THE MASS FIRE POTENTIAL OF URBAN STRUCTURE AND FORM

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STEPHEN WARREN SCHAR

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ABSTRACT

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by Stephen Warren Schar

This thesis addresses the potential for the spread of mass fire which exists in many urban areas. The specific physical pattern of each community possesses all the variants in form and structure possible, yet some of these forms and patterns create hazards to the effective provision of public safety and community needs. When the physical features of any community, by their congestion, deteriorating condition or mere distribution, create a block to the ability of fire departments to end the fire, then conditions of spread exist. In situations where uncontrolled fires join, mass fire is the result. It is the primary objective of this thesis to examine and identify the parameters which determine when, where, and how a fire can be expected to spread to mass fire proportions.

The parameters which are identified are all descriptors of the physical condition of the community as well as the atmospheric environment. It is shown that all parameters concerned with fire can be classified as either atmospheric conditions, fuel conditions, or topographical features. These three major classifications are examined for the elements which are critical in the spread of fire. Concepts of heat transfer by conduction, convection, and radiation are examined for pertinence to urban fire spread, and related to the types of fuels found "typically". These general mechanics by which fire spreads are related to the urban "fire environment".

The importance of the expected volume of the fire in relation to the expected water supply is discussed, and is shown important in the ability

of a community to contain the fire. The distribution of fire facilities is briefly discussed in relation to the distribution of residential and commercial areas of the community. Standards for the areal distribution of control forces as well as water supply are presented as derived by the American Insurance Association.

An important element in the identification of basic parameters for mass fire spread is the schedule for fire grading and rating applied by fire engineers in the determination of fire insurance rates. The importance of "conflagration breeding blocks" as derived from this table lead directly to the identification of those elements of the block's condition which make it a breeder. These elements are applied directly to the basic parameters of fire spread to provide descriptive fire spread parameters for an urban area.

The ten parameters identified for basic fire spread are refined to five directly applicable to areal description. This translation allows the author to present the parameters in the form of two models, as taken from fire research sources. The parameters of urban fire spread, as applied within the models, involve (a) the construction features of buildings and structures, (b) the likely configuration and intensity of initial fire, (c) the intensity of development of the area, (d) the expected atmospheric conditions, and (e) the fuel type. The models which result are directed at the Hazard within blocks, and the Spread between blocks.

These models are sensitive to differences in the types of land use found within blocks, the amount and kind of open space found, and the distribution of buildings within the blocks. The concern of planning in these three areas is no less important. Urban planning seeks to plan the physical development of the community along principles which respect the health, well-being, and safety of the community. This thesis identifies those parameters and <u>their</u> <u>critical</u> <u>values</u> which would enable a planner to determine the areas of maximum fire danger within the community.

Historical evidence of the occurrence of mass fire is cited as a justification of this topic's relevance to urban planning. The relevance lies chiefly, however, in the final determination of the importance of physical planning to the prevention or attenuation of conditions which cause fire spread in massive proportions. If individual fires spread through relatively high density areas because of unfavorable structural and design characteristics, a mass fire may logically be the result of inadequate physical planning and corrective action.

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By

Stephen Warren Schar

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

This thesis is directly concerned with the passive, but vital, role of urban physical form in the public safety of the community. The specific physical pattern of each community possesses all the variants in form possible, yet some of these forms and patterns create blocks and hazards to the effective provision of public safety and community needs. The extent of these restrictions, and their nature, are of the most urgent concern in the planning and provision of those services which deal with emergencies and the protection of life and property. Such emergency or public safety services generally include fire protection, law enforcement, pollution control, and civil defense.

The specific emphasis in this study deals with the violent, disastrous emergency of fire. In each municipality, the organization most directly involved with fire protection control and prevention is the fire department. Yet in either peacetime or wartime situations where loss of life or property may assume large and disastrous proportions, civil defense is also concerned. The factors which affect the operations or effectiveness of these two agencies will be our major interest.

The objectives of the fire protection function are generally considered to be (1) the prevention of fire starts: (2) the prevention of loss of life and property in the event a fire does start; (3) the confinement of a fire to the place of origin; and (4) the extinction of the fire. These involve the services of those trained in fire prevention and fire fighting. Both are strongly influenced in their effectiveness by the physical form of a community and its pattern of land uses.

The objective of this thesis is to examine, in depth, the critical parameters governing the spread of a fire of conventional magnitude to that of a mass or group fire. These parameters must,of course, include large human variables, such as the performance of fire department operations. As elements in fire spread, human errors merit much consideration. The focus of this study is upon physical, environmental variables however; and we shall, therefore, limit ourselves to a discussion of community structure as an element. Ambient fire conditions must be included, as we shall show.

The importance of this topic lies in its relevance to the intense urbanization of our society today. Fire cannot be considered a small danger to life and property in developed areas, especially in areas of high intensity of land use and structural development. People cause fires by commission or omission and, therefore, where people congregate so may fires be expected to develop. When a high probability of fire ignition is coupled with a dense distribution of "fuel," fire may be expected to spread. The extent of spread is our concern here. Our objective, as stated above, is a close examination of the urban structure as a fuel array, a spread determinant, and a critical parameter in the early attenuation of mass fire.

The treatment of mass as a fuel and space as a channel for heat flow are somewhat alien to the urban planner and designer. He is unaccustomed to having his well-structured setting of buildings and space referred to as fuel loads and fire breaks. This concept is the target of this study. Unless the urban planner is inclined to an understanding of the problems faced by disaster experts and pre-planners, he may well be working at cross purposes with them.

CHAPTER 1

THE CONCEPT OF MASS FIRE

The danger of uncontrollable fire exists in every area of the country, be it urban or non-urban. Destructive fires may vary in nature and size from those involving small amounts of fuel to some involving vast areas of combustible material. While small fires may be extinguished with little effort, the large-scale fire may continue to burn unchecked until the available fuel is consumed. Somewhere between the two extremes of scale an uncontrolled fire passes beyond the capabilities and investments of human control. Such instances are termed major fires. If, however, such fires involve several structures, areas or large quantities of combustibles at one time, the term "mass fire" is rightfully used.

Definitions

Three terms are commonly involved in the discussion of major fires. These terms are mass-fire, conflagration, and fire-storm. They differ significantly in physical behavior, conditions necessary for their propagation and continuance, and impact upon fire fighting efforts.

Mass Fire. Mass-fire is commonly taken to mean "a fire which occurs when a single fire extends to cause simultaneous burning of many individual structures or when several separate fires merge into a single fire involving a large number of buildings."[1] Mass fires need not involve only structures in urban areas, however. Forest fires frequently evolve into mass fires. Forest fires are, in fact, the most prevalent form of mass fire in this country today.

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[1] B.M. Cohn, L.E. Almgren, and M. Curless, A System for Local Assessment of the Conflagration Potential of Urban Areas. (Chicago: Gage Babcock Associates, Inc., 1965), p. 7.

Conflagration. The conflagration might best be defined as "a 'mass-fire' involving many simultaneously burning structures and having a moving front. The direction of spread is generally in the direction of the prevailing wind and is influenced by topography as well as by the availability of fuel and combustibles."[2] The point of importance here is the "moving front," generally in the direction of the "prevailing wind." Conflagrations, as a form of mass fire, can occur in both cities and forests. In both, the moving front is long compared to its width and ignites new fuel ahead of it and leaves smoldering ashes in its wake.

The designation of many large-scale fires as conflagrations is frequently improper. In general practice the term is applied only to fires extending over a "considerably large" area and destroying large numbers of buildings. It is best to use the term conflagration conservatively. For certain fires of a moving nature the term "group fire" may be more descriptive. These include fires within the limit of an industrial plant property even if several buildings are involved, and fires in a group of mercantile buildings, particularly within a single city block. In both such cases, buildings may be so close together that a fire may spread from some of the buildings to adjoining ones, but it is unlikely to spread outside the plant area because of fire wall barriers, streets, or other open spaces.

Conflagrations, as described by the above definition, generally take one of four different forms in urban areas. The first of these include fires which start in hazardous structures in congested and high building-density areas. These spread in one or more directions before being brought under control. These fires usually spread first to nearby structures of similar quality and chiefly spread in the direction the wind is blowing.

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[2] Ibid., p. 6.

A second type of conflagration includes fires which occur in primarily residential sections, and spread beyond control due to closely built combustible construction and wooden shingle roofs. Conflagrations which result from extensive forest and brush fires entering a municipality over a wide frontage comprise a third type. Finally, explosions and intense flame-out may result in fire over a wide area.[3]

Fire Storm. The fire-storm is the third of the large-scale fires. It is a mass fire which involves many simultaneously burning structures and has a stationary front. It is characterized by strong inward-rushing winds created by the incredible demand for oxygen to support combustion in a large area of fire. Complete destruction within the burning perimeter is the result. "Essentially all the fuel over the fire area is simultaneously ignited and simultaneously burns, producing a thermal convection column so strong that it completely dominates all normally important atmospheric factors. The very strong inflow of air at the periphery prevents any significant outward fire spread."[4]

Certain fundamental characteristics of a fire storm occur in any fire, but are seldom of the right combination to produce a fire storm even in large areas where a high density of combustibles exists. On a similar scale is the familiar column of smoke and superheated gases that rise over the fire, while air is drawn in at the sides. The difference is chiefly in the volumetric scale of the inward rushing wind, and its speed. In either case, total destruction is the result in the innermost area of the fire, in the area of most complete combustion. The "front," as it were, is

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[3]George H. Tryon, Editor, Fire Protection Handbook, Twelfth Edition, (Boston: National Fire Protection Association, 1962), pp. 1-56, 57.

