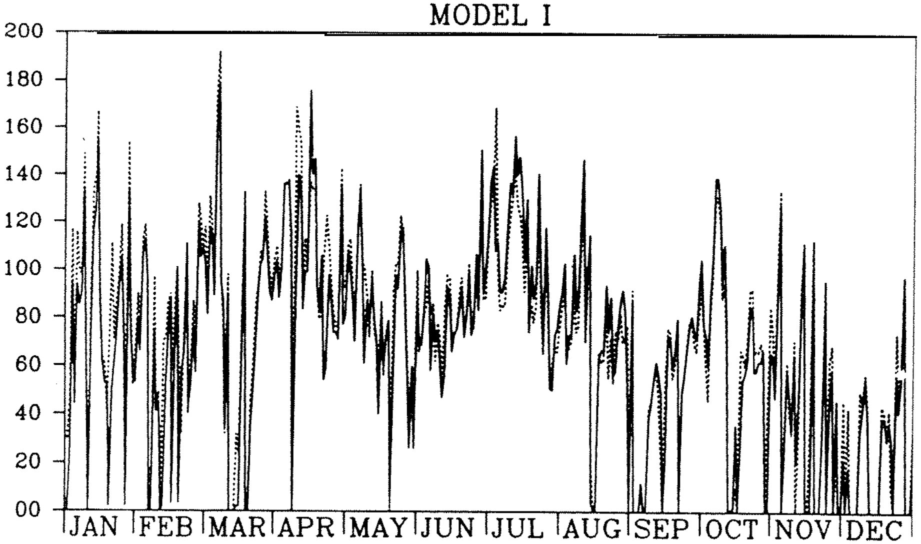
ATHENS 1986
MODEL I



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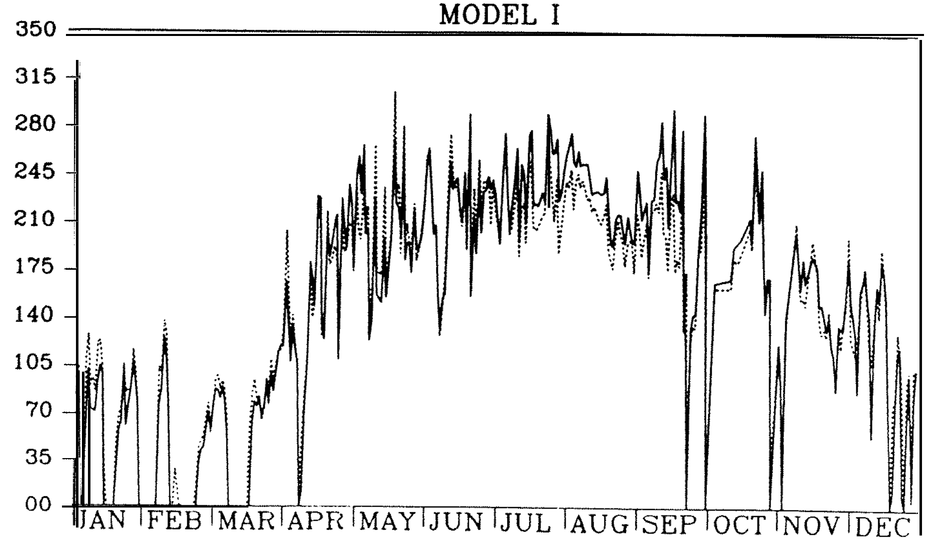
STONYFORD 1986
MODEL I



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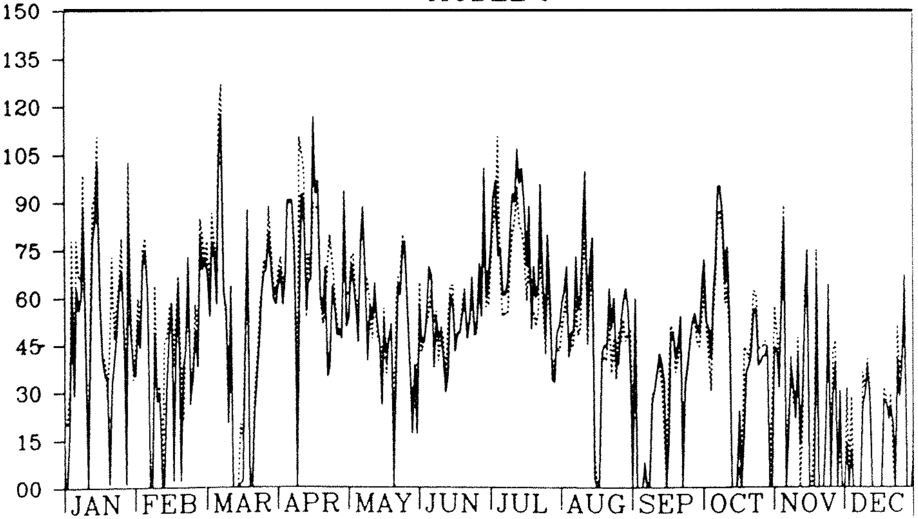
MODEL J



