INCORPORATING A HUMAN RISK FACTOR IN AVALANCHE DANGER RATING SYSTEMS

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ABSTRACT Stability ratings describe the probability that natural avalanches may occur and the nature of the trigger required for avalanche release. Hazard ratings describe the consequences to life and property if an avalanche is triggered. Avalanche danger rating systems use a 1-5 danger level scale that assesses the probability of natural and human triggered avalanches based on snowpack stability. There is variation in the use of the words risk, hazard, danger, but no definition considers the number and kinds of backcountry travelers and their patterns of use.

The National Fire Danger Rating System (NFDRS) uses inputs of fuel, weather and topography to determine how a fire would behave (i.e. rate of spread, flame length and energy release) if ignited on a given day. Integral to the system, however is the likelihood of ignition on a particular day. Thus the final index of the NFDRS integrates potential fire behavior (hazard) with the probability of ignition (risk).

This paper describes a process by which avalanche danger rating can be adjusted to account for risk where risk is a number related to the potential number and mode of travel of humans to which an area will be exposed during a given day. The proposed process is analogous to the NFDRS where avalanche triggers are considered similarly to sources of ignition. The inputs include the average number of human triggered avalanches in a forecast area, the relative contribution of each type of trigger (e.g. snowmobiler, skier, boarder etc.) and the number of triggers per day over a five-year period.

KEYWORDS: Avalanche danger rating, human risk

1. INTRODUCTION

During the winter of 1999-2000 we were asked to assist with the recovery of the body of a snowmobiler killed while highmarking a remote cirque in southeast Idaho. The backcountry avalanche advisory issued by the Bear River Avalanche Information Center for that day stated "Deep hard slab instabilities do continue to lurk out there . . . These hard slabs are difficult to predict . . . remain alert if descending steep lee aspects or highmarking open bowls today. The avalanche danger will be **LOW** or isolated today, implying that natural and human triggered avalanches are unlikely." The incident occurred on a warm, sunny Saturday following several days of snow and strong winds with gusts near 100 mph. Warming temperatures and a general decrease in avalanches observed or reported were responsible for the decrease in the avalanche danger rating.

In producing avalanche advisories words such as danger, hazard and risk are often used to tell the user the probability that an avalanche will occur in the forecast period. There is considerable variation in the use of the words danger, hazard and risk. According to Webster "*danger* is the general term for liability to injury or evil, of whatever degree or likelihood of occurrence; *hazard* implies a foreseeable but uncontrollable possibility of danger, but stresses the element of chance; *risk* implies the voluntary taking of a dangerous chance".

Clearly on that day there was some uncontrollable possibility of injury due to an avalanche and the snowmobiler took a dangerous chance. No different perhaps than any other winter day where over snow travelers recreate in avalanche terrain. Had the number of recreators in that area, however, been factored into the danger rating would the risk have been greater? Knowing that, would the snowmobilier have taken the same chance? Of the words used to describe avalanche potential only risk addresses numbers of users. This paper attempts to account for risk where risk is a number related to the potential number and mode of travel of humans to which an area will be exposed during a given day.

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2. FIRE AND ICE

Of nature's spectacles wildland fires and snow avalanches are among the most awe inspiring. Oddly, as physical phenomena they have much in common (Figure 1). Weather, especially wind, exerts considerable influence over the probability and behavior of both fire and avalanches. In wildland fires it is the fuels complex that mediates the influence of weather into observable fire behavior. Similarly, weather creates the mountain snowpack, the stability of which determines whether an avalanche is possible when inclined to starting zone steepness. Thus these two phenomena can be viewed looking only at the physical attributes of each. However, the potential for a fire (low fuel moisture, low RH and wind) or an avalanche (snowpack layer instability, steep slopes) does not necessarily mean one or the other will occur. A fire requires a source of ignition (lightning or humans) and avalanches require triggers (additional snow or humans). The probability of a fire or an avalanche must therefore consider the types and numbers of ignitions or triggers.

3. NATIONAL FIRE DANGER RATING SYSTEM

Fire danger rating systems have been used in the United States since 1934. The national system was introduced in 1964 and implemented in its present form in 1978 (Andrews, P.L. 1987). The National Fire Danger Rating System (NFDRS) uses inputs of fuel, weather and topography to determine how a fire would behave if one were to ignite on a particular day (Figure 2). Integral to the system is the likelihood of ignition on that given day. The fire load index of the NFDRS integrates potential fire behavior (hazard) with the probability of ignition (risk) (Deeming and others 1978).

