Forest Fire Danger Rating In

Canada and California

by

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Since the beginning of the century forest fire danger rating research has been carried out both in the United States and Canada. In the United States most of this research has been carried out by the experiment stations of the U.S Forest Service. Independent research has been carried out at many of the experiment stations with the result being that many different approaches were developed to the fire danger rating problem. Eight of the ten primcipal fire danager rating systems that exist in the United States were developed by seven different experiment stations[10]. In Canada as in the United States, almost all of the danger rating research has been carried out by the Federal Government; however, unlike in the United States, the research was carried out by only one research group and consequently, only one major rating system was developed.

The aim of this report is to describe the evolution of the Canadian danger rating system fromits beginning to the present. Also, this report will describe the new California rating system and compare it with the present Canadian rating system.

Development of the Canadian Forest Fire Danger Rating System

Fifty years ago, in 1916, Mr. E.H. Finlayson recognized the possibility of using weather factors as a measure of the forest fire situation.[20]. He attempted to place a weighted value on temperature, rainfall, wind and relative humidity as a measure of forest fire hazard. Finlayson's paper was the first published on fire danger rating in C nada. In 1926 the C nadian Department of the Interior began fire danger studies under the direction of Mr. J G Wright at the Petawawa Forest Experiment Station. Between 1929 and 1939, most of the basic research was carried out and the framework for the present day forest fire danger rating system was developed.

In 1929, the first major Canadian paper on fire hazard research was published by J.G Wright.[16)] In this paper, Wright stated that since "the moisture content of a fuel determines its behavior in the presence of potential source of ignition and if the weather factors which influence this moisture content can be isolated and measured, it should be possible to determine the inflammability of the fuel under given weather conditions; in other words, to build up a chart from day to day showing the cumulative effect of the weather upon the fire hazard."

During the summer of 1929, Wright worked on the effect of weather factors on the moisture content of pine duff fuel types. He used duff baskets and duff hygrometers to measure the duff moisture content. The duff basket method of measuring the moisture content of top layer duff is still used today. Using these two measuring techniques, it was found that duff moisture content could rise to nearly 300 percent. The duff was classified as to its inflammability based on its moisture content.

Zone (rated by test fires)	Top Layer Duff M.C
Non-inflammable	Over 23%
Low "	23% - 20%
Medium "	20% - 16%
High "	16% - 11%
Extreme "	1% or lower.

Studies were begun on evaporation, relative humidity, rate of change of inflammability, the effects of rainfall, and the rate of drying after rain. From these studies charts were drawn to compute the daily hazard knowing the amount and length of the last rain, humidity, wind velocity, and the wet bulb temperature on the days following the rain. The principle being that knowing the moisture content of the fuel before a rain one could calculate how much the rain increased it and by knowing what the drying rates were on the following days one could calculate how much moisture content was lost. Thus by knowing the fuel moisture content, the inflammability could be determined.

In 1932 a major paper on fire hazard research was published by Wright[17]. This paper presented a great many of the fundamental principles on which danger rating is based.

Fire hazard was defined as the relative amount, character, arrangement, and moisture condition of the fuels. Fire danger was defined as the sum of risk, inflammability, and hazard together with damage probability and degree of difficulty with which a fire could be put out. Risk was defined as the probability of fire and it related only to those agencies that caused fire.

The relationship between fuel moisture content and fire danger was investigated. Four different species of wood were tested for inflammability at 19 per cent moisture content and at oven dry moisture content. The table below presents the results of the experiment.

Temperature	Avg. Time to Ignite Oven Dry Woods (Min.)	Avg. Time to Ignite 19% M.C. Wood (Min.)
400°F	20	32
600°F	2	5
650°F	1	3

One pound of oven dry pine duff was evenly spread over a 10 sq. ft. area. The amount of heat required to burn this at 70°F and with an ignition temperature of 650°F when it contains 25% moisture content is listed below.

		B.T.U.
To dispose of the water		330
To heat 8 pounds of air		1114
To heat 1 pound of duff		189
	Total	1633

Small scale test fires were lit in top layer duff. The moisture content was determined before the fires. Each fire was rated as to degree of inflammibility. Results confirmed the findings of the summer of 1929.

Wright also mentioned in the same paper[17)] the work that he carried out in the measurement of fire danger under hardwood canopies. He discovered that in the autumn after the leaves begin to fall, that a heavy rain will pack the dead leaves to form a compact mat which retains the moisture and offers little opportunity for a fire to start or spread. The matting phenomenon was related to species. Oak leaves remained loose and inflammable much longer than those of maple or aspen. In open stands, in the fall, frost and drought kill herbaceous plants forming an excellent fire-carrying medium. Under dense hardwood stands there is usually insufficient time before the new leaves come out for the material to become dry enough to constitute an appreciable hazard. Under the open hardwood stands in the spring the grass and dead leaves and bracken dry out very quickly after the snow leaves and rapidly spreading fires may occur.