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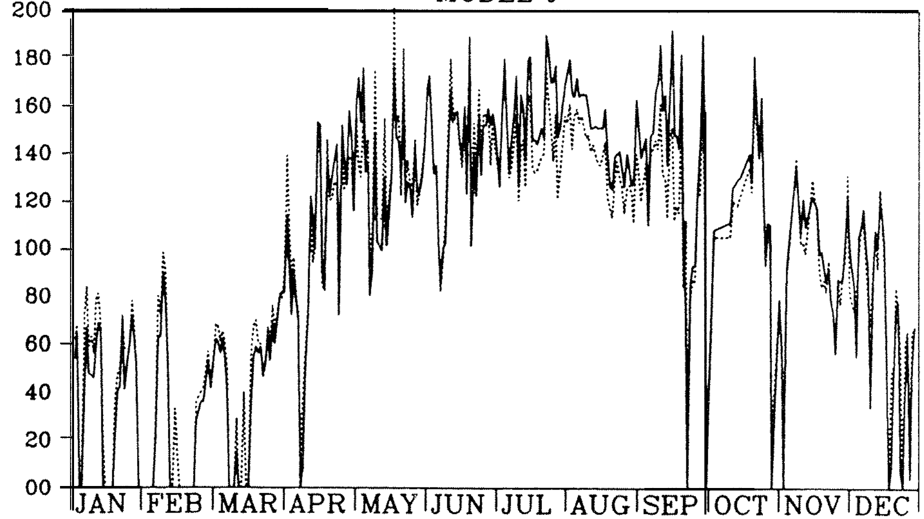
MODEL J



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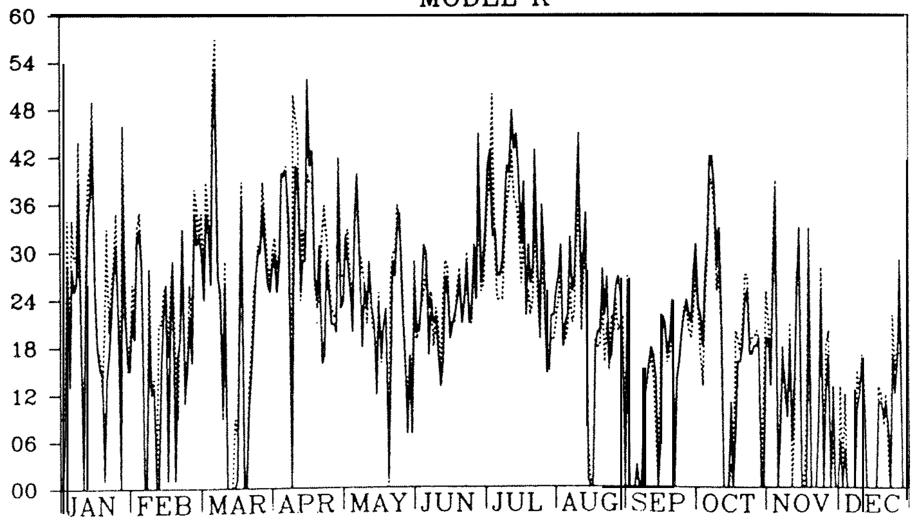
ATHENS 1986
MODEL K



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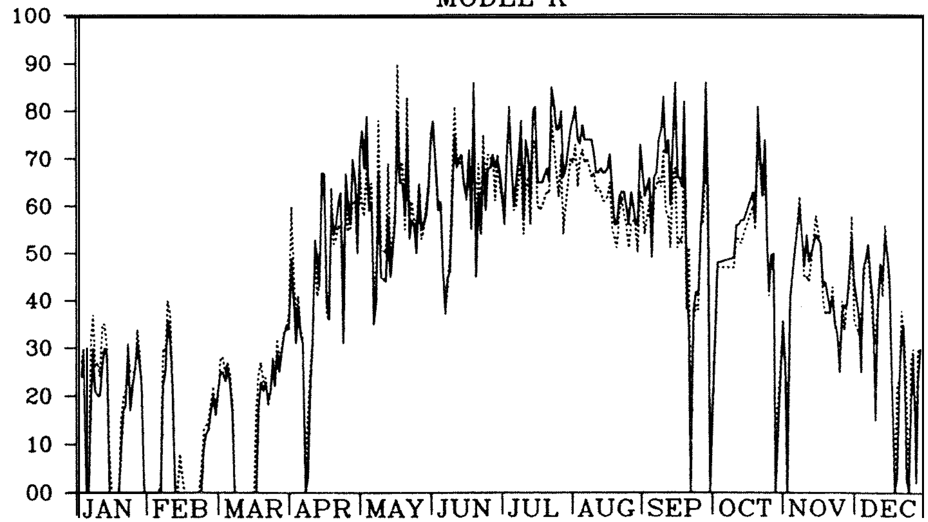
MODEL K