Drive up any mountain canyon in the west in summer and you are likely to be greeted by Smokey Bear telling you what the fire danger is for that day. The danger may change from one day to the next depending on the likelihood of an ignition. For example the danger will be greater on July 4th than the 5th, all things being equal, because of humans with fireworks. Similarly the opening of deer hunt, Saturdays in general and the 24 hours following observed lightning activity will all be rated higher than days of normal risk. The system was developed with fire suppression and especially presuppression readiness in mind. Certain levels of fire danger allow fire managers to authorize stand-by fire fighting money to reduce initial attack time.

Fire managers quantify human risk by determining the five-year average number of fires in the rating area, the relative contribution of each source of human ignition (e.g. machine use, incendiary, campfires, smoking, etc.) and how the number of ignitions varies from day to day.

4. AVALANCHE DANGER RATING SYSTEM

Figure 2 shows how avalanche danger rating may be viewed similarly to fire danger rating incorporating human risk. The system proposed here uses the physical parameters that create the probability of a natural avalanche at present, or into the future as conditions change. The system further assesses the activity of humans to determine the risk of a human-triggered avalanche, which is quantified as a human-caused occurrence index (HCOI). The probability of a natural avalanche when combined with the HCOI determines the avalanche danger for that rating period and attempts to quantify the number of avalanches likely to be triggered per one million acres.

Calculating HCOI requires inputs of human caused risk and avalanche probability. The avalanche probability index is derived using conventional assessments of weather, snowpack and terrain. The procedure for evaluating HCR can be partitioned into two phases. Phase one involves analyzing historical avalanche and weather records to 1) to derive the human-caused risk scaling factor (HCRSF), 2) identify risk sources and 3) to determine risk source ratios.

Phase two must be done daily and involves assigning a daily activity level to each risk source and computing human-caused risk. A risk source is an identifiable human activity that historically has been a major cause of avalanches in the forecast area. A risk source ratio is the portion of the human triggered avalanches that have occurred in a forecast area chargeable to a specific risk source. A risk source ratio is calculated each day of the week for each risk source. The scaling factor adjusts the prediction of the basic human triggered avalanche occurrence model to fit local experience.

4.1 Phase One

4.1.1 Calculating the HCRSF

A HCRSF relates to the number of human triggered avalanches in a given forecast and is calculated as follows:

$$HCRSF = \frac{\Sigma \text{ avalanches}}{\text{Average AD x Acre Days}} \quad (1)$$

where Σ avalanches is the total number human triggered avalanches over a five year period; Average AD is the mean avalanche danger rating weighted by the number of days in the respective forecast season over the five year period and acre days is the product of forecast area millions of acres and the number of days in the forecast season. HCRSF adjusts the prediction of the basic human triggered avalanches to fit local experience. The scaling factor uses the most recent five years' data and uses the total number of human-triggered avalanches which occurred in the forecast area, the total number of days in the forecast season, the average avalanche danger rating and the number of acres in the forecast area.

Consider an example from the last five avalanche seasons on the Salt Lake Ranger District as summarized in the following tabulation.

a	*b*	*c*	*d*	*e*	*f*
Year	**No. of HT* avalanches**	**Year's mean AD†**	**Avalanche Season (days)**	**(*c* x *d*)**	**Average AD (Σ*e* / Σ*d*)**
1996	50	3	170	510	
1997	80	3	160	480	
1998	93	3	165	415	
1999	65	4	135	540	
2000	42	4	130	520	
Totals	330		760	2455	3.2

*HT, human-triggered; Source: UAFC Annual Report 1999-2000.
†AD, avalanche danger.

This example assumes that the typical avalanche season for the forecast area occurs from December through April and varies in length and average avalanche danger. Additionally, conventional values assigned avalanche danger ratings (i.e. 1 – 5, low to extreme danger, respectively) are reversed to derive logical scaling factors (i.e. 1 – 5, extreme to low danger, respectively). The average avalanche danger is the average of the yearly average ADs' weighted by the number of days in the respective avalanche season. The weighting occurs in columns e and f. The number of human-triggered avalanches for each year only accounts for those reported. Observations, or circumstantial data may indicate that totals significantly underestimate the actual number of human-triggered avalanches. Accounting for unreported incidents may require modifying numbers to reflect actual totals.