[4]National Academy of Sciences - National Research Council, A Study of Fire Problems, (Washington: The Academy, 1961), p. 24.

concentrated on the rising column of flame and hot air. Although certain buildings or areas may escape destruction in a conflagration (due to convection currents, fire barriers, or fire fighting efforts), near complete destruction is the result of the fire storm.

One of the major factors necessary for the creation of a fire storm is the simultaneous ignition of many fires, and their joining. This requirement was used during World War II on several German and Japanese cities. In Dresden, Hamburg, Leipzig and a few other cities, fire storms occurred with great loss of life. These fire storms were the result of the merging of thousands of individual building fires. They were started by saturation incendiary bombing with a mix of high explosives to "open up" the structures to fire bombs.

In one of these fire storms, the heavily built-up areas of the city were blanketed with a high density of incendiary bombs and high explosives. Within minutes of the first attack with these weapons, roughly two-thirds of the structural units within a four and one-half square mile area were burning. This entire area developed as one mass fire. A vertical heat column developed over the central area in the absence of a strong ground wind. This thermal column was estimated to have attained a height of more than two and one-half miles with a diameter of one and one-half miles. The rapid upward movement of "superheated smoke and burning vapors in the thermal column induced strong indrafts of air from around the entire perimeter of the burning area. Streets entering the burning area became air intake channels. The inrush of air through these channels assumed gale-like proportions."[5] Within forty-eight hours, complete destruction was accomplished.

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[5]Lloyd Layman, First Fire Research Correlation Conference, (Washington: National Academy of Sciences - National Research Council, 1957), p. 8.

Control of Mass Fire

There are several essential differences between peacetime and wartime mass fires. These shall be discussed briefly later. Their similarity rests upon one point, however. That is their effect upon fire fighting capability which is geared to fighting normal fire problems. Prominent fire-research groups have concurred in the philosophy that fire-control action which can minimize the effects of these disasters involves concepts inherent in most fire control practices today, but with added emphasis on pre-planning and hazard reduction.

Such pre-planning might be directed along lines involving "(1) the reduction of the number of potential ignitions, (2) the provision for isolation or rapid extinguishment of fire starts to prevent formation of serious fires, and (3) the minimization of fire-spread potential should large-scale fires be produced."[6] It should readily be apparent that in situations in which equipment and/or manpower is incapacitated or insufficient to meet all fire starts, the form of the urban area itself may become the most effective deterrent to further fire spread. Not only should it be possible to reduce the probability of large-scale fire spread through development principles, it is conceivable that once fires threaten to spread, their effects might be minimized through the passive nature of urban design.

The mass-fire problem can certainly not exist in all urban areas. We shall later examine the reasons why. What is important to realize from the very beginning, however, is that the physical urban form, as shaped by natural land forms and man-made development, is a prime determinant of the relative danger of mass fire.

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[6]National Academy of Sciences, A Study of Fire Problems, p. 24.

CHAPTER II

THE URBAN MASS FIRE

The uncontrolled spread of fire within human settlements is by no means a recent phenomenon. The first recorded conflagrations and mass fires occurred as far back as 2000 B.C., and reportedly destroyed Sodom and Gomorrah. Troy was razed by fire, and prior to the Christian era, Rome suffered six great fires. Rome's worst conflagration occurred in 64 A.D., and reportedly lasted seven days. London has likewise had its share. As early as 1086, the city has been reported to have burned from one end to the other. The Great Fire of London in 1666 destroyed 13,200 houses and many important buildings. That fire, which continued for five days, was fought with little else than buckets, swabs, and little two-quart hand squirts.[7]

Fire Loss

There can be little doubt that the factors which led to such large-loss fires included the building methods of the day, and inadequate fire control facilities. One would expect that the relatively sophisticated fire control equipment and building controls of today would make the mass fire much less of a danger. Such a conclusion is contrary to fact. Fire losses in the United States annually run in excess of $1.8 billion. In 1966, losses included an estimated $1.5 billion damage to buildings and contents, and another $.3 billion to vehicles, forests, and other property. Deaths from fire numbered 12,100.[8] Much of this property loss, it must be noted, occurred in fires which can be classified as mass fires.

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[7]Layman, p. 9.

[8]Percy Bugbee, "Fire Administration," The Municipal Yearbook 1967, Orin F. Nolting, Ed., (Chicago: International City Managers Association, 1967), p. 374.

During the period from 1926 to 1961 conflagrations and mass fires in the United States and Canada caused destruction to "more than 6000 buildings."[9] Table B-1 in Appendix B, lists some selected mass fires and conflagrations in the United States and Canada since 1910. Conflagrations are still possible, especially so when the elements discussed in the previous chapter occur in the correct proportions. The relative infrequent occurrence of the conflagration in proportion to the total number of building fires may tend to provide a false sense of security. It can be seen from close examination of Table B-1 that many of the major fires occurred in relatively small communities. There can be little doubt of their economic and psychologic impact upon those areas.

This chapter is devoted to a study of the urban fire environment. The reasons the fires in Table B-1 became conflagrations are therefore important, for they shed valuable light on the means of controlling the spread of mass fire. A study of the causes of spread of all the major mass fires in the United States and Canada from 1900 to 1961 reveals the major elements in the spread of these fires. Table 1 below lists these for the periods 1901-1925, 1926-1961, and 1901-1961.

Note should be made, in examining fire loss tables, of elements of inflation in monetary value, of increased fire reporting and recording skill and accuracy, of changing definitions of loss typologies and categories, etc. The point to be taken, however, is that despite our technological improvements, fires are still capable of running uncontrolled and destroying dozens of lives, hundreds of buildings and structures, thousands of acres of forest land, and millions of dollars of real and personal property.

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[9]Tryon, pp. 1-58.

TABLE 1

PRINCIPAL FACTORS CONTRIBUTING TO CONFLAGRATIONS IN THE UNITED STATES AND CANADA SINCE 1900

	Factor	Number of Times Contributive			Proportion of Total		
		1901 to 1925	1926 to 1961	1901 to 1961	1901 to 1925	1926 to 1961	1901 to 1961
1	Wood shingle roof	45	24	69	25.4	9.2	15.7
2	Wind velocity greater than 30 m.p.h.	22	40	62	12.5	15.3	14.2
3	Inadequate water distribution system	23	32	55	13.0	12.2	12.6
4	Lack of exposure protection	18	29	47	10.2	11.1	10.8
5	Inadequate public protection	23	22	45	13.0	8.4	10.3
6	Unusually hot or dry weather	4	22	26	2.4	8.4	5.9
7	Delay in giving alarm	5	13	18	2.8	5.0	4.1
8	Congestion reduced fire fighting access	5	12	17	2.8	4.6	4.1
9	Delay in fire discovery	4	14	18	2.4	5.3	4.1
10	Forest or brush fire entered town	2	10	12	1.0	3.8	2.7
11	Failure of water supply	5	6	11	2.8	2.3	2.5
12	Ineffective fire fighting	4	6	10	2.4	2.3	2.3
13	Inadequate private fire protection	1	9	10	0.5	3.4	2.3
14	Fire department at other fires	4	3	7	2.4	1.1	1.6
15	Hidden fire spread	2	4	6	1.2	1.5	1.4
16	Severe winter conditions	2	3	5	1.2	1.1	1.1
17	Earthquake, floods, hurricane	1	3	4	0.5	1.1	0.9
18	Non-standard hose couplings	2	1	3	1.2	0.3	0.7
19	Rags stored outside buildings	2	1	3	1.2	0.3	0.7
20	Burning brands from lumber yard	0	2	2	0	0.6	0.5
21	Dry vegetation near buildings	0	2	2	0	0.6	0.5
22	Explosion of liquified natural gas	0	1	1	0	0.3	0.2
23	Explosion of ammonium nitrate	0	1	1	0	0.3	0.2
24	Slow response of fire department	0	1	1	0	0.3	0.2
25	Fire alarm failed	1	0	1	0.5	0.0	0.2
26	Explosion of explosives truck	0	1	1	0	0.3	0.2
		177	262	437	100%	100%	100%

Source: Fire Protection Handbook, Twelfth Edition, 1962. N.F.P.A., p. 1-64.

Fire Spread Contributors

Wood shingle roofs have been the largest single contributor to conflagratory fire spread since 1900. However, the enforcement of building codes, and general changes in construction methods in recent decades have undoubtedly lessened the importance of this factor. When viewed as a characteristic of a special "fuel," the flammability of the exposure surfaces of a building or structure is of major concern--not only to the protection of that structure--but to the prevention of fire-brand ignition and creation.