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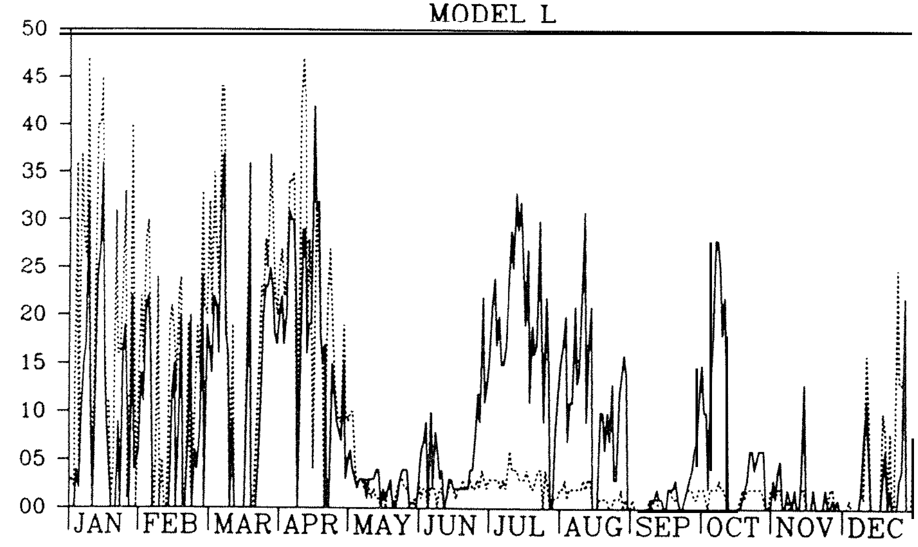
ATHENS 1986
MODEL L



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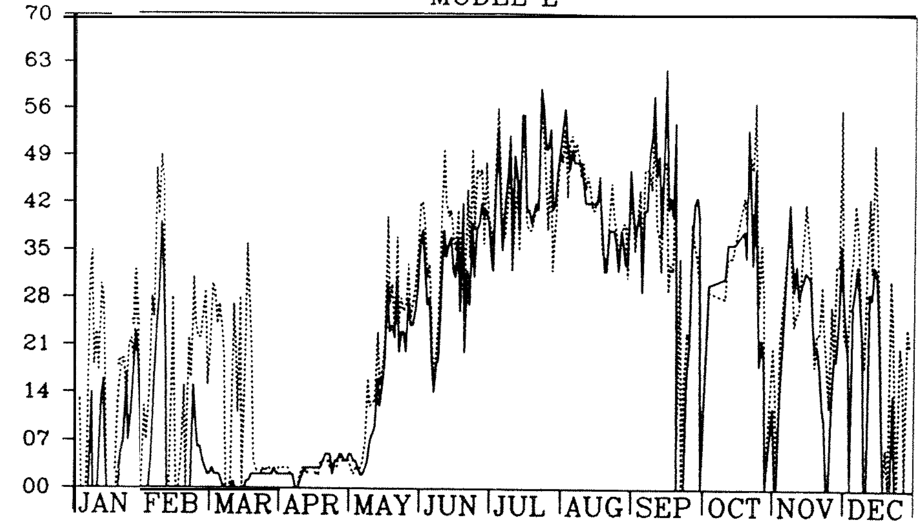
MODEL L



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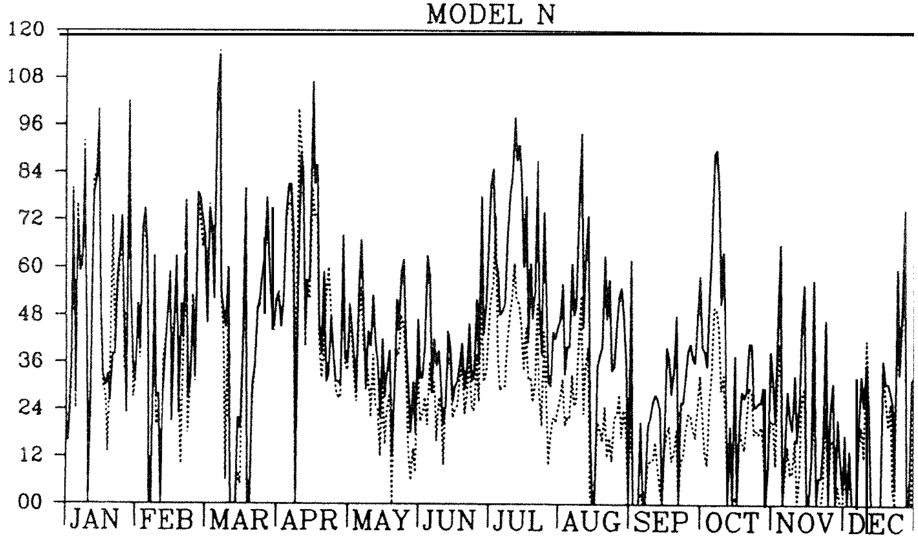
MODEL N