The effects of rainfall, air temperature and wind on inflammability were investigated. One important conclusion was made about the effect of wind -

"It has been shown that about 16 percent of the heat generated in a duff fire in still air goes toward supporting combustion, the rest passes upwards. It will be readily seen that a horizontal current of wind will drive some of this escaping heat against adjacent fuels and so expediate combustion."[17)] It was also found that the wind velocity 4 feet above the ground under a hardwood canopy was about to that above the trees.

Duff temperature, solar radiation, soil moisture content and rate of evaporation were also studied in relation to inflammibility. It was concluded that the soil moisture content beneath the duff layer had very little effect on the moisture content of the top layer duff. Wright stated that the rate of evaporation was the greatest single factor controlling the rate of drying of forest fuels - combining the effects of relative humidity, temperature, wind velocity and solar radiation. Based on this finding it was hoped that evaporation would provide the key to fire danger rating problems. Consequently much research during 1929 to 1939 was concerned with techniques of measuring evaporation and correlating it with fuel moisture. The preliminary fire hazard tables used evaporation as one of the main parameters.

In 1933 Wright published the first Canadian forest fire hazard tables. These tables required daily measurements of rainfall, rate of evaporation, and relative humidity and gave an index of inflammability. The index of inflammability was determined by (300 - Duff moisture content). Three hundred is the maximum possible duff moisture content. With an index of 276 or below fire would not burn. The index was calculated in the evening for that same day.

Fire Hazard Zones	Index
Nil	Below 276
Low	276-281
Moderate	282-285
High	286-289
Extreme	289+

The relative humidity used was the lowest two hour average read from a hygrograph. Evaporation rate was determined by a Livingston atmometer or a specified evaporating pan.

The fuel types on which the tables were based were divided into two types, fast-drying sites and slow-drying sites. A hazard develops first in the fast-drying sites and progresses gradually to the slow-drying sites. The hazard was calculated each day for both types.

The index calculation was begun knowing the inflammability index before a rain (300 - fine fuel moisture content). A rain of a specified duration reduced the index depending on the amount. Knowing the previous days inflammability index and the current days amount of evaporation, a deduction could be made to yesterdays index for todays new index. When the previous days index reached 280 it was necessary to combine relative humidity and evaporation to obtain the new index.

The first slide rule was developed in 1934 for determining the hazard in the rapid drying pine sites [19]. In 1935, another paper was presented by J.G. Wright in which he reported further results of fire danger research.[21]

It was obwerved that the inflammability of pure red pine duff at a given moisture content was much greater than that of mixed softwood duff From this it was learned that fuel arrangement was very critical Dew as a source of fuel moisture was investigated and it was found that under a forest canopy the temperature of the duff at night is practically always higher than that of the air above it and under such conditions there is no condensation of moisture unless fog is present.

Not only the amount of rain but the duration of rain and the moisture content ofthe duff before the rain are important in determining the effect of rain on duff moisture content. The moisture content of the partly decompost decomposed humus layer beneath the top layer duff influences the drying rate of the top layer duff.

Further, research in hardwood stands revealed that once the leaves have been flattened out by rain after the canopy crown is 60 percent or more developed, there is sufficient shade to prevent them from curling up again.

q Based on the studies carried out in hardwood stands, the inflammability index was modified to include the hardwood fuel types. The fire season was divided into spring, summer and fall periods. In the spring period the hazard in the hardwoods was assumed to be the same as the fast drying pine site. Corrections had to be made after a rain of more than .02 inches.

Fast drying hazard	Hardwood hazard
Nil	Moderate
Low	High
Mod	High
High	High
Extreme	Extreme

In the summer period the hardwood hazard is nil except after 12 or more consecutive days of dry weather after which the hazard becomes moderate to high.

In the fall period two units were added to the fast drying index to obtain the hardwood index.

Somewwork was done on mixed wood hazard. The slow drying tables were considered to be sufficiently accurate to represent the mixedwood hazard in the spring. In the summer period nine consecutive days of dry weather were required to develop a low to moderate hazard. During thefall period the fast drying tables were used with corrections.

In 1935 Mr. H W Beall developed a formula for determining the average fire hazard in a rating area, When the degree of hazard in each forest type was known.[21] "In a forest area composed of diversified types, the average hazard gives a much better idea of the increasing general danger in a prolonged dry period than the hazard chart for a single type."[21]

In 1937, Beall presented two papers describing a method of solving correlation sproblems when three or more variables were involved.[23, 3] Using these techniques it was possible to determine the relationship between changesin the moisture content of fuels on the forest floor and several of the weather elements.