The third term in the equation is million acre-days (A – Days). It is the product of the forecast area, in millions of acres and the total number of days in the five avalanche seasons. The Salt Lake Ranger District is approximately 289,000 acres.

$$\begin{aligned} A - Days &= Area \ X \ \Sigma d \\ &= 0.289 \ MM \ X \ 76 \\ &= 220 \quad (2) \end{aligned}$$

For this example, calculating the HCRSF:

$$\begin{aligned} HCRSF &= \frac{330 \ X \ 2}{3.2 \ X \ 220} \\ &= 0.94 \quad (3) \end{aligned}$$

We assume that for every reported avalanche one goes unreported so we have multiplied the total reported avalanches by a factor of two. Developing complete records for high use areas in a given forecast area will produce a more stable scaling factor over time.

4.1.2 <u>Determining Risk Source Ratios</u>

The risk source ratio (RSR) is the relative contribution of each type of trigger. The Westwide Avalanche Network classifies human triggers to distinguish between skiers, snowboarders, foot travelers, and vehicles. The RSR is calculated by dividing the five-year number of avalanches into the number caused by each trigger type for each day of the week.

For example an estimated total of 660 avalanches were triggered on the Salt Lake Ranger District from 1996 – 2000. By day of the week, the numbers of incidents were distributed as follows:

Number of Human -Triggered Avalanches

Risk Source	Mon	Tues	Weds	Thurs	Fri	Sat	Sun	Total
Snowmobiler	2	0	4	0	0	18	8	32
Skier	22	73	55	39	67	79	109	468
Snowboarder	22	30	6	16	6	20	34	134
Other	2	2	6	0	0	16	0	26
5-Year Total								660

The RSR is calculated using this formula:

$$RSR = \frac{\text{No. of avalanches for day of the week}}{\text{Total number of avalanches}} \quad (4)$$

For instance, the RSR for snowmobilers on a Saturday would equal:

$18 \div 660 = 2.72 \sim 3$

Using this formula the array of RSRs by day of the week for the 4 risk sources in the example would be as follows:

Risk Source Ratios

Risk Source	Mon	Tues	Wed	Thurs	Fri	Sat	Sun
Snowmobiler	1	0	1	0	0	3	1
Skier	3	11	8	6	10	12	17
Snowboarder	3	5	1	2	1	3	5
Other	1	1	1	0	0	2	0

4.2 Phase Two

4.2.1 Evaluation of Daily Activity Level

The HRSF and RSR are semi permanent values that are derived objectively. The daily activity of each risk source (i.e. trigger), however, may vary each day. For example, Monday may be a low activity level for all triggers, but if the Monday is President's Day the activity of all triggers will be higher. Similarly all activity levels may increase on clear days after storms as "powder flu" equally affects all risk sources. In a university town semester breaks may increase the activity levels of backcountry skiers and boarders, but the activity level of snowmobilers will likely remain normal. Consequently each risk source is rated each day for its individual activity level. The assessment is relative to what is normal for that day of a typical week during the forecast season.

Because daily activity level evaluations are subjective, the following guide can be used.

Daily Activity Level	Relative Value	% of Occurrence	Description
NONE	0	5	Risk source inactive.
LOW	1	10	Risk source activity well below normal for the day of the week.
NORMAL	2	70	Activity normal for the day of the week.
HIGH	4	10	Risk source about twice as active.
EXTREME	8	5	Activity of the risk source unusually high.

4.2.2 Calculating the Unnormalized HCR

Using Table 1, the daily activity level is combined with the RSR to derive the partial risk contributed by each risk source. The unnormalized HCR is the sum of partial risks contributed by each of the risk sources.

Table 1. Partial risk factor derived from risk source ratios and daily activity level

DAILY ACTIVITY LEVEL	Risk Source Ratio																			
	0 ↓ 5	6 ↓ 10	11 ↓ 15	16 ↓ 20	21 ↓ 25	26 ↓ 30	31 ↓ 35	36 ↓ 40	41 ↓ 45	46 ↓ 50	51 ↓ 55	56 ↓ 60	61 ↓ 65	66 ↓ 70	71 ↓ 75	76 ↓ 80	81 ↓ 85	86 ↓ 90	91 ↓ 95	96 ↓ 100
None	1	1	1	1	2	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6
Low	1	1	2	2	3	4	4	5	5	6	7	7	8	9	9	10	11	11	12	12
Normal	1	2	3	5	6	7	8	10	11	12	14	15	16	17	19	20	21	22	24	25
High	2	4	7	9	12	14	17	19	22	24	27	30	32	35	37	40	42	45	47	50
Extreme	3	8	13	18	23	29	34	39	44	49	54	59	64	69	74	80	85	90	95	100

For example, it is a bluebird powder day on a Sunday during Christmas break. The following are RSRs and daily activity levels determined for each risk source on the Salt Lake Ranger District.