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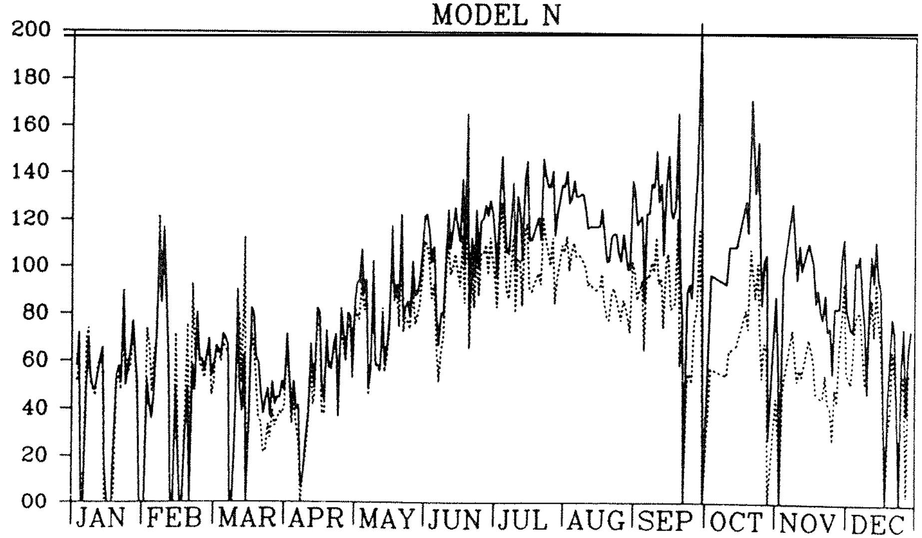

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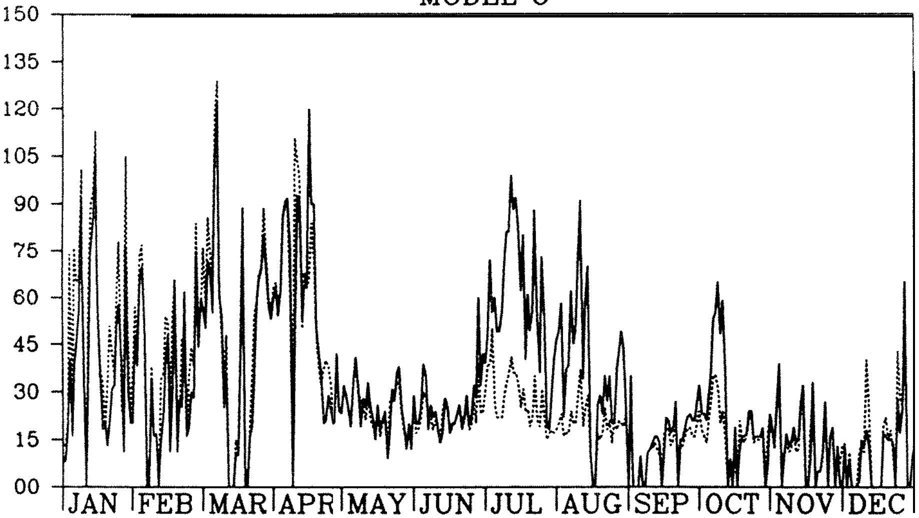
MODEL O



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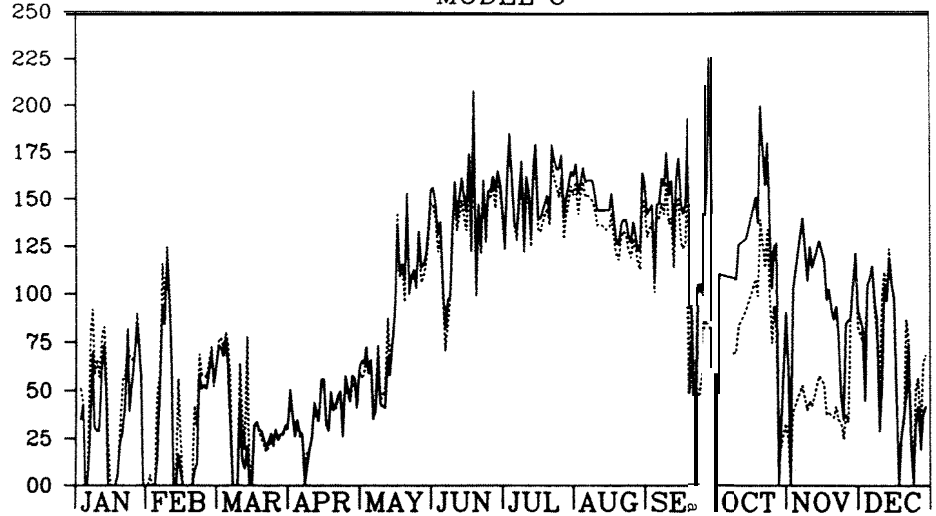
MODEL O



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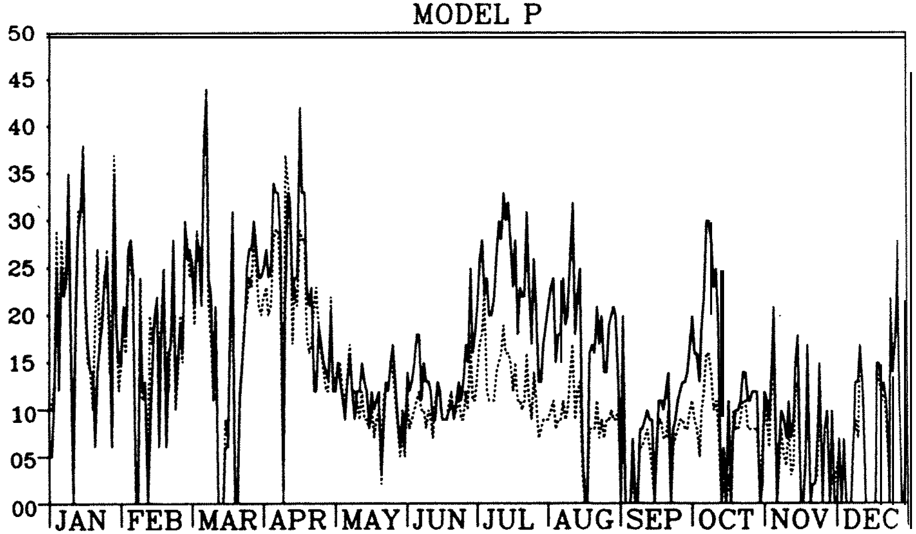
MODEL P