It was recognized after the setting of many test fires that the relationship between the moisture content and the inflammability of litter in the pine and hardwood types was not constant[22]. Freshly fallen litter burned at much higher moisture contents than old litter, the difference amounting in some cases to more than 20 percent moisture content. It was suggested that the freshly fallen litter might contain volatile compounds which might be driven off in the oven along with the water vapor and result in apparent high values of moisture content. Because these material swould evaporate slowly under outdoor conditions, they would be gone by the next fire season. "Thus, the real relationship between moisture content and inflammability might be quite unaffected by seasonal change, although the apparent relationship varied owing to the drying off in the oven, at certain seasons, of volatile matter which would be counted as water."[22]

In an attempt to prove this theory,fuel moisture content was determined by the oven drying method and the xylol process. The difference between the two methods was assumed to be the result of a loss of volatile material. But, after careful experimentation no significant differences were found and it was concluded that the theory put forth was not correct. It is interesting to note that the complete answer to this problem has not yet been found.

In 1938, a revision to the 1933 forest fire hazard tables was published.[23)] The new tables provided for the measurement of hazard in pine types, tolerant hardwood types, and full canopied mixwood stands. The major new features were:

1) Corrections for wind velocity
2) Allowances for seasonal variation
3) Use of a ttracer index
4) Use of a hazard scale from 0 to 16.

For the first time wind was used to give a more accurate idea of the rate of spread of a fire. It was assumed previously that the effects of wind on fuel moisture reduction would be reflected in the evaporation measurement. The wind correction was in the form of an addition of -1 to 3 index units onto the final index depending on the velocity.

The tracer index was very similar to the index of inflammability used in 1933. It varied from 0 to 150 and was determined by the formula (150 - fine fuel moisture content). It feflected the influence of the amount and durablen of rain an increasing moisture content and the effects of relative humidity and evaporatin on decreasing moisture content.

The tracer index applied to all fuel types. Combining the tracer index, season of year, and species of duff gave the hazard index for each species.

The mew tables required rainfall measurements, evaporation measurements, relative humidty measurements, and wind measurements.

Accuracy data for the new tables were determined by analysing the occurrence of fires.

Radius of Zone (miles from weather sta.)	Accuracy for all Fires
10	96%
20	92%
30	89%
40	87%
60	85%

An important point to note is that the hazard was calculated at 6L00 p.m. each day after evaporation had ceased.

Grass-fire hazard tables were prepared in 1938[24)]. The hazard in grass depends upon the amount of green grass present and the moisture content of the dead grass. A new tracer index was developed that used the day's evaporation and the number of effective drying hours since the last rain of .02 inches or more. A rain of .02 inches was sufficient to saturate dead grass and additional effects of heavier rains is negligible. The new tracer index was worked out independantly of the previous day's index. It was considered that the moisture content in grass could change so rapidly that it was only affected by the current weather. The influence of past weather was allowed for by effective hours since rain. The tracer index was used in combination with the percentage of green grass to obtain the grass hazard index.

The effective hours since rain were simply the number of hours since the last rainfall. The period between 4:00 p.m. and 8:00 a.m. was not considered.

The hazard was worked out at 6:00 p.m. after the days evaporation was completed.

In 1939, tables wereprpaepared to predict the mid-afternoon tracer index based on weather readings taken at noon.[4)] This was the first time that the tables could be used for predicting the hazard for the current day. These tables also were the firstnot to have evaporation as one of the parameters. In place of evaporation wind was added. Previously wind had been a rate of spread coorection made to the final hazard. Evaporation for the current day obviously could not be used in these tables since the index was calculated at noon instead of 6:00 p.m. Thus the use of evaporation was dropped from the tables not because it was found to be inadequate, but because of the impossibility of determining it from a noon reading.

Two other important changes were made in these tables. Air temperature and month of the year were indluded in a table of corrections to be applied to the tracer index. Once the corrected tracer index, calculated at noon, was determined, it was applied to the appropriate hazard table.

In addition to predicting a mid-afternoon tracer index this report[4)] gave a table that for approximated daily variations of hazard for any forest type. In this table, for the first time, the effects of low and high night winds on the hazard were considered. Thus by knowing the estimated wind speed at night, the mid-afternoon hazard index and the time of day, it was possible to calculate the approximate hazard for a particular fuel type at any time during the day. The mid-afternoon hazard index used for this was the current day's index predicted at noon either by using the previous day's weather predictions or the actual noon weather readings, depending on the time ofthatthe the hazard was required.

In 1939, Mr. B.S. Wright carried out the first Canadian studies of the hazard associated with cut-over areas.[25)] These studies were carried out in a specially prepared slash area in Quebec. In this report, it was stated that "the inflammability of any fuel is roughly inversely proportional to the moisture content (within the inflammability range) and thus a means of measuring the moisture content of slash was first requisite." Samples were taken from various parts of slash piles and oven dried but it was found that "the sampling error of interior slash is so high that direct application of the results was impossible." It was then decided that indicators were required to give the moisture content by direct observation each day. Two indicators were required; one for the interior of the slash pile and on e for the exterior.