It is important to note that the NFPA statistics show the contribution of wood shingle roofs to conflagration to be diminishing, while the "lack of exposure protection" is shown to be increasing in importance as a parameter. Exposure protection relates to the variables of distance (from an exposed structure to a fire source) and construction material and type on the exterior building surface. Both parameters pertain to fuel characteristics, and both are subject to building restrictions and legal standards.

Wind velocity is (Table B-2) a prime determinant in mass fire spread. It would not seem reasonable to assume that wind speed has increased over the years, but more likely that investigatory methods after mass fires have become more thorough and scientific. The importance of wind in spreading forest fires is well documented. The chief value of Tables 1, B-2, and B-3 lie in the presentation of relatively stable elements in the spread of mass fires. Those variables which have decreased within the last four decades have been subject to public regulation and physical planning. As the public services of a community are improved, the public safety likewise improves. The improvement of the fire insurance based "rating and grading schedule" for communities has allowed municipalities to compare their general "fire environment" with that of other areas, and so improve along certain areas. Failures in control practices have, therefore, decreased in importance. We will later document the importance of "mutual aid" in achieving greater fire fighting ability.

Factors not immediately subject to improvement (Table B-3), such as weather conditions, have subsequently risen in importance as spread parameters. In communities relatively isolated from other urban areas, the danger of uncontrolled rural fire entering the town is of vital concern. An example of such would include the destruction of isolated southern California subdivisions by forest fire.

The congestion of large urban areas has frequently contributed to the spread of fire by delaying the arrival of sufficient fire control forces.[10] In addition, the inaccessibility of buildings in highly developed areas has not only hampered control efforts, but increased the possibility of transfer of fire by mass. Despite these conditions, however, a high percentage of fires do not reach mass-fire proportions. Table B-4 presents the average building fire loss as being approximately $1342 in 1967. The annual loss per capita by fire amounts to approximately $5.90. This seems a relatively small amount, unless you multiply it by 180 million persons. The size of a community can be an important variable in the amount of fire loss which might result. Quite often the generally higher fire control capability of larger urban areas, and the greater reliability of water supply are important fire loss factors. The per capita fire loss in 1967 for communities under 20,000 persons was $8.24, as compared to $5.90

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[10] Such delay has not always been the result of congested auto traffic and such as found under normal operating conditions. Under conditions of riot and civil disorder, as existed in the Watts uprising in August, 1965, the presence of rubble in the streets, burned automobiles, and the kindling and re-kindling of numerous fires present monumental problems to fire services. - See H.F. Jarrett <u>Fire Data from the Watts Riot: Results of Preliminary Analysis and Evaluation</u>, (Santa Monica, California: System Development Corporation, May 10, 1966).

for those over 20,000 in size. Larger cities had fewer building fires per 1000 population as well as a lower average building fire loss.

CHAPTER III

THE URBAN FIRE ENVIRONMENT

One of the prime determinants in the potential magnitude of a fire is the size of the area vulnerable to the rapid spread of fire. In repeated instances in past years, large-loss fires have involved extensive areas, thus placing the distance fire will spread among the first parameters of concern. The horizontal distance of possible fire spread is not the only dimension of concern. The entire fire envelope, a cubic space, must be considered. This cubic space is most frequently bounded by structural members, as in a building fire, but in the case of fires which spread beyond a closed environment, the stratification of atmospheric conditions might conceivably create an effective wall or ceiling for the fire envelope.

Fire Volume and Area

In the "usual" instance of an urban fire, active control measures will be brought to bear. The effectiveness of fire fighting methods and proper use of extinguishing agents are important factors in controlling the spread and volume of fire. The exposure planes of a fire when considered as a volume or cubic mass, rather than as a strictly linear function, carry geometrical growth implications relating to both distance and intensity of heat radiation. An examination of large-loss fire statistics will indicate that the majority of large-loss (implying an individual loss of $250,000 or more) structural fires may be expected to occupy more than 100,000 cubic feet in volume.[11] Such a volume, when abstractedly considered as a fire envelope, can be seen to present large exposure planes for both radiative spread and control measures. In this vein, the National Fire

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[11] Warren Y. Kimball, "Control of Large-Loss Fires," Fire Journal, Vol. 62, No. 6, November, 1968, p. 73.

Protection Service has indicated that 25,000 cubic feet is approximately the maximum volume in which fire can be readily controlled and extinguished with manual application of fire hose streams.[12] The availability of additional water for control has been of little effect, since the requirements of volumes greater than this size outweigh the ability of control groups to provide effective application.

Table B-6, abstracted from the Kimball NFPA study, presents data gathered on 396 large-loss fires in the United States in 1967. It can be determined from the table that in excess of 78 per cent (243 of the 311 fires where area could be determined) of the large-loss fires resulted in loss of greater than 80 per cent of the property involved. Of these, 23 per cent caused extensive damage to other areas as well. The 80 per cent destruction mark was taken in this study to indicate whether or not the fire fighting forces were able to control the fire in the immediate areas of involvement. Significantly, Kimball states that the majority of fire fighting effort in these fires was aimed at protecting the exposure faces of adjacent areas.[13]

Water Supply

A prime purpose of the application of water to fires concerns the lessening and absorption of the heat of the fire area. A usually acceptable standard of one gallon per minute per 100 cubic feet of fire area is seen necessary for efficient containment and cooling of fire by hose streams.[14] Kimball states, however, that it is not unusual for fire fighters in urban areas, where supply and flow are ample, to apply water at the density rate

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[12] Ibid.

[13] Ibid., p. 74.

[14] Ibid., p. 76.

of four or more gallons per minute per hundred cubic feet of involved fire envelope. Under fire conditions in the presence of large-volume, large-area fires, as shown in Table B-7, the water application rate does not as a rule even approximate the one gallon per minute per hundred cubic feet ratio. In fact, in only 20.4 per cent of the cases reported by Kimball did the water density equal or exceed the 1.00 g p m mark necessary for cooling and extinguishing the fires. The efforts of fire fighters in such instances must be limited to the protection of exposure faces, and the blocking of further expansion. Reflection as to the large number of fires involving in excess of 80 per cent loss (Table 7) would lead one to suspect that the inability to deliver enough water to the right place at the right time is crucial to the spread and size of major fires. Had more water been available, fire fighters would in all likelihood have applied it at greater densities.

Several reasons for the failure or inadequacy of water supply under heavy draught conditions are presented by Kimball.[15] In more than 20 per cent of the instances involving fires in properties protected by public or private water systems, inadequate supply at the hydrants was listed as a problem. These hydrant deficiencies were found to include four chief factors:

1 - Excessive distance to hydrants from fire site

800 to 1500 feet or more

2 - Poor hydrant distribution

3 - Nearby hydrant fenced or locked

4 - Inadequate hydrant connections

Fire hydrant inadequacy is by no means a new problem. Yet it can be generally stated that lay opinion holds that fire hydrants are

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[15] Ibid.

"everywhere" and well distributed. There is ample evidence to indicate that many recent shopping center and industrial development sites are not as well protected as they might be. Kimball cites instances of long hose lays necessitated by fenced or "protected" hydrants--lays of as much as 1500 feet.

> "That delay (caused by the need for long hose lays) was considered one of the principal reasons for the loss of the plant. At another fire, in a large university dairy barn, only one hydrant was provided on a large water main. Although the hydrant was used to capacity, the amount of water applied on the fire was needlessly limited." [16]

The importance of water supply, and adequate distribution of hydrants cannot be overstressed. Table B-8 indicates, however, that although inadequate water supply at hydrants is chief among reported supply deficiencies, laxity of upkeep, inattention to safety precautions, and other human factors are of recurring importance.

Mutual Aid

The majority of large-loss fires in 1967 were fought by more than one fire department. The fire services' concept of mutual aid, with application also to civil defense is applied daily by large as well as small communities to augment and bolster their physical and human fire resources. This mutual aid from neighboring communities must be supported by a water supply system at the fire scene capable of meeting the demands of multiple units. Kimball states that it is clear that those responsible for the foresight of mutual aid plans frequently neglect to plan and provide an adequate fire flow to implement their plan. The plan, which on paper seems adequate, is sometimes inadequate in practice. In such cases, the result is a waste of manpower and equipment.

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[16] *Ibid.*, p. 75.

Where water supplies are adequate, a good mutual aid system can generally give a small community the emergency resources needed. Table B-9 presents the mutual aid response to the 1967 large-loss fires reported by Kimball. In 54.5 per cent of the reported fire cases, mutual aid response was used. Conversely, however, this ability of nearly every community to gather resources much in excess of its normal capacity may be responsible for a major problem at many large-loss fires. The ability to rapidly mobilize pumping and tanking capacities may be a causal factor in the inadequate provision of water storage and consequent flow.

The implications of an inadequate water supply and a greater dependence on mutual aid are broad for mass-fire situations. Such mass-fire situations may require wholesale protection of mile-square areas. The protection of exposure flanks under such conditions, even assuming ideal atmospheric conditions, will necessarily involve a massive water supply as well as a high level of mutual aid. The lessening of a community's ability to provide either of these control elements will require a reliance upon some other element of protection--an element which will not vary with deployment decisions but remain an integral part of the community's form.