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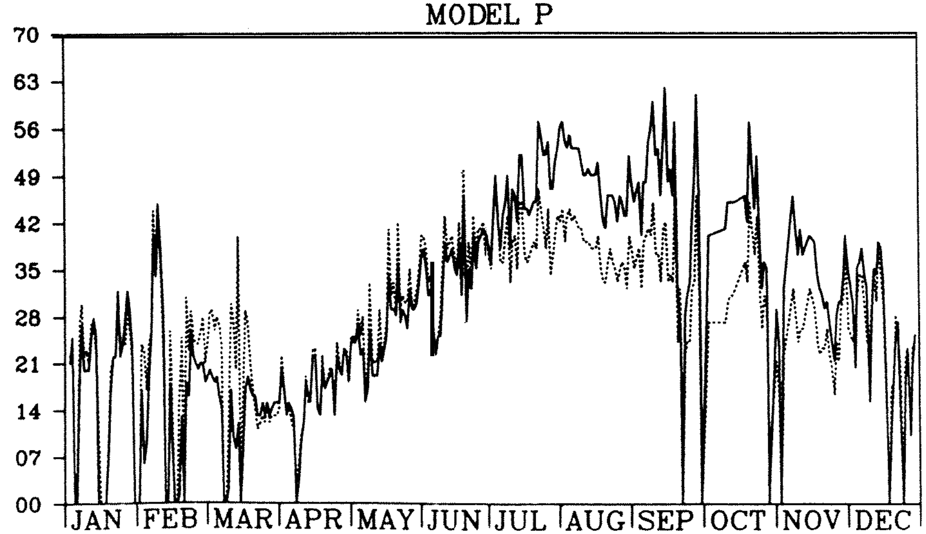
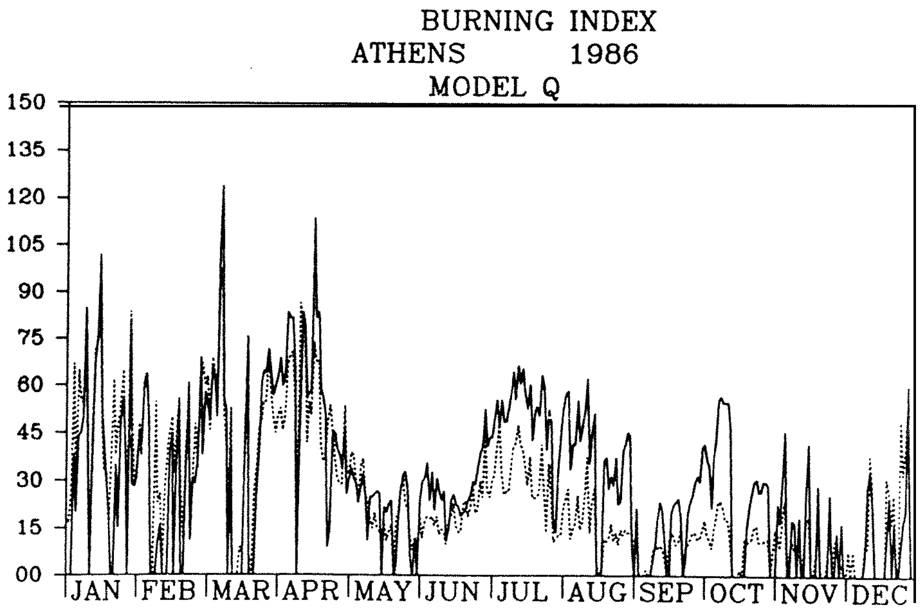
MODEL P