Trays of actual slash best represented the exterior slash and red pine cylinders 1 inch in diameter and 18 inches long proved to be the best indicators for the interior slash. The inflammability had to be related to the fuel moisture content. This was done by the burning of fuel of known moisture content in a standard sized burner. This method gave an indication of the inflammability but no measure of the lateral spread of the fire. The burner also did not take into account the inflammability of the surrounding fine fuels or the effect of green vegetation. Wright attempted to use a galvanometer and a thermopile to measure the intensity of the burn but the attempt failed because the instrument measured radiation from other sources.

Actual test fires in slash were set to test the accuracy of the inflammability zones predicted by the burner method. From these tests it was conclusively shown that fire will not spread in exposed slash alone if the interior is not dxpoesdughato burn. Based on these studies, slash hazard tables were drawn up. These tables gave hazard ratings for balsam and spruce slash of various ages (green to brown) for specific times of the fire season knowing the tracer index found in the fire hazard tables.

An attempt was made in 1939 to make a danger index table for a specific area.[5)] The danger index table was to take into account many of the following:

1) Hazadd index
2) Prevalence of fire starting agencies
3) Value of timber protected
4) Speed with which different parts of the area can be reached in case ef fire
5) The facilities which exist for detection and suppression.

A definite procedure was set up in this report to consider the heavy fuel moisture content. A cummulative drought correction was based on the number of consecutive days that elapsed since thettracer index last fell below 90 following a week with a total rain of at least 1/2 inch. It was intended that this correction would allow for the increase in fire danger over long periods with little or no rain. It not only was for heavy timber but also for humus found beneath the top layer duff and in the swamps. The effect of light showers which do not penetrate the heavy fuels was ignored.

The danger index tables were divided into spring, summer and autumn sections. These sections were further divided according to date, weather conditions and the condition of hardwood and ground foliage.

Thus by knowing the tracer index and the previously mentioned factors a daily danger index from 0 to 16 could be calculated. The preliminary danger index was corrected for cumulative dry weather, for wind velocity, and for atmospheric clearness. An adjustment for risk of 1 or 2 units could be added by the forestry officer when the risk from any sources was known to be high.

Two formul~~a~~i were developed to combine the hazard indices of the various fuels into one administration danger index. The weighting factors in the formuli were based on the fuel class, the risk, and the area. Seven fuel classes were recognized. One formula applied during the spring period and the other during the summer period.

For each red pine hazard index from 0 to 16 and season of the year the probabilities of fires starting were listed in a table. These probabilities were not combined in the danger index.

The reliability of the Eastern tables for use in Manitoba and Sasktchewan was checked by Beall in 1939[6]. It was donw by comparing the frequency of occurrence and size attained by actual fires with the degree of hazard shown by the tables at the time each fire started All the fire data was sorted by distances from the nearest weather stations to give an idea of how the fire danger tables decreased in accuracy as the distance out from the weather station increased.

Average hazard index and average number of fires per day were correlated. Average tracer index and total number of fires were correlated. Average number of consecutive days dince the tracer index was last below 90 and total number of fires were correlated. kThis study showed that the measure of drought was very poor. The incidence of fires in the nil and low hazard zones was considered to be important. "The index can be considered satisfactory only if such fires are confined to incipient lightning fires."[6]

The dangers in using fire incidence and fire occurrence in assessing the reliability of the tables are given below[6)].

1) Under conditions of prolonged drought the public becomes increasingly fire conscious.

2) The intensity of fire control activeeies by protection agencies increase during long periods of dry weather.

3) The likelihood of rain occurring within a short time after a fire starts probably increases with the length of time since the last rain--especially wherethe weather pattern altennates between high and low pressure areas cyclically.

4) In some areas lightning can start an unusually high number of fires in the nil and low classes.

5) Most weather stations are situated at ranger stations and therefore it is reasonable to expect larger fires further from the weather station because of poorer accessibility.

6) Rainfalls are not uniform. The weather station could receive a large amount while neighbouring areas remain dry.

The average area burned per fire within each hazard zone may be converted to a percentage with the extreme equal to 100. Als, the average number of fires per day in each hazard zone may be dtermined. These were plotted by Beall and he found that the curves were parabolic indicating a relatively small increase in fire control activity through the zones of low and moderate with a large increase in the high and extreme zones.[6)] For ease in effecting adjustments in the duties and number of personnel a curve of more linear shape would be preferable.

In 1940 Beal pointed out that the hazard rating system possessed an important advantage over other methods of hazard measurements.[7] Peedicted weather conditions could be applied directly in the tables and thus the accuracy of the hazard forecast was limited only by the accuracy of the weather forecast.

The year of the big change was 1946. Beall presented the last major revision to the old hazard rating method that had been developed by Wright[8].