Risk Source	RSR	Daily Activity Level	Partial Risk
Snowmobiler	3	Normal	1
Skier	12	Extreme	13
Snowboarder	3	Extreme	3
Other	2	Normal	1

The unnormalized HCR equals 1 + 13 + 3 + 1 in this case, 18.

4.2.3 The Human-Caused Occurrence Index

Human caused occurrence is calculated using the nomogram (Figure 3). The inputs are the unnormalized HCR and the scaling factor. Again consider the Salt Lake Ranger District; entering nomogram A with an unnormalized HCR of 18 and a scaling factor of 0.94, the HCOI is 3.9 and represents an estimate of the number of human triggered avalanches likely over one million acres for that day.

Depending on the value of the HCOI an adjustment may be considered in the overall avalanche danger rating for that day. Indexes should not be taken too literally and are intended to indicate what will happen on the average under similar conditions.

5. DISCUSSION

Avalanche forecasters understand the physical parameters that contribute to avalanche formation and release more than the human dimensions of the users. The focus of avalanche centers has moved increasingly toward avalanche education as a means of increasing avalanche awareness in backcountry users. Similar trends exist in many areas of natural resource recreation management as managers attempt to understand the social, economic, political, cultural and psychological attributes of resource users. These are difficult concepts for physical scientists to embrace, yet their importance cannot be overlooked.

Consider Smokey Bear a figure as recognizable worldwide as Santa Claus. His message "only you can prevent forest fires" utters from his lips in a dozen languages. The analogous mission of avalanche educators is to imprint into the minds of winter travelers the message that only they can prevent avalanche accidents. The national fire prevention program has been a huge success and yet in the Rocky Mountains, for example, humans start only one third of fires, the remainder being lightning caused. Similarly there are many more natural than human triggered avalanches in the backcountry, yet it is well known that the victim or member of the victim's party triggers most fatal avalanches. Clearly an increased understanding of recreational behavior of the various user groups is needed.

Much has been published about the variation of the nature of stress imparted on the snowpack by snowmobiles, skis, boots or snowboards. Additionally there is considerable variation in the amount of terrain affected by different user groups. A single snowmobilier may affect more starting zones in a day than a skier in a season. And now many forecast areas see snowmoboarders and snowmoskiers as machines are increasingly used to access remote backcountry terrain for skiing and boarding. How can the variation in numbers and types of users, different forms of equipment and amount of terrain affected be considered in development of a quantitative index of human activity?

We believe this can be achieved by determining a human caused occurrence index using human caused risk scaling factor and risk source ratio analysis. However, the fundamental inputs needed to derive these values are difficult to obtain or unknown. Avalanche centers need to focus on improvements in data gathering by using surveys and interviews to obtain more meaningful and complete records of avalanches triggered. The only fact that appears certain is that we grossly underestimate the number of avalanches triggered. This is a significant problem in using the National Fire Danger Rating System as a model for avalanche danger rating. Most fires ignited are detected excluding perhaps those extinguished by rain before detection. We feel that most human triggered avalanches go unreported as many users are unwilling to admit having triggered a slide.

The equation we developed for the scaling factor can vary if 1) the number of avalanches increases or 2) the mean avalanche danger or number of days in the avalanche season changes. The example we developed using the Salt Lake Ranger District depicts an area of relatively small size with a large number of backcountry skiers active on most days of the week. Consider a helicopter operation whose permit area is 3000 acres and whose season consists of 20 days when the helicopter was booked and able to fly. If as few as 10 avalanches were triggered over the five-year period and the mean danger was moderate when the tours occurred the scaling factor approaches 10. Conversely in an area like the Bear River Avalanche Information Center which encompasses 1.5 million acres in northern Utah and southeastern Idaho and has few reported avalanches the scaling factor will be much lower at approximately 0.1.