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MODEL Q
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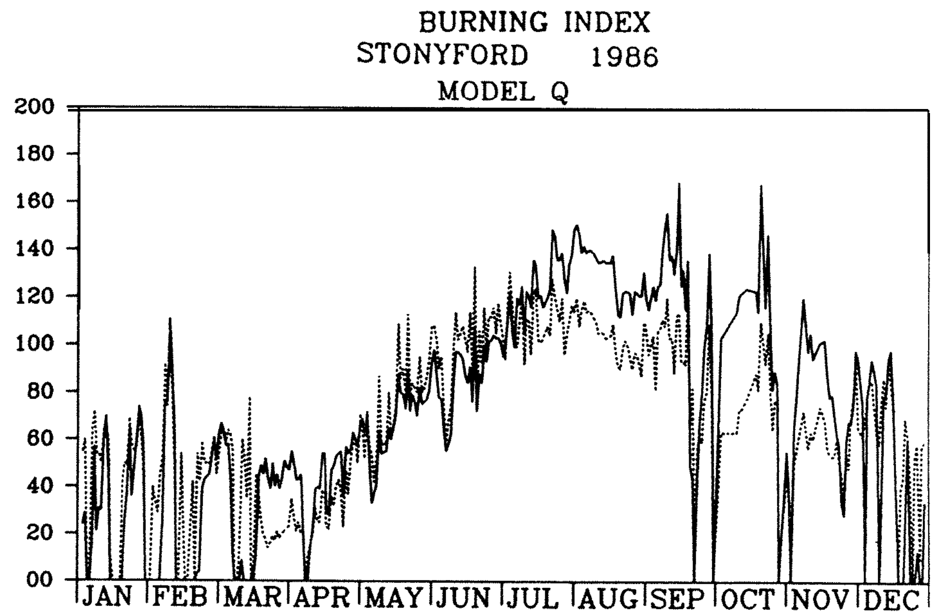
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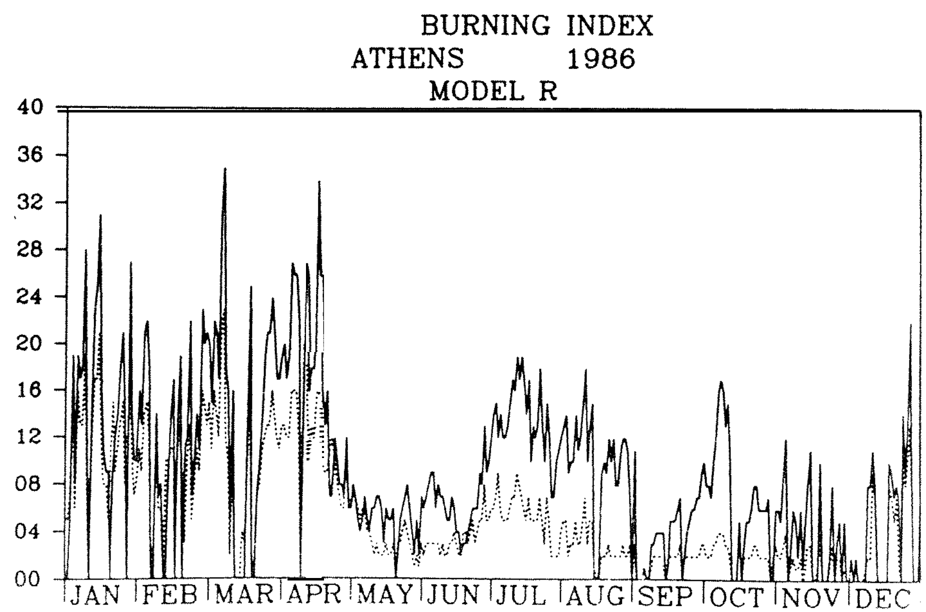
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MODEL R
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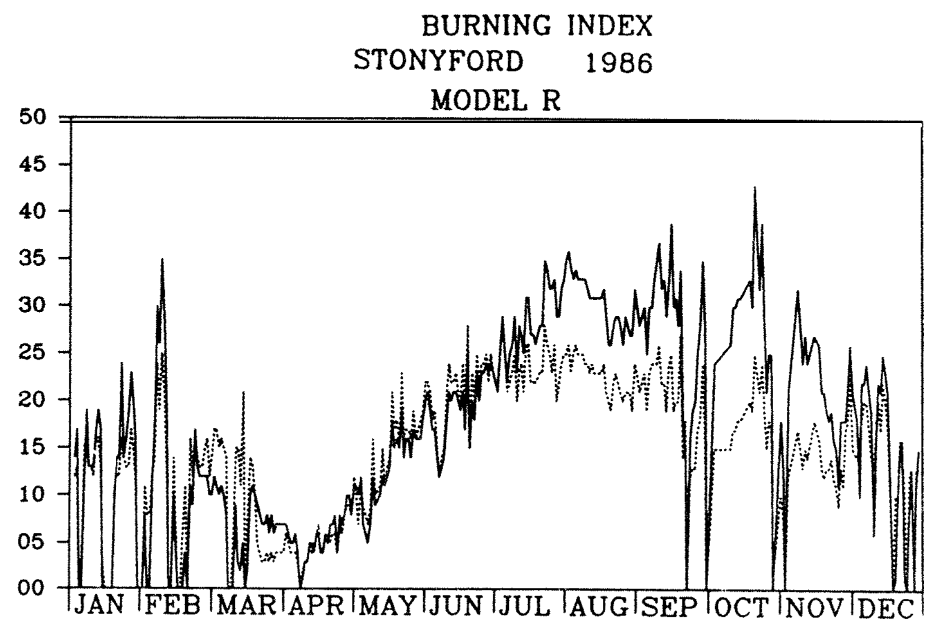
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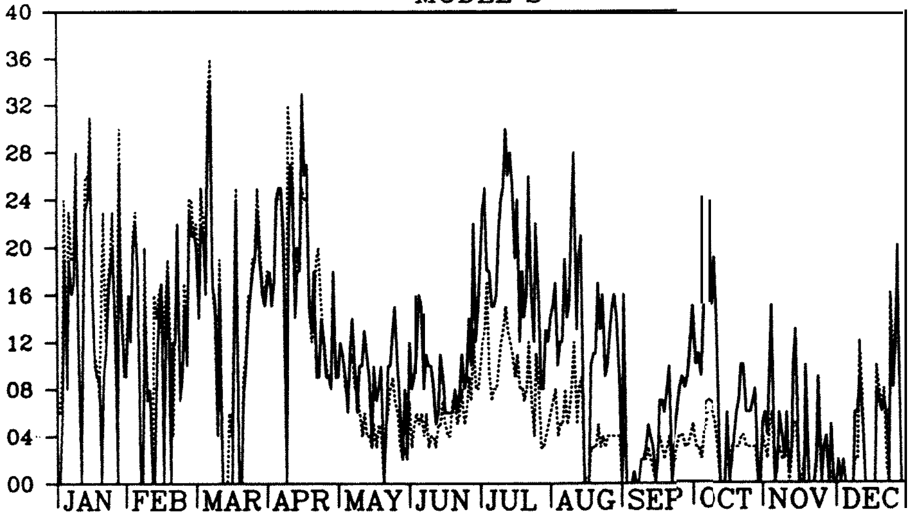
ATHENS 1986
MODEL S