The name was changed from hazard index to fire danger index. The new tables were to apply to general conditions within a region and not for just a specific fuel type.

Weather readings were required only at 8:00 a.m. and at noon and evaporation and duration of rainfall records were not required. Relative humidity, temperature, wind velocity depth of rain and the tracer index were the parameters used.

The drought index tables took the place of the old cumulative drought correction. The effects of drought were included in the fire hazard and fire danger tables. The ten separate hazard index tables that were used previously were reduced to three tables representing the more important fuel conditions. Included also weas a revised grass hazard table. Seasonal changes in the development and withering of leaves, plants and grasses as well as changes in the length of day were still included in the new tables.

Steps in obtaining the Danger Index.

1) Today's tracer index was calculated using two tables. The rainfall table showed the wetting effect of rain on the surface litter and the dry weather

table showed the effect of temperature, wind and humidity onnthe drying.

2) The drought index was calcuated knowing yesterday's drought index and the amount of rain taht fell since yesterday. The drought index increased one index number for every day without rain up to a maximum of 25.

Amount of rain since yesterday (inches)

	.00	.06	.11	.15	.19	.23	.27	.31	.35
	.05	.10	.14	.18	.22	.26	.30	.34	.38
Approx Drought Index Reduction	-1	0	2	4	6	8	10	12	14

	.39	.43	.47	.57	.55	.60	.65
	.42	.46	.50	.54	.59	.64	+
Approx Drought Index Reduction	16	18	20	22	23	24	25

3) After today's tracer index and the drought index were found the hazard index for a particular forest type was calculated. The hazard tables combined the day's tracer index and drought index along with seasonal effects to show the hazard in one of the following fuel types:

a) Fast-drying pine stands and hardwood forests in the spring and fall when there are no leaves on the trees.

b) Slash

c) Heaths, dry barrens, and old burns with little or no tree growth but with a cover of bracken fern, sweet fern, blueberry, scattered grasses, and other seasonal plants.

c) Grass

4) The fire danger index was an average hazard index and was calculated for three broad regions: a) Eastern Canada, b) Central Plains, and c) East Slope of the Rocky Mountains. The danger index was calculated knowing the region, season, tracer index and the drough index.

5) The danger index was corrected for wind velocity in order to allow for the effect of wind on fire behaviour.

Summary

Wind Temperature Humidity

Rain

Dry Weather Table

Rainfall Table

Drought Table

Tracer Index
(Surface fuels)

Drought Index
(Heavy fuels)

Region

Season

Specific Hazard Tables

Fire Danger Table

Wind Correction Table

Fire Danger Index

Hazard Index

The first extensive study of the effects of night weather conditions on fine fuel moisture content was carried out in 1948 by Mr. J.C. Mcleod.[11] During this study it was discovered that fine fuel moistures reacted more directly to the difference between the afternoon and following night relative humidities than to the night relative humidity alone. It was found that nocturnal wind did not have an effect on the rate of absorption of atmospheric moisture by fine fuels. It was also found that nocturnal temperatures do not in themselves have any significant effect on fuel moisture. Based on the findings of this study, a night relative-humidity correction to the fire danger index was made. This table required yesterday afternoon's relative humidity, the highest realtive humidity last night, and today's corrected danger index. Macleod found that during a particularly dry season corrections for low night humidities were required 46 percent of the days. This table was incorporated in the second edition of the Forest Fire Danger Tables published by Beall in 1950.

It was suggested that an inexpensive way to obtain maximum night humidity was to use two minimum thermometers, one of which would be a wet-bulb[11]. This method assumes that the maximum humidity occurs when the minimum temperature is reached and that an earlier depression caused by a very low relative humidity will not be lower than the minimum wet bulb temperature reached at the time of highest humidity. A check of accuracy of this method revealed that it was correct to within 5% relative humidity 85 percent of the time and correct to within 15% relative humidity 96% of the time.

During the period between 1950 and 1965 the three original danger index regions were divided into six smaller regions, and three additional regions were added in British Columbia and the North West Territories. Between 1956 and 1958 notes on the preparation of danger index tables were written by Mactavish[12).

Dur1959thMrpeDi6d Williams presented a method of evaluating fire season severity.[14)] Because fire control people asked "was the reduction in losses this year the result of our intensified effort or was this an easier fire season than last" a reliable method of measuring fire season severity was needed. Severity indices have been devloped in the United States - based on both fire occurrence and area burned and the assumption that a constant fire starting potential exists and that the number of fires starting and the size of each attains depend on weather alone. In Canada it was felt that these last assumptions were not valid because in high danger periods steps such as forest clossure and cancellatin of burning permits are taken to reduce the risk. Also, because of the opening up of new areas each year to the public and industry the riskkof man-mmused fires is greatly increased.

Instead of using fire occurence and size as a measure of severity the relative severity of the various danger classes was evaluated according to the hbehaviour of fires in each class. Rate of spread andresistance tocontrol would be a measure of severity. But there is not enough data of this type available from actual fires to assess the severity.