We earlier spoke in terms of fuel needs, fuel density, and the like. These basic fire needs may well present the opportunity for the least expensive and most reliable form of mass-fire protection. I refer, of course, to the living pattern, the development pattern of the community. Adequate building codes, together with effective inspection and strict enforcement provide the basis for a good fire prevention program for the community. The spacing requirements of all types of structures have been researched and studied quite carefully in terms of individual structures. What has not been so carefully researched is the overall distribution of the urban "fuel" in terms of its mass-fire capability. The density of development, and the "strategic" separation requirements of buildings and structures, are of importance both in terms of fuel spread and protection distribution. One need not think in terms of nuclear holocaust to realize the importance of fire protection unit deployment.

Fire Departments

The degree of overt fire protection afforded a city is not so much a function of its population as of its density of population and the intensity and value of its developed property. As a corollary statement, people cause fires, reflecting the direct proportionality of an area's fire "frequency" to the density of its population. Within cities and among cities, however, the population density varies widely. Among the cities in the United States with population in excess of 500,000, the population per square mile varies from 2,000 to 25,000 persons.

Unquestionably, population density is related to land use, as is the value of developed property in monetary terms. Areas with intense population densities, implying much built-up land, multi-story dwellings, and buildings of all types present a potential fire hazard. In light of these concerns, Kimball points out that

> "the average resident population per fire department pumper company in New York City is 37,200 persons and per ladder truck company, 61,500. A first-alarm response of four pumper and two-truck companies involves fire companies protecting an average of approximately 15,000 persons. These fire companies cover an average of about six square miles."[17]

Table 2, below, presents the relationship between fire department coverage and population density for twenty of our most populous cities.

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[17] Warren Y. Kimball, "Population Density and Fire Company Distribution," *Fire Journal*, Vol. 59, No. 2, March, 1965, p. 39.

TABLE 2

RELATIONSHIP OF FIRE DEPARTMENT COVERAGE TO POPULATION DENSITY - 1963

City	Population (000)	Land Area (Sq. Miles)	Population Per Sq. Mile	Average No. of Building Fires Per Sq. Mile	Sq. Miles Per Pumper Company	Sq. Miles Per Truck Company
New York	8,000	315	25,500	98	1.47	2.4
Chicago	3,551	224	15,900	94	1.87	3.6
San Francisco	740	47.6	15,600	71	1.01	2.6
Philadelphia	2,000	129.7	15,400	45	1.87	4.3
Boston	697	47.8	14,600	45	1.06	1.7
Buffalo	533	39.4	13,600	53	1.31	2.6
Washington,D.C.	800	61.6	13,000	51	1.93	3.6
St. Louis	750	61	12,300	59	1.42	2.6
Baltimore	939	78.7	12,000	52	1.35	2.6
Detroit	1,670	139.6	11,900	45	2.73	4.6
Cleveland	876	78	11,200	41	2.05	4.3
Pittsburgh	604	54.1	10,700	28	1.04	1.4
Milwaukee	741	91.1	8,100	21	2.27	4.3
Cincinnati	503	76	6,600	29	2.00	5.0
Seattle	557	88.5	6,300	13	2.40	8.0
Los Angeles	2,480	458	5,400	16	4.20	12.0
New Orleans	628	119	3,100	9	4.15	16.6
Houston	938	354	2,600	12	6.47	19.7
Dallas	680	279.9	2,400	9	5.81	23.4
San Diego	573	284	2,200	6	10.50	94.5

Source: Warren Y. Kimball, "Population Density and Fire Company Distribution," Fire Journal, March, 1965, p. 40-41.

Cities with population densities in excess of 12,000 persons per square mile average well under 2 square miles per pumper company. In cities with population densities under the 12,000 figure, the average coverage per pumper company is well over 2 square miles. A notable exception, Pittsburgh, has topography requiring much closer coverage, resulting in a 1.04 square mile per pumper company.

The distribution of truck companies is, of course, related to the number of multi-story buildings and structures in a given area. The median distribution of ladder truck companies for these twenty cities is one truck company per 50,000 people and for each 4.3 square miles. Dallas has one truck company for each 23.4 square miles and each 56,700 persons. Boston, on the other hand, maintains one truck company for every 1.7 square miles, and each 24,800 persons. Policy in Boston requires, however, that two trucks respond to every first alarm building fire. This would imply then that Boston's truck coverage is based on 3.4 square miles and 49,600 persons.[18] The determinant of the "doubling" here is undoubtedly the degree of congestion and structural quality. Both these factors have been previously mentioned as crucial in the distribution of fuels as well as protection units.

Department Distribution Standards

The American Insurance Association (AIA), which succeeded the National Board of Fire Underwriters (NBFU) in 1965, has revised the distribution standards for fire companies. Prior to 1963, the response distances were predicated upon the type of district (high-value of residential) to be protected, but revised standards are now also dependent on the volume

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[18] Ibid., p. 40.

of water (fire flow) required. Because of general improvements in streets, equipment and other factors, the standard response distances have also been adjusted.

The standard response distances depend to a large degree upon the ability of public water systems to supply sufficient volumes of water at hydrants. The AIA's Safety and Engineering Division, in reappraisal of standards, formulated a schedule for water system adequacy based on "average" conditions in communities of varying sizes. These standard required fire flows are presented in Table B-10. It is deemed essential by the AIA that in setting required fire flows consideration must be given to the congestion of buildings and structural conditions in the district under consideration. If conditions of these two variables warrant, the required flows may be adjusted accordingly. The AIA does not ignore the differences between residential and high-value (commercial and industrial) districts, either.

> "For districts other than residential, outside the high-value district considered, the required fire flow shall be considered on the basis of structural conditions and the congestion of buildings and . . . the required duration shall be as indicated for four to ten hours . . . For residential districts, the required fire flow shall be determined on the basis of structural conditions and congestion of buildings. In districts with about one-third the lots in a block built upon having buildings of small area and low height, at least 500 gpm is required; if the buildings are of larger area or higher, up to 1000 gpm is required; where districts are more closely built or the buildings consist of high-value residence, apartments, tenements, dormitories, or similar structures, 1500 to 3000 gpm is required, and in densely built districts with three-story and higher buildings, up to 6000 gpm is required."[19]

These capacities, as well as those required by Table B-10, do not ignore the concept of area served, however. Adequacy cannot be considered only a function of the total supply of water deliverable to a district, but must also consider the number of hydrants available as outlets.

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[19] James F. Casey, Editor, The Fire Chief's Handbook, Third Edition, (New York: Reuben H. Donnelly Corporation, 1967), p. 66.

The use of excessively long hose lines reduces the water pressure as well as limiting flexibility of control efforts. Prior to 1963, the NBFU conducted a study on the placement of hydrants, in which they expressed a preferance for the area-served distribution rather than the lineal spacing method. The AIA adopted these proposed figures for spacing as shown in Table B-11. Implicit in these figures is the variation based not only on community size (reflecting the overall demands on the water system and the probability of multiple fires) but on the degree of high-value development (which may result in lowered water pressures and an inadequate fire flow) and the physical congestion more likely to be found in higher level communities. In addition, the use of automatic sprinklers in high-value commercial and industrial structures is now commonplace. The AIA has recognized the supply to these sprinklers can be taken from the municipal water mains without providing for a secondary supply. This use of primary supplies may present problems of system failure in older structures, necessitating changes in supply procedures. Each such change affects the total effectiveness of the water system.[20] The importance of the fire flow available in any response district has become a prime factor in pre-planning for fire actions as well as the placement of pumper and truck companies.

The AIA has set the following standards for the distribution of fire companies.[21]

> "<u>High-Value Districts</u>. The standard response distance. . . is now 1½ miles for districts requiring fire flows less than 4500 gpm. The standard distance is 1 mile for districts requiring fire flows of 4500 gpm or greater but less than 9000 gpm. The standard distance is 3/4 mile for districts requiring fire flows of 9000 gpm of more.
>
> "The standard response distance for the first-due ladder company. . . is 2 miles for districts requiring . . .

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[20] <u>Ibid.</u>, p. 68.

[21] <u>Ibid.</u>, p. 71.

less than 4500 gpm. The standard . . . is 1½ miles for districts requiring . . . 4500 gpm. . . but less than 9000 gpm. The standard distance is 1 mile for districts requiring fire flows of 9000 gpm or more.

"Residential Districts. The standard response distance is 2 miles for the first-due engine company and 3 miles for the first-due ladder company. For sparsely built residential districts with buildings having an average separation of 100 feet or more, the standard response distance for both engine and ladder service is 4 miles. For closely built residential districts requiring more than 2000 gpm fire flow or having buildings three or more stories in height, including tenement houses, apartments or hotels, the standard response distances are 1½ miles for engine companies and 2 miles for ladder companies, but are to be reduced to 1 and 1½ miles, respectively, when the life hazard is above normal."