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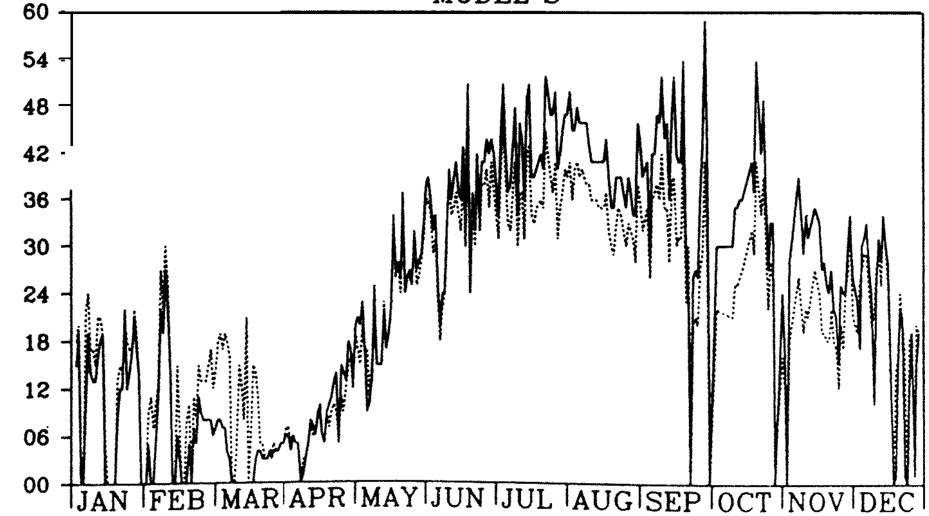
MODEL S



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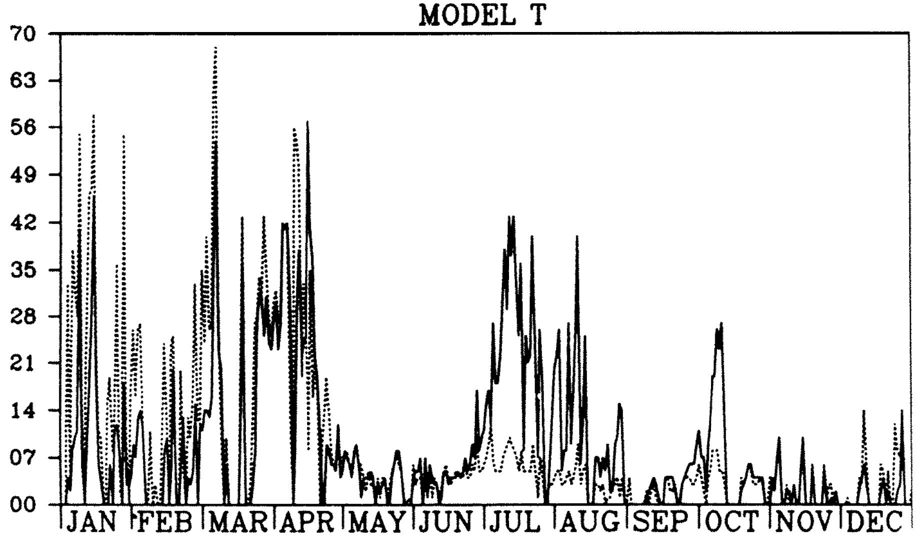
MODEL T