The rate of spread data were found from the test fire data that had been used to set up the hazard tables for specific fuel types. The average perimeter of each test fire after 2 minutes was calculated for each danger index class.

The resistance to control was measured by the drought index. An average drought index was calculated for each danger index class. For each danger index class the ratio of the perimeter and drought was calculated with the moderate class taken as unity. The product of the perimeter ratio and drought ratio in each danger index class gave the severity factor.

Fire Danger Class	Avg Drought Ind.	Drought Ratio	Avg. Perimeter	Perimeter Ratio	Severity Factor
Nil	--	--	0	0	0
Low	4.0	0.39	4.6	.60	0.2
Moderate	9.5	1.00	7.7	1.00	1
High	15.8	1.66	18.0	2.35	4
Extreme	24.0	2.42	39.0	5.06	12

The severity of a fire season was calculated by multiplying the number of days in each class times the appropriate severity factor and dividing the sums of these values by the total number of days in the fire season (A weighted average using the severity factors as the weights).

A fire danger rating system cannot predict the occurrence and behaviour of every fire and thus it cannot predict the exact fire load. But the system shoud "indicate in a consistent manner the meanffire load we can expect fromday to day." 16) Over long time periods and a large area the numbers of fires the acres burned should be closely related to fire danger classes. This is the principle used to evaluate the danger rating system.

In a study made by Beall in 1950, it was found that the danger index is highly reliable within a 25 mile radius of the weather station and was unreliable farther than 100 miles from the station 9). This fact can be used in evaluating the rating system. All fires occuring in these zones can be grouped according to the class of fire danger on the day when the fire started. Areas burned can be classefied in a similar manner. Average number offfires per day dand average size in each danger index class in each zone can be used to evaluate the reliability of the danger index.

THE CALIFORNIA FIRE DANGER RATING SYSTEM

In 1955 the California Division of Forestry, the U.S. Forest Service, and the U.S. Weather Bureau began a cooperative project to develop a fire danger rating system for California. The system that was developed as a result of this project, attempted to estimate the effects of weather on fire spread, intensity and ignition. The various indices that make up the California system, their interpretations, and the elements that make up them are shown on the preceding page.

Assumptions on which the rating system is based.

(1) Three fuel sizes exist

(a) Fine fuels - the moisture id determined by the current weabher conditions.

(b) Medium fuels - ½ inch stick moisture content pepresents the moisture in this fuel size.

(c) Heavy fuels - react slowly to weather conditions.

(2) Fire spreads in the fine fuels in all fuel types

(3) The rate of spread determines the control job

(4) Fire intensity is related to the availability of heavy fuels (physically and at the proper M.C.)

Fine fuel moisture content was found to be closely estimated by the formula

$$\frac{4 \,/\, E.M.C. \,/ \;+\; /\, \tfrac{1}{2}\text{"Stick } M.C. \,/}{5}$$

As can be seen, the equilibrium moisture content (which may be determined by the relative humidity of the air) is given 4/5 the total weight while the 1/2 inch stick moisture content adds only 1/5 the value of the fine fuel moisture content.

A formula was developed under controlled conditions to predict rate under controlled conditions to predict rate of spread knowing wind velocity and fuel moisture content. It was assumed that rete of perimeter increase was a measure of job control and thus the forward rate of spread as predicted by the formula, was converted to perimeter increase. This was incorporated into a spread index table that had a range of 0 to 100 depending on the wind and fuel moisture content combination.

A grass burning index was developed to estimate the effect of green plant material on the moisture content in grass fuels. For 100% cured grass the computed fine fuel moisture content applied. The percent cured and the spread index were combined to give the grass-burning index.

Direct measurements of medium fuel moisture content are obtained from the 1/2 inch sticks. From moisture data observed over a 13-year period in heavy fuels and from the corresponding weather data a realationship between the weather factors and the 1/2" stick moisture content and the heavy fuel moisture content was established. A build-up table was developed based on this relationship which measured the drying and wetting of heavy fuels.

Fuel Stick Moisture Content ⟶ Build-up Addition + Previous Day's Build-up -(Precipitation x 20) = Today's Build-up

The intensity index for brush fuels takes into account effect of succulent new growth on the moisture content of the brush fuels. The cumulative effect of moisture in heavy fuels is included in the timber intensity index.

Rate of spread and fire intensity have a common "denomination" -- the fire control job which is defined as the number of square feet of line required to contain a fire. Intensity determines the width of the line and since intensity is related to the moisture content of the heavier fuels dry out. The fire control job was assumed to be twice as difficult when the heavy fuels are at thier dryestcompared with moist heavy fuels. The weighting factor was used to determine the fire intensity index for timber fuels.