In these examples there will also be variation in the risk source ratio. For the helicopter operator guides or guests who will be skiers or snowboarders will trigger slides. Most of the activity of helicopter companies might occur on weekends or holidays. Certain high-end helicopter companies like those in Canada may be most active on clear powder days when the aircraft can fly and clients are most apt to pay. In large rural areas like the Bear River Center or the Gallatin Center the number of snowmobiles far exceeds skiers or boarders. Most of the activity will be on Saturdays, Sundays and holidays. In Utah and southeastern Idaho there is noticeably less use on Sunday than Saturday because of the cultural influence of a largely Mormon society.

The point is that there will be considerable differences in quantifying human risk by forecast area based on size, avalanche danger, user group characteristics, length of season and variation in activity levels. The information presented was prepared from limited data. Accurate and valid assessments require the collection of complete data over several years. We encourage practitioners to maintain detailed records to allow validation of the process and provide suggestions for improvements to make the system a more useful tool.

6. ACKNOWLEDGMENTS

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7. REFERENCES

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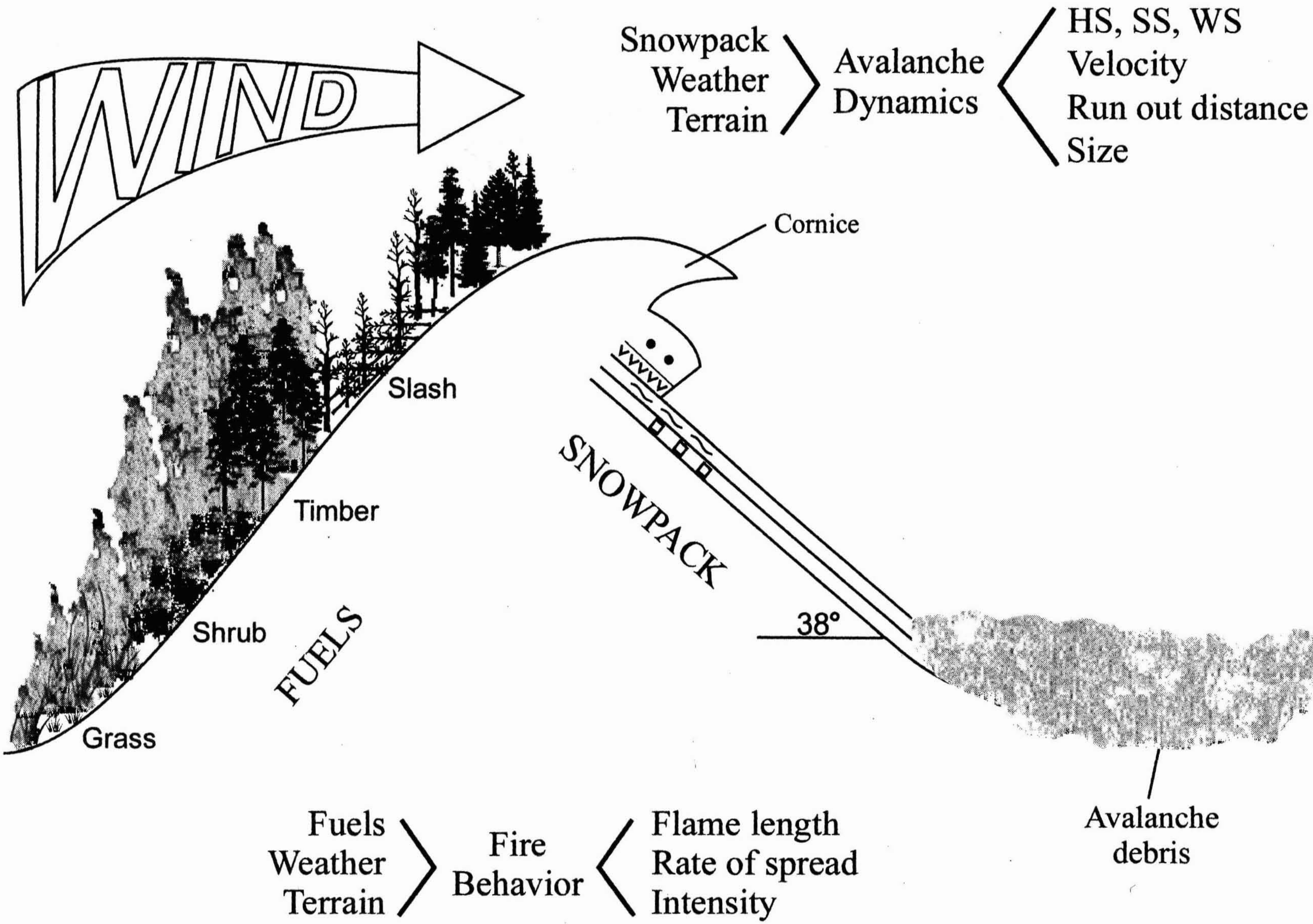