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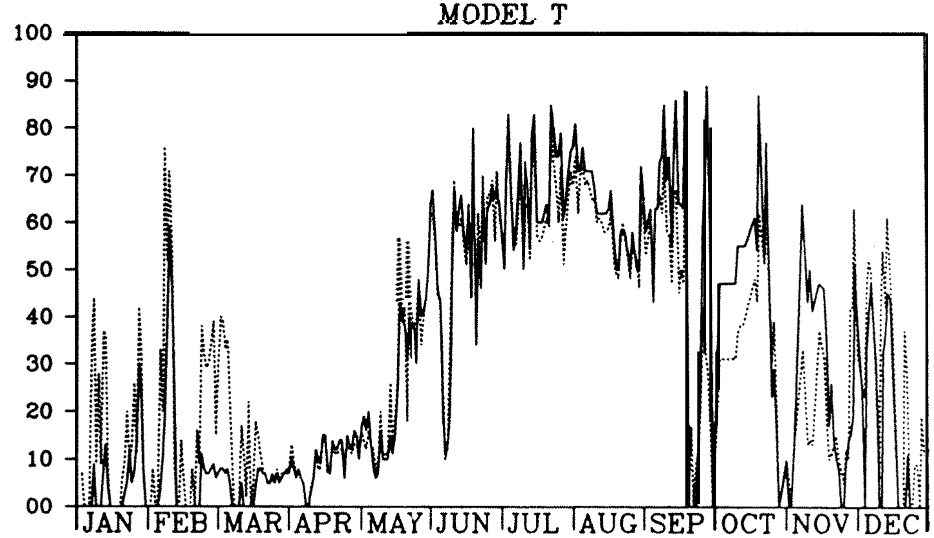
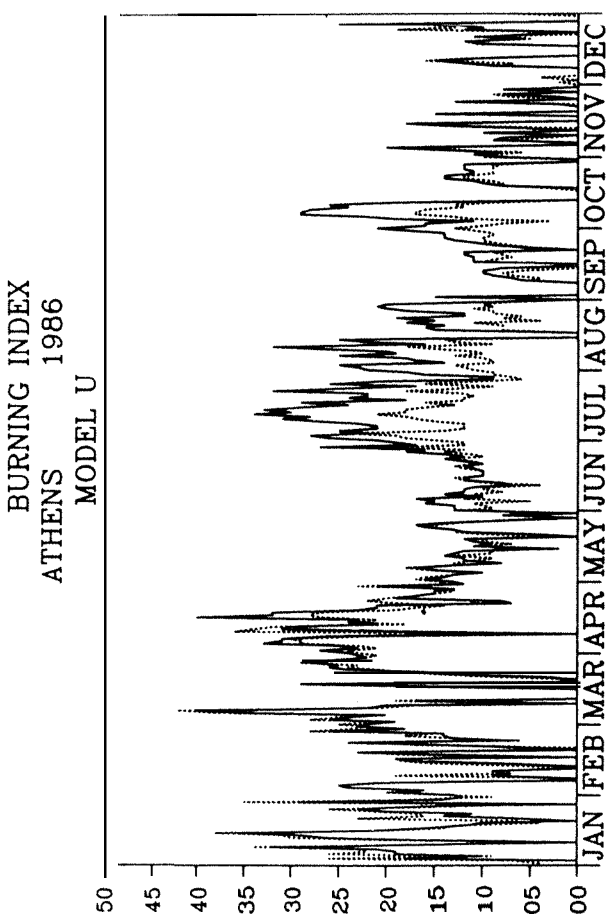
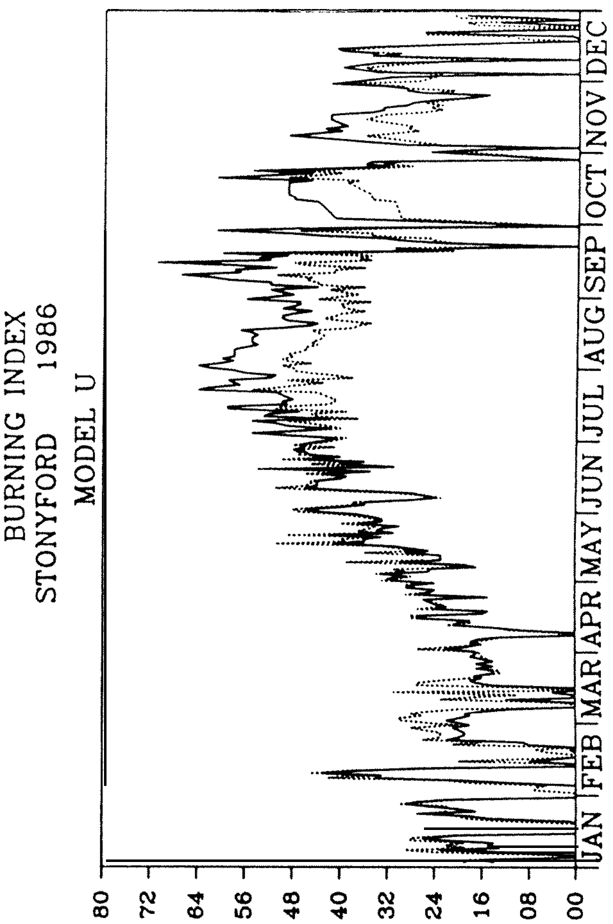
MODEL T







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Burgan, Robert **E.**

1988 Revisions to the 1978 National Fire-Danger Rating System. Res. Pap. SE-273. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1988. 39 pp.

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Keywords: Fire potential, fire, wild-land fire, fuel, moisture, weather.

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