Fire Environment Grading and Rating

The emphasis which we have placed on the provision of adequate water supply and fire company distribution is not only of concern to pre-fire planning. It is reflected strongly in the municipal fire grading and rating system used by insurance companies in determining fire insurance rates. The Standard Schedule for Grading Cities and Towns of the United States with Reference to Their Fire Defenses and Physical Conditions is administered by the AIA. It classifies communities on a relative basis. Under its classification system, a Class 2 city is a better risk than a Class 3 city, but poorer than a Class 1 city. Revision is periodic, and generally thorough. Table 3, below, presents an abbreviated listing of the items of concern to fire engineers.

Correlation to Community Population

For various reasons, the determination of classification for a city has had strong correlation to the ranked size of that community. Figure 1 purports to show a significant relationship between insurance classification and population growth. As a relatively small and unprotected

TABLE [illegible]

INTER-RELATIONSHIP AND COMPOSITION OF MUNICIPAL CLASSIFICATION AND

TABLE 3

INTER-RELATIONSHIP AND COMPOSITION OF MUNICIPAL CLASSIFICATION AND

SPECIFIC FIRE INSURANCE RATES

General Area of Concern	Municipal Grading Schedule: Number of Items of Specific Concern	Relative Value	Deficiency Points	Rating Schedule
Water Supply	32	34%	1700	
Fire Department	34	30%	1500	Town Grading
Fire Alarm	23	11%	550	+ Construction
Building Laws	4	4%	200	+ Occupancy
Fire Prevention	8	7%	350	+ Hazards
Structural Conditions	17	14%	700	+ Exposures
Climatic Conditions	5	---	---	+ Private Protection
Divergence	1	---	---	
Totals	127	100%	5000	= FINAL RATE

AIA CLASS		1	2	3	4	5	6	7	8	9	10
Points of Deficiency	FROM —	0	501	1001	1501	2001	2501	3001	3501	4001	4501
	TO —	500	1000	1500	2000	2500	3000	3500	4000	4500	5000

Source: James F. Casey, The Fire Chief's Handbook, New York: Reuben H. Donnelly, Inc., 1967, p. 64.

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town, a community is likely to be in Class 9 or 10. As a village with some water supply and a fire department, it may find itself in Class 7 or 8. As general improvements are made and municipal services are added, the classification tends to advance toward Class 3. Table 4, below, presents data for 1967, and would tend to support the general conclusions one might draw from Figure 1. In 1967 only 18 cities (out of the 1542 reporting) are in Class 2. No cities qualify for Class 1, chiefly because of "deficiency points resulting from a failure of cities to provide specific restrictions on building construction."[22] A further element was "climatic" conditions, which create greater fire spread risks and mobility problems.

It is important to remember that the variations in achievement by different communities as measured by the fire defense grading is as much dependent on the city's financial and provision of public service status as its physical improvements. Fire protection is still a community service, and as such, is subject to variances in management, internal pricing and allocation of resources, and changes in municipal policy. The point is that the sudden demands of a large scale mass-fire emergency are much more likely to be successfully met by a well-run fire protection system in a well-graded city. In that the adequacy of the municipal water system and the responsiveness of the fire agency represent nearly 65 percent of the grading scheme, (Table 14), a high rating may be taken as a good approximation of ability to meet the disaster.

As a counter to this point, however, it must be noted that the "preparedness" parameter is only one of a dozen which determine the extent of mass fire spread. The contingencies which inevitably result in any

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[22] Orin F. Nolting and David S. Arnold, Editors, Municipal Year Book, 1967, (Chicago: International City Managers Association, 1967), p. 392.

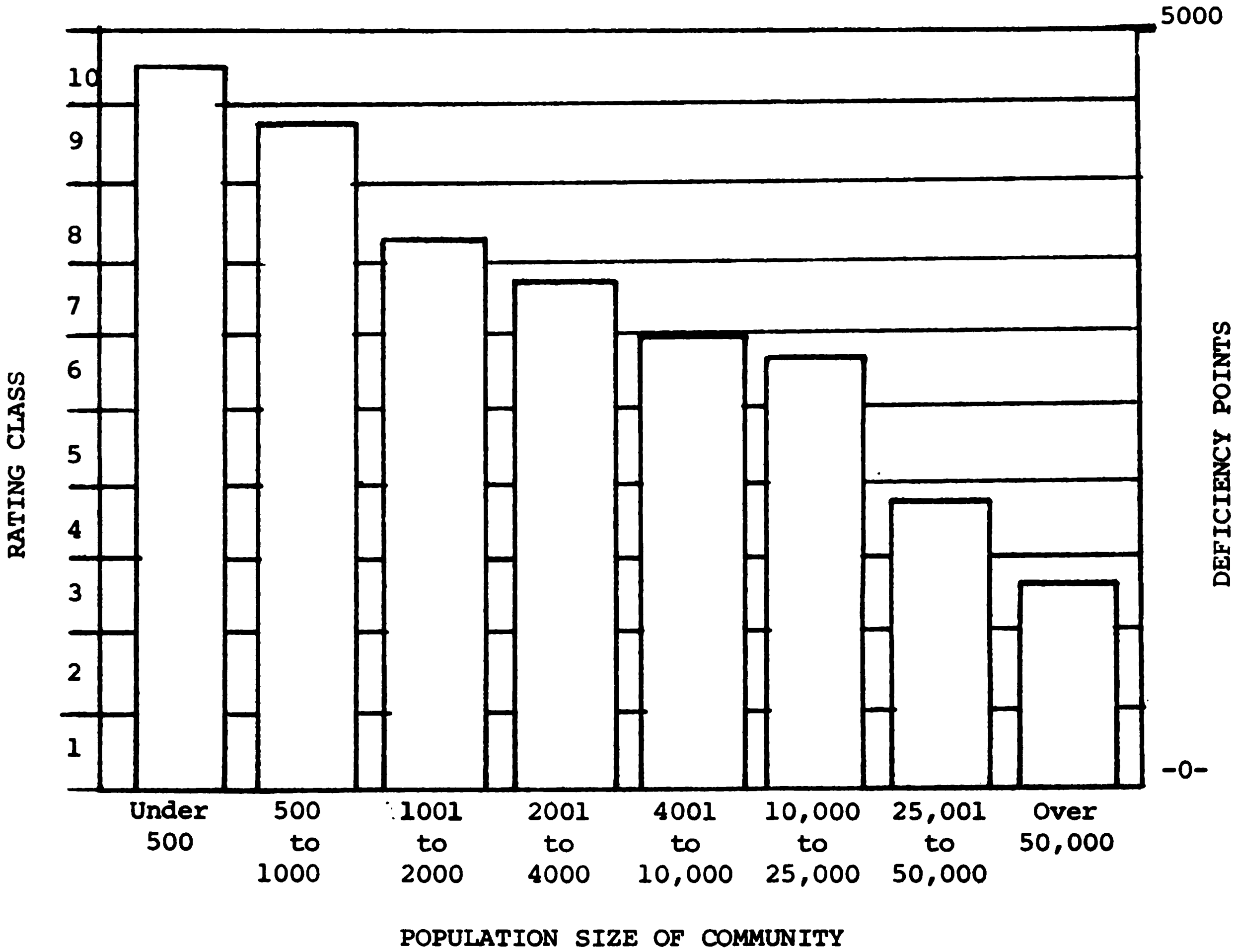
RATING CLASS

Figure 1

Average Insurance Rating Class

By

Community Size



NOTE: CLASS 1 insurance rating reflects the highest possible fire preparedness, CLASS 10 the lowest.

Source: The International City Managers Association, *Municipal Fire Administration*, (Chicago: The Association, 1956), p. 32.

TABLE 4

DISTRIBUTION OF CITIES OVER 10,000 ACCORDING TO TOTAL FIRE INSURANCE CLASSIFICATION

			Population of Reporting Cities by Class					
Fire Insurance Class	Reporting Cities in Each Class	Percentage in Each Class	Cities over 500,000	250,000 to 500,000	100,000 to 250,000	50,000 to 100,000	25,000 to 50,000	10,000 to 25,000
1	0	0.0%	0	0	0	0	0	0
2	18	1.2%	10	4	1	3	0	0
3	183	11.9%	10	21	38	57	37	20
4	311	20.2%	1	0	30	55	109	116
5	420	27.2%	0	0	6	43	120	251
6	445	28.8%	0	0	1	13	86	345
7	139	9.0%	0	0	1	3	16	119
8	25	1.6%	0	0	0	0	1	124
9	1	0.1%	0	0	0	0	0	1
10	0	0.0%	0	0	0	0	0	0
Total Reporting	1,542	100.0%	21	25	77	174	369	876

Source: The Municipal Year Book, 1967, International City Managers Association, Chicago, 1967, p. 392.

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emergency can easily offset the ability of a water supply to adapt to large volume demands. The elements of community form and structure are fully considered in the AIA fire defense grading schedule. When combined with building law considerations, the structural conditions of a community account for 18 per cent of the final municipal grading.