Figure 1. Conceptual model illustrating relationship between the physical parameters responsible for wildland fires and snow avalanches.

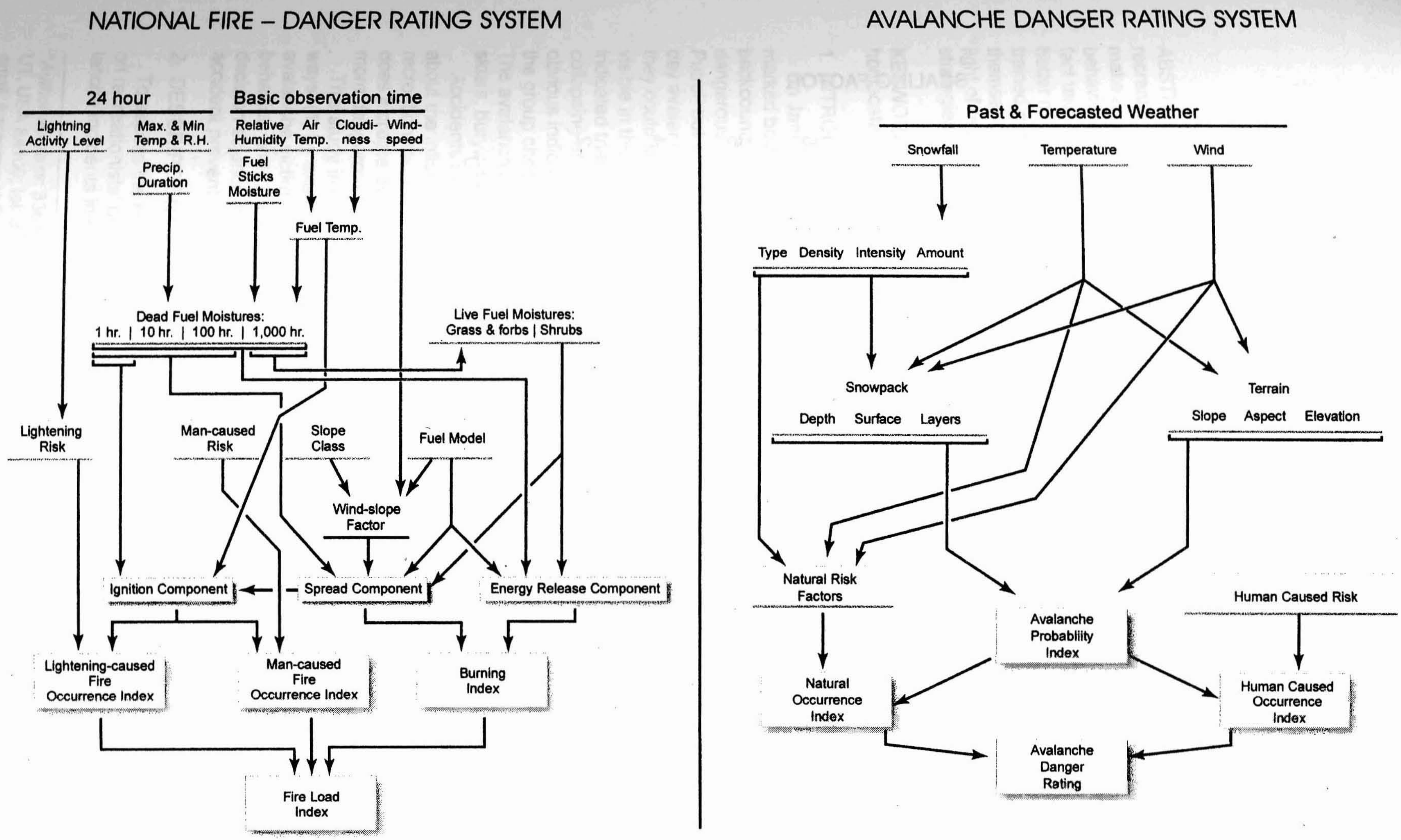

Figure 2. Flow charts relating physical and human risk variables for fire and avalanche danger rating.