The spread factor is the rate of perimeter increase and is a measure of the length of line needed to contain a fire. This point requires a closer look. Davis[10)] in his comments on Gisborne's first Danger Meter stated that a danger index must not include a mixture of flammability and organizqtion factors. The spread factor is a measure of flammability, and length of line needed to contain a fire is a function of the detection system, the acessibility, the suppression organization or, in other words, the organization factors. Thus, the control job concept, which represents a combination of length and width of line determined by the rate of spread and intensity, in order to be at all useful must be subjected to "local interpretation."

The effect of slope is similar to the effect of wind on fire spread. Because of this relationship it was possible to add correction factors to the spread index for given slope classes. This correction would be particularly useful at going fires.

The 0 to 100 burning index scale is divided into low, moderate, high, very high and extreme. The divisions were made so that 5% of the days would fall in the low class, 45% in the moderate, 25% in the high, 20% in the very hig, and 5% in the extreme. All scales are linear, with respect to expected work load.

The state was divided into fire danger rating areas based on climate and fuel. The fire weather readings from a station in each area would be representative of the entire zone. The classification of climatic type was based on afternoon temperature and moisture measurements. Each rating area was further divided into major fuel types--grass, brush, and timber. The major fuel type (or types) is specified for each rating area and a burning index for this type must be calculated each day .

Two additional indexes are calculated. The ignition index which shows the iggitability and the chance of a fire is determined knowing the dry bulb temperature and the fine fuel moisture content. The fire load index which is a meaaure of the job load per day is found by combining the ignition index and the burning index. The burning index to be used in this table is specified for each region.

The fire weather severity can be found each day or for the year by camulating the daily fire load index values.

The indices can be calculated at any time during the day, however. It is standard practice to calculate them at 14:30. The main purpose of calculating the indeces is to predict the situation for the next day so that the administration can take the appropriate action to meet the expected needs.

The prediction of each separate index is done on graphs showing the trend up to the present The prediction for the next day is an extension of the trend line. A major disadvantage in this system is that predicted major changes in weather can only be subjectively dealt with.

An important fact to noteis that the California system is designed so that changes can be made to it without a major revision to the entire system. The system is divided into independent subsystems and thus a change in one subsystem will not seriously affect the other subsystems.

COMPARISON OF THE CALIFORNIA AND CANADIAN SYSTEMS

(1) The California system requires a 1/2" stick moisture content measurement plus a humidity measurement to obtain a fine fuel moisture content.

The Canadian system does not use a stick moisture measurement but instead uses a rainfall measurement, a humidity measurement, a temperature measurement, and a wind measurement. The effects of temperature and wind on the rate of drying and the influence of rain on the increasing the moisture content are presumably taken into account in the California system by the 1/2" stick moisture content. Using 1/2" sticks to integrate these factors is obviously much easier than a complex table as used in the Canadian system. However, this disadvantage is compensated for by the fact that predicted weather factors cannot be used to predict fine fuel moisture content in the California system.

(2) The actual fine fuel moisture content is determined in the California system. In the Canadian system, the tracer index represents the fine fuel moisture content (Tracer Index = 150 - Fine Fuel M.C.). There doesn't appear to be any reason why the tracer index couldn't be replaced by the actual fine fuel moisture content. This would probably enable the field personnel to better understand what the tables accomplished

(3) The California rating system clearly defines what each index represents in terms readily interpreted by administrative personnel. For example, the spread index is a measure of the control job; the burning index is a measure of the job load per fire; the ignition index indicates the chance of fires. The fire load index is a measure of the job load per day.

The Canadian system does not have its indices clearly defined in terms readily adaptable to administrative decision making. The tracer index is a measure of fine fuel moisture content. The drought index is a measure of the heavy fuel moisture content. The hazard index represents the danger of a specific fuel type. The danger index is an average hazard index forhthe region.

(4) Even though both systems are called danger rating systems, neight actually gives the fire danger as defined by Davis.[10)] For this reason, both are subject to local interpretation. That is, after the appropriate index has been calculated, the local forestry officer must apply subjective corrections for fire rks, visibility, assessibility, value of timber or porperty to be protected, and the state of his suppression organization. It is this subjective correction that is the major weaknnss in the two systems.

(5) The effect of succulent growth is taken into account by seasons which are defined in terms of leaf development in the Canadian danger index. This factor is taken into account in the California system by days since new growth. The two different approaches reflect the different nature of the fuels.

(6) The Canadian system provides a table to correct for low night relative humidityes. No such correction factor is available in the California system. Presumably the 1/2 inch stick should take this into account.

(7) Both systems enable a severity index to be calculated on a daily basis.

A simple cumulation of the fire load is the severity index for the California system. The Canadian system requires that a multiple of the danger index be cumulated each day.

(8) The California grass burning index accomplishes approximately the same thing as the Canadian grass hazard tables. In addition to percentt cured, the Canadian index also adds a seasonal correction. Also, days i since rain is included in the calculation but this factor is probably taken into account by the 1/2" stick moisture content.