Structural Condition of the Community

The 14 per cent of the fire defense grading schedule allotted to structural conditions is designed to be applied in a "district" wide manner of study. In large cities, a separate grading may be applied to each high-value district; in smaller cities, it is designed for application to the principal commercial, high-value area. The important factors used for the grading of this section include the size of the area or district bounded by fire breaks or elements of the city's form which will act as fire breaks, the widths of streets, and the accessibility of blocks. Narrow streets, the inaccessibility of buildings, congestion of the district and of individual blocks, poor general structural conditions and exposures from surrounding sections all increase the probability of sweeping fires. Buildings of fire resistant construction, sprinklered brick buildings, fire breaks, and fire barriers all tend to constrict a spreading fire.

Briefly, then, the important elements of the structural conditions division of the AIA fire defense grading schedule are as follows:

1. The Area of the District. Since an undivided area increases the probability of fire spread, breaks and barriers in the area are important. To be recognized as substantial breaks the specific breaks should have a total width of at least 150 feet. Such breaks would include rivers, parks, streets, railroad tracks, vacant land, railroad embankments, depressed or raised freeways,

and possibly groupings of mutually supporting fireproof or sprinklered structures which effectively subdivide a district. Since overall size of the subject district is important, deficiency points are allocated for areas greater than 10 acres in size. For example, a 50-acre contiguous district is assessed 4 points, while a 400-acre contiguous district is charged with 50 deficiency points.[23]

2. Street Widths in the District. The critical street width dimension for grading purposes is 50 feet. Where buildings are uniformly set back of the street line, the width of the street may be "assumed" (in the schedule's terminology) as the distance from building front to building front. Deficiency points are charged on the basis of the percentage of total street length within the district of width less than 50 feet. For instance, "for each 10 per cent of total length 50 feet wide or less, assess 5 points."[24] Such factors as street widths in high value districts may be seen as having mixed value, especially when viewed in light of the wide range of construction materials possible, window exposure and the like. The principle of the distance of separation of "fuel piles" is an important one, however.

3. Accessibility of Blocks. A block "shall be considered inaccessible if more than 50 per cent of the number of buildings have only one side accessible from a street, alley, driveway, or courtyard and other open spaces readily accessible from the

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[23]International City Managers Association, Municipal Fire Administration, (Chicago: The Association, 1956), p. 398.

[24]Ibid.

street."[25] The inability of fire control equipment to reach an area of fire, or to set up a fire line to control a spreading fire is crucial. The presence of closed "fuel piles" is a definite invitation to spreading.

4. Area of District in Open Space. The mitigating value of undeveloped land for fire breaks is again recognized here. The deficiency point system is based upon the per cent of the area of the district in streets and open spaces which cannot be built upon, including one half the width of the district-bounding streets. This measure, of course, recognizes those areas prohibited from development or structural use by codes and ordinances. It assesses points on the basis of the schedule listed below:

TABLE 5 PENALTY SCHEDULE

50 per cent open or over	=	0 penalty points
40 per cent	=	20 penalty points
30 per cent	=	50 penalty points
20 per cent	=	90 penalty points
10 per cent	=	130 penalty points

(Source: Municipal Fire Administration, 1956, p. 399.)

It can be seen that an extremely high value is placed on the degree of open space in a high-value district. This is, of course,

[25] Ibid., p. 399.

consistent with basic combustion principles. It would also seem that the high degree of development of large central core cities would, through this grading factor, prevent that core city from achieving a Class 1 grading, even if its other elements rank high in relation to other cities.

5. Per Cent of Block Area Built Upon. As a corollary to item 4, this factor attempts to assess deficiency points and award credit points for the degree of development by blocks. An example of the assessment scale is below:

TABLE 6 ASSESSMENT SCALE

Per Cent Built Upon		
0 per cent	=	140 credit points
30 per cent	=	40 credit points
50 per cent	=	0 points
80 per cent	=	35 deficiency points
100 per cent	=	70 deficiency points

(Source: Municipal Fire Administration, 1956, p. 399.)

Parking spaces, though a developed use, are not considered as built upon here. It can be seen that 50 per cent of an area in developed use, and likewise 50 per cent in open space is seen as the desirable norm by the standard grading schedule. Obviously, the configuration of the space around the structure is an important variable. The schedule implies, however, that where less than 50 per cent of the block is built upon, the lack of congestion is considered below "normal," and "credit" or minus-deficiency points are allowed.

6. Height of Buildings. The height of buildings influences not only the fire environment of a district, but also that district's classification as to density of population, intensity of use, and level of value. In determining the number of points to be charged for the character of the district, however, the schedule bases its scale upon the previously measured quality of the Water Supply and Fire Department. Undoubtedly, it has been determined by fire engineers that the ability of a well-trained fire control group to apply an adequate stream of water and other control measures to upper stories of frame buildings and non-fireproof structures and buildings will offset a certain amount of the problems caused by these large buildings. Where water supply and fire control fall below a certain level, points are assessed on the basis of frame buildings 2 and 3 stories high, frame buildings 4 stories and over, frame buildings 6 stories and over, non-fireproof non-frame buildings over 2 and over 5 stories, and for non-fireproof non-frame and semi-fireproof buildings over 6 stories.[26] These assessments of deficiency points all attempt to recognize the exposure problem of upper-story fires as well as the difficulties encountered in fighting multi-story fires.

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26 Ibid.

7. Frame Areas. A frame area "shall be construed as including continuous frame buildings which do not have a separation equal to 2 feet of clear space or a brick-filled wall with no openings in the wall.[27] This portion of the schedule attempts to recognize the extreme hazard of such frame areas as breeder areas as well as easily ignited spread areas. The total lack of exposure protection (either in terms of geometric distance or physical non-flammable barrier) is emphasized not only in the grading schedule section on building laws and fire prevention, but here under structural conditions as well. It assumes much importance for matters of mass-fire propagation and spread as well as for individual control efforts. Points of deficiency are assigned under this category in terms of the percentage of the district in contiguous frame construction as well as the size of the area in such construction.

8. Conflagration Breeding Blocks. Closely allied to item 7 , this evaluation section attempts to single out blocks within the district which "have a hazard distinctly greater than normal for the district, and are grouped; that is, the separating space is less than 100 feet . . ."[28] The system assesses 5 deficiency points for each block in groups of two or more adjoining blocks. Thus, blocks which are penalized under the frame construction section are quite likely to be additionally penalized here.

9. Exposure to the District. The fire engineer here attempts to take into account the prevailing wind direction and the

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27 Ibid., p. 400.

28 Ibid.

prevalence of frame construction and wooden shingle roofs in the exposing sections. He considers each of the four exposure sides or planes separately, and then assigns from 5 to 20 points per side.

Environmental Conditions

It can be seen that the consideration of structural conditions attempts to measure not only the type of materials and conditions existing, but also the placement of those materials throughout a district, and the quantity of each condition in each block of the district. If up to date and well done, it is an exceptionally comprehensive analysis of the fire environment of the community as well as the municipalities' ability to control and extinguish fire. Since two subject cities of possibly similar construction in two different areas of the country may be exposed to different climatic situations, however, it is necessary that a consideration of various restricting climatic conditions be taken. The AIA fire engineers determine climatic conditions or data for each municipality in four distinct categories. These are:

1. The Frequency of High Winds. The frequency of high winds as well as their duration are important not only to the spread of fire, but to the humidity of an area as well. Certain areas are exposed to continual or high winds for the major portion of the year, and so are penalized a certain number of points.

2. Snowfall in Excess of 10 Inches per Month. The amount of snowfall received can hamper fire control efforts by restricting control apparatus access, damaging water supply, or causing structural failure and consequent exposure of building contents to fire hazard. An allied hazard is the severity of cold weather. The severity of a winter, as well as its

length can immobilize storage of water supplies as well as fire fighters. It presents a very real problem in the freezing of water during fire fighting.

3. Hot Dry Weather. Hot dry weather is an exceptionally dangerous atmospheric condition, especially in forested areas. The lack of humidity in the air increases the danger of spontaneous combustion as well as reduces the amount of humidity in fuels and makes them more susceptible to ignition.

4. Unusual or Exceptional Conditions. These conditions include those disasters or natural phenomenon which are not measurable by the above and which offset protection and increase the probability of fire starts. These include the frequency by which forest fires may enter a city, the probability of tornadoes, or hurricanes in the region which may result in numerous fires and interruption of fire control mobility. Blizzards and severe snow storms impede the fire operations. Earthquakes may injure buildings, rupture water supply mains and cause fires.

Divergence in Water Supply and Fire Control Capability

Finally, the NBFU (and now the AIA) have determined that the relative strength of the community water supply and the relative ability of the fire department should not differ by a significant amount, in order to insure that a lack of supply or an inefficient control group will not be tolerated by the community. Where the Class assigned to water supply (that is, Class 1 through 10) differs by more than 2 Classes from that assigned to the fire department (that is, Class 1 through 10), there shall be added to the total points of deficiency (of the community) a certain number of points varying with the amount of divergence between the classes of the two factors."[29] The table is represented below in part.

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[29] Ibid., p. 401.