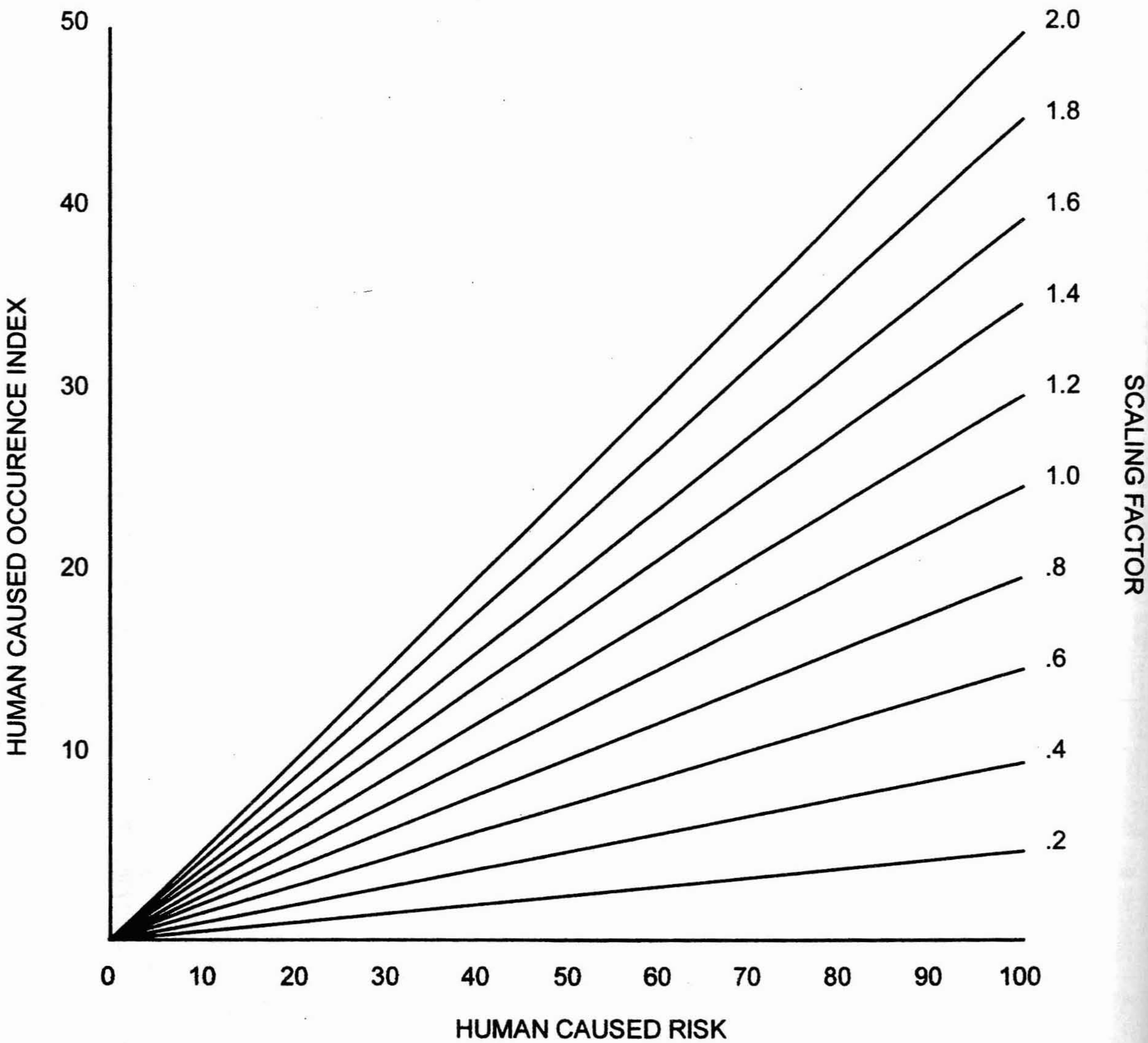

Figure 3. Nomogram used for deriving Human Caused Occurrence Index