(9) The Canadian system does not obtain a moisture measurement of medium sized fuels. Only fine and heavy fuels are recognized. The California system obtains the medium sized fuel moisture content directly from the 1/2" sticks.

(10) The Canadian drought index attempts to accomplish what the California build-up index does. However, from reports received from the field, the drought index is not satisfactory. The California build-up index takes one additional factor into account--the 1/2" stick moisture content.

(11) The two systems both have 5 classes of danger. The Canadian classification is based on the behaviour of the small scale test fires, while the California system's classification is based on an arbitrary percentage of the number of days in a fire season that are desired in each class

(12) The California system has a range of 0 to 100, while the Canadian system has a range of 0 to 16. The 0 to 16 scale is too narrow in range to accomodate all the extreme conditions and because of this, there are plans to revise the scale to a 0 to 100 range.

(13) The modification of any part of the Canadian tables requires a major revision in the whole system. A modification in the California tables requires changes in that particular subsection only.

(14) The California system can be used to calculate the danger at any time during the day. The Canadian system can only be used to give the danger ragint in the afternoon and weather measurement must be taken at noon. Also, the California system allows for a slope correction which is not' considered in the Canadian system.

(15) AAsmentioned previously, there is no predictive aspect in the California system. The indices apply at the specific time at which they are determined. The main purpose is to predict for the nextdday using trend lines. The main purpose of the Canadian index is to predict the danger at the worst part of the current day based on measurements taken about 4 hours previously. However, because the Canadian system requires only weather parameters and no fuel stick moisture measurement, the prediction of the next day's danger can be made simply by applying the predicted weather factors. The accuracy of the danger prediction is limited only by the accuracy of the predicted weather parameters.

(16) The Canadian system allows for hazard calculations for several specific fuel types other than grass. The California system recognizes a brush grass and timber fuel type only.

(17) Both systems are complex to calculate and neither system has been adapted to a slide rule.

(18) Perhaps the biggest difference between the two systems is in their

method of construction. The State of California has been divided into 138 more or less homogeneous fire danger rating areas on the basis of climate and fuel type. Each rating area represents that approximate range for which a fire danger rating, taken from a weather station within the area, will apply. Only the three fuel types are recognized--grass, brush and timber. It is assumed that the same basic relationships on which the rating system is based will apply to each area and therefore the same set of tables will be applied in each area. The major fuel classification of each area determines which burning index or indices will be used.

The Canadian system is similar to the California system in that it assumes the tracer index and the drought index principles will apply in all areas. However, the similarity stops at this point. C nada has been divided up into very general climatic regions (Some of the regions are larger than the State of California). Each climatic region has been classified by major fuel types. As many as six or more fuel types were recognized in the regions. In each fuel type many test fires were set and rated. Most of the fires were set at the peak of the hazard--usually at mid-afternoon. Corresponding fuel moisture measurements were made at the same time and the test fires were lit. Morning and noon weather readings were taken at a central weather station each day. Test fire observations were correlated with fuel moisture measurements. The fuel moisture measurements were in turn correlated with the earlier weather readings. In this manner the predictive aspect was built into the tables. The hazard ratings for each fuel type were then combined to give the danger rating for the area. The combination was accomplished by weighting each fuel class, According to area and importance.

By constructing a separated danger table for each region it was hoped that many pecularities in the daily weather pattern common only to that region would be accounted for in the tables. If low night humidities or heavy dew or high afternoon temperatures were common then these would be reflected in the rating system. Presumably, the California system accomplishes this through the use of the 1/2 inch stick measurements.

It requires at least one fire season to collect enough data ina region to develop a set of fire danger tables. A minimum of two field workers is required to collect this data. Close to another year is required to organize, analyze, prepare and publish the tables. Because of a limited budget and the time requirements to develop a set of tables relatively large climatic regions have been selected. This perhpas is a major fault of the Canadian tables at the present. The existing climatic regions must be further subdivided into more homogeneous climatic areas, and new tables must be made for each new area. Since the procedures for taking the field measurements and analyzing the data have been standardized it would appear that the data analysis could be handled by a computer. The problem of transferring the field data into a form suitable for use in a computer sould be overcome if the field data were placed on mark sensing cards directly in the field. The use of a computer would eliminate the time requirement problem.

The California approach to danger rating probably would not be satisfactory in Canada at the present, without anlarge amoung of additional research. Under the California system, for example, all of Ontario would be classified as timber. But the fire hasard in hardwoods or mixed woods is very different than the fire hazard in a fast drying jack pine site. In order for the California system to be applied, fire behavior in all of the major fuel types would have to be determined so that separate burning indices could be set up. Once these were made, however, a province the size of British Columbia could be divided into hundreds of danger rating areas, each with its own tables with very little effort.

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