TABLE 7

CLASS DIVERGENCE PENALTY SCALE

Divergence in Class	Additional Deficiency Points
2	0
3	45
4	90
5	150
8	420
10	680

It can be seen that a community which developed a sound water supply and attempted unwisely to rely heavily on mutual aid agreements would find itself penalized additional deficiency points. The purpose of the standard fire defense grading system then would appear to be the insurance of a balanced ability by the community to meet a fire disaster. As we shall see, the public service orientation of much of the grading system must be accompanied by a recognition that the physical form of the community is equally as important in the control of massive spreading fires. The grading schedule considers the community structure, but places little emphasis upon the overall form. This is perhaps understandable, for it is undoubtedly difficult to establish parameters of physical form which are meaningful to mass-fire control not to mention the determination of critical levels for those parameters. The establishment of critical parameters requires an examination of the basic properties of fire propagation and spread as well as an understanding of the urban fuel environment. With such a basis, a discussion of the parameters of mass fire can begin.

CHAPTER IV

MODELING URBAN MASS FIRE SPREAD

The most desirable form for a section on parameters would be a simple listing, with modeled results attached indicating their respective degrees of variability from the ideal. Such a form would require extensive experimentation and observation. Much of this has taken place, yet on a scaled version not yet sufficient for our purposes. We are forced, therefore, to either undertake our own research, or to search the literature for an examination of the critical parameters concerning mass-fire propagation and spread. There is a small amount of literature available, and some of it is excellent.

Urban Vulnerability Model

Perhaps the most direct and applicable is a study carried out at the United States Naval Radiological Defense Laboratory in San Francisco, California.[30] It not only presents a vast amount of scientifically obtained research material, but presents conclusions and hypotheses in a convincing and logical manner. The authors realize that entirely different sets of parameters may dominate the fire environment under different atmospheric, natural, and cultural conditions. It would be possible to imagine large group fires which could jump all bounds of reality and consume vast areas of an urban area. Such conditions might result under certain types of nuclear thermal pulse and damage. Yet this is an extreme case, in which the conditions would all favor unlimited expansion of the blaze. Such an extreme must be considered less probable than other combinations of parameters.

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[30] R.H. Renner, S.B. Martin, and R.E. Jones, Parameters Governing Urban Vulnerability to Fire From Nuclear Bursts, Phase I, (San Francisco, United States Naval Radiological Defense Laboratory, June 30, 1966), pp.70-86.

A second type of extreme would involve the damage done by blast from a nuclear weapon, or a phenomenally large area of damage done by an earthquake. Under this extreme, though large amounts of fuel are exposed, the conditional parameters are not found in the right combinations and sequences, and massive fires which might be expected do not materialize. The extreme might also occur in urban areas where the fuels are generally "hardened," and although all other conditions seem favorable for fire spread, the fuel is not suitable.

In both of these instances the extreme conditions of fuels and ambient conditions affect the outcome of the fire not only as sensitive parameters, but also by bringing about a "gross change in character of the fire from that of the more usual range of values" of the parameters.[31] Therefore, the result is likely to be an extensive reordering of the sensitivity of the parameters to their critical combinations and interactions. If we remove from consideration both these extremes of end result, the outcome is liable to be, as Renner, Martin, and Jones determined, the "cases where the final fire outcome is in large measure determined by the magnitude of the primary fire."[32] In fires resulting from nuclear blast, this will bear direct relation to the area "flashed over" by initial thermal radiation. In the non-nuclear case, with which we are concerned this will not hold true since we are primarily involved with the spread of fire beyond the primary ignition. This assumes that the end result fire was born of a single fire, lost beyond control. In the event of non-nuclear

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[31] Ibid., p. 73.

[32] Ibid., p. 74.

multiple ignitions, which might result from natural disasters which precede and cause fire starts, this postulate of self limitation may be applicable. Multiple initial fires may mark the perimeters of the fire, or merge and consume the urban kindling fuels within their immediate range. The end expression of the mass fire in such a case may have been well outlined by the initial fires.

Basic Parameters

In the terms of the previous discussion on fuel geometry and ambient atmospheric conditions, the parameters in the propagation of mass fire might be stated as those below. They are listed in order of decreasing sensitivity, that is, in the order of the decreasing magnitude of their effect upon the furtherance or attenuation of mass fire.

Parameter	
1. Fuel Concentration	Determine Occurrence
2. Size of Initial Fuel Area	
3. Initial Fire Density	
4. Fuel Type	
5. Surface Wind	Determine Severity
6. Distribution of Initial Fire	
7. Atmospheric Structure	
8. Topography	

The first four of these parameters determine whether a mass fire will occur, and "influence its magnitude of severity." The last four "determine whether it will behave as a conflagration or a firestorm."[33] These basic parameters must be "translated" to the urban environment, however, to be of value to a substantive study. When the parameters are thus translated, and applied to a specific type of fire, they are quite

[33] *Ibid.*, p. 72.

likely to shift somewhat in order of importance and sensitivity. Renner, et al., postulate that these parameters do indeed shift in emphasis varying with the type of mass fire and its agent--namely conflagration, firestorm, or spreading fires of conventional magnitude.[34]

In these three types of mass-burn there is little relationship between the number of structures initially fired and the number ultimately destroyed. Indeed, the extent of fire vulnerability of the area is a function primarily of the spread and ultimate magnitude of the fire's physics. Spreading fires of conventional magnitude may well be an early stage of conflagrations or firestorms, dependent on the satisfaction of several factors. The parameters for conventional fire spread must be satisfied, yet the conditions for mass fire spread must not be achieved. The fuel configuration must evince a high concentration and contiguity of buildings and fuels, combined with buildings and structures which have combustible exteriors. Further, atmospheric conditions must be considered as hazardous fire weather.

Conflagrations, as differentiated from spreading fires of conventional magnitude, require a "high density of fuel loading, a brisk surface wind, a large number of structures in (the) fire area simultaneously on fire, (and) a large fire area."[35] The Naval researchers estimated that surface wind velocities would have to be greater than 8 miles per hour, with an initial fire density of greater than 50 per cent of the structures in the initial fire area on fire. They further postulate a required minimum initial fire area of .5 square mile.[36]

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[34] Ibid., p. 83.

[35] Ibid., p. 84.

[36] Ibid.

Firestorm start criteria include requirements for a high fuel density, a low initial surface wind (as contrasted to the high wind required for conflagrations), a large number of buildings and structures in the fire area simultaneously on fire, and a large, roughly circular, fire area. The surface wind would probably be below 8 miles per hour, with initial fire density and fire area similar to that for conflagrations.

In all three cases we are concerned (in the urban area) with the spread of fire either from structure to structure or from an exterior fuel to a structure. The parameters governing these two types of spread in urban areas vary to a slight degree in their order of importance and sensitivity. In the instance of spreading fires of conventional magnitude the parameters have been fairly clearly delineated by Renner, Martin, and Jones. For example:

Structure to Structure Spread [37]

1. The specific construction features of the structures are the major parameter in this spread type. Of concern are the number, size, and location of outer wall openings. The combustible nature of the outer coverings, both roof and side wall as well as the roof type all affect the exposure criteria. Further, the overall building dimensions and the shielding it provides for interior fuels are elements of concern.

2. The degree of intensity of the immediate urban "sub-area" is the second parameter of concern. This parameter must consider building densities, height of structures, and the separation distances between structures.

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[37] *Ibid.*, pp. 79-80.

3. Fuel type is a vital parameter, determining the general combustibility of an area. Under this parameter are grouped concerns with the density, size, age, composition and other factors governing the ignition thresholds, burning times, and heat concentration and radiative properties of the structural fuels.

4. The building fuel load reflects not only the quality of the structure, but the general quantity and type of interior fuels.

5. Of a non-structural nature, the configuration and intensity of the initial fired-structure is a vital factor. The placement of the ignitors determines the path the fires will follow, and hence the specific extent of the ultimate burn.

6. The moisture content of urban fuels is chiefly determined by atmospheric quality. The atmospheric measures of relative humidity, recency of precipitation, and general air temperature are all elements determining the general susceptibility of fuels to flame.

7. The wind speed and direction not only determine the area of final burn but the rapidity of spread and the duration of the fires as well. The ability of winds to cause "jumping" fires is crucial in this type of fire.

8. The number, geometry, weight and life times of firebrands are affected both by fuel quality and wind geometry. If mass-transfer of fire occurs, the likelihood of jumping fires is very great. Further, the susceptibility of structures to firebrands is an important element.

TABLE 8

RANKING OF IMPORTANCE FOR
PARAMETERS GOVERNING THE DESTRUCTION OF RESOURCES BY FIRES

Parameters	Conventional Spread: Structure to Structure Ranking	Conventional Spread: Exterior to Structure Ranking	Conflagration Spread Ranking	Firestorm Spread Ranking
Construction Features of Structures	1	5	1	5
Builtupness of Urban Sub-Area	2	4	11	1
Fuel Type	3	-	13	3
Building Fuel Load	4	-	7	4
Configuration and Intensity of Initial Fires	5	-	6	2
Moisture Content of Fuels	6	-	10	12
Wind Speed and Direction	7	9	4	6
Number and Geometry of Firebrands	8	-	2	-
Degree and Shape of Flames from Openings	9	-	12	9
Structural Susceptibility to Firebrands	10	-	3	-
Width and Configuration of Firebreaks	11	3	5	7
Flow of Gases Above Fires	12	-	15	8
Snow Cover	13	13	16	-
Fuel Distribution	14	-	8	10
Ambient Condition of Fuels	15	10	14	-
Topography	16	15	17	11
Proximity of Exterior Fuels to Structures	-	1	9	-
Exterior Fuel Load and Type	-	2	-	-
Firebrand Characteristics of Exterior Fuels	-	6	-	-
Relative Humidity and Precipitation	-	7	-	-
Proximity of Exterior Fires to Structure Openings	-	8	-	-
Housekeeping	-	11	-	-
Location of Exterior Burning on Structures	-	12	-	-
Shielding of Fuels by Foliage	-	14	-	-

NOTE: (1) Highest Ranking of Parameter Importance
(-) None or Negligible Importance

Source: R.H. Renner, S.B. Martin, and R.E. Jones. Parameters Governing Urban Vulnerability to Fire from Nuclear Bursts, Phase 1., USNRDL. pp. 79-82.

9. The width and configuration of firebreaks is not as important in this fire type as in the others. Since the fires do not join and are of conventional magnitude fire breaks are not put to the true test.

The spread of fire from exterior fuels to structures, and in the instances of conflagrations and firestorms involve essentially the same parameters as above, but in different orders. Table 8 attempts to list the various parameters in order. From examination of this table, one can deduce that the parameters most likely to be of major importance in the fire's spread, regardless of type of fire, are the construction features of the buildings and structures of the area, the configuration and intensity of the initial fires, the intensity of "builtupness" of the urban sub-area, the building fuel load, the wind speed and direction, and the fuel type. We shall examine these parameters more closely.

Classifying the Urban Area

The application of specific parameters (which we have identified) to an urban area requires that we are able to typify an urban sub-area or district in some type of homogeneous classification. This is necessary so that we may attempt to examine within each homogeneous area the degree to which a parameter of physical form is adaptable. In other words, the variance between different districts or geographical areas of a large city or urban area may be large in all matters of socio-economic, cultural, and natural assets. This is likewise true in terms of physical form, general structural types, and general fire environment. A means of generalization is then desirable and necessary to enable us to simplify descriptions of differing portions of the urban area. Were we not to apply a general descriptor to homogeneous areas of the physical community, we would be forced to consider the structural condition of each building and structure. At this point in our discussion of parameters, and in view of the characteristics of mass fire, such an individual treatment might well be avoided for a generalization of conditions. Thus, each generalized sub-area can be described as possessing certain general properties.

The Naval research team points out the applicability of techniques of remote sensing to apply spot analyses to each area, and therefore determining a distribution level or value for each of the parameters within an analysis area.[38]

Urban planning has relied heavily upon broad classifications of land usage in the past. This division has been done with specific goals in mind, and with the understanding that constraints and conceptual limitations to the system existed. Land use as a criteria for generalization might be very useful, since data is not only readily available in most instances, but the general conceptual divisions have considerable merit in terms of the degree of fire risk possessed by each type of use. Fire engineers and experts have used the basic land use classifications in the past to examine the conventional fire danger in different areas of study cities.

Forest Service Approach. F.M. Sauer, Craig C. Chandler, and Keith Arnold, in a 1953 USDA study of post attack fire ignitions, divided risks into two broad classes as shown:[39]

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[38] Ibid., p. 90.

[39] F.M. Sauer, Craig C. Chandler, and Keith Arnold, Primary Ignitions Following Atomic Attack on Urban Targets, (Washington: United States Department of Agriculture, 1953).

Class 1 - Residential

Within this class, quality of housing as well as construction features were used to rate the fire risk. Elements of congestion, fire breeding, and general inhabitant housekeeping evidently led to the three sub-categories of Good, Poor, and Slum.

Class 2 - Commercial

This broad category included a range of commercial-industrial enterprises, defining risk areas not so much by their general housekeeping features but by the known or suspected degree of fire risk or explosiveness of the interior fuels and the structural distribution of the establishments. The sub-classification included specific risk levels for Large Manufacturing, Small Manufacturing, Wholesale Distribution, Downtown Retail Distribution, Neighborhood Retail Distribution, and Waterfront land uses.

This system used a mixed and perhaps not-too-thorough categorization, using modes of qualification as well as quantification.

A second group of fire experts devised a system which appears to have gone too far towards generalization, in that it attempts to categorize land uses in terms which may lead to problems of application. Chandler, Story, and Tangren apply the five categories of Light Residential, Heavy Residential, Commercial, City Center, and Massive Manufacturing to the entire urban area.[40] Clearly there is a duplication of categories, such

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[40] Craig C. Chandler, Theodore G. Storey, and Charles D. Tangren, Prediction of Fire Spread Following Nuclear Explosions, (Berkeley: Pacific SW Forest and Range Experiment Station, United States Forest Service, 1963), p. 29.

as between Commercial and City Center. Such a classification seems to have been influenced by such theories of urban development as the concentric and sector notions, and vastly overgeneralizes. The three authors apply burning speed data to the five categories and derive a set of possible burning times.

Civil Defense Approach. The Office of Civil Defense, in Technical Manual TM-8-1, presents a listing of the nine categories which they use in determining fuel loading, estimating damage and loss, and estimating other weapon effects essential to emergency planning.[41] These categories are based not only on differences as land uses, but also on potential for emergency development or as areas of high life or property loss. These nine areas are:

Residential

Commercial

Industrial

Transportation

Storage

Institutional

Special

Recreational

Unused Land

These areas can each be thought of as broadly "homogeneous" in terms of their fire vulnerability, relative degree of fuel loading, value of recovery (that is, post-attack or post-disaster production recovery) potential, and degree of open space available for emergency shelter and

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[41]Federal Civil Defense Administration, Civil Defense Urban Analysis, Technical Manual TM-8-1, (Washington: FCDA, 1953).

fire-safe environment. It would be necessary, however, for mass fire study purposes to evaluate sub-areas within each analysis land use district, since the critical fire parameters will exist in varying mixes.

Study Approach. Conceptually, the importance of land use as a criteria for assigning homogeneity cannot be denied. Yet other elements must be considered; elements which might be used as sub-categories within a land use system, or as a separate system for assigning homogeneity. Our concern here is with the fire vulnerability of general areas of the urban scene, and as such we must consider the impact of fire upon adjacent, but not necessarily homogeneous, land use areas. Residential and commercial areas of nearly equal density and fire loading are much less likely to present a fire load boundary. It would be relatively easy to derive a set of subjective criteria for homogeneity, yet the derivation of a comprehensive set is much more difficult. Possible areas for consideration might include distinctions between variables of:

Land Use (human activity)
Occupancy of Buildings
Density of Structures
Fireload per Unit Area
Economic Divisions
Population Divisions
Political Divisions
Ground Cover and Vegetation Cover
Insurance Rate Zones [42]

The decision to use one criteria or another will be dependent primarily on the sensitivity of each of the basic fire parameters to variable conditions

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[42] Renner, p. 91.

within homogeneous areas of the urban scene. Any of the areas, or sub-areas within the areas, will be termed homogeneous when they can be described by identical or near identical values of the respective defined fire-spread parameters. The Naval researchers postulate that the occurrence of each parameter within a district may be described along a distribution curve determined by spot analyses and surveys.[43] The degree of homogeneity is then relative to the variance of the parameters from a constant value for that "type" of district.

Very little has been said up to this point about the suspected size of these homogeneous areas. The size of each area would be determined not only by the amount of continuous identical land use and fire load, for example, but also by the existence of natural barriers and firebreaks. Firebreaks might be considered to be streets, bodies of water, large vacant areas, or very low-fuel-load areas. In other words, inconsistencies in fuel loading over the urban area would in large measure create boundaries to fire spread, and render impractical the designation of a fire area which crossed such a boundary. The designation of fire zones, containing areas of near equal or homogeneous mass fire risk will most frequently be accomplished by essentially linear systems of open space, of varying width and make up. This concept of fire zones, and basically homogeneous fire risk districts, is neither new nor novel, yet it is not frequently applied explicitly. Rather, its implementation is a side effect of much of urban development. Existing examples of the past use of fire zones in legal control of building development undoubtedly reflect concepts of fuel

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[43]Ibid., p. 93.

concentration and fuel loading held at the time of construction. Whether these concepts of the value of fuel loading variance are understood or applied in legal tools today is questionable. Principles and methods for the attenuation of conventional means of fire spread are successfully applied in many areas, yet the difference in parameters of spread for conflagrations and mass fires indicates a need to examine the measures held effective for conventional fire spread.

Conflagration Potential Model

The potential for the spread of mass fire may be determined by an application of the parameters for fire spread which we previously presented. These parameters, when applied within a homogeneous area of study should give an estimate of the potential mass-fire hazard for that area. Considerable work has been done on this aspect of the mass-fire problem, specifically by the aforementioned Renner, Martin, and Jones, and also by Messers. Cohn, Almgren, and Curless of Gage Babcock and Associates. The Gage Babcock report series, entitled A System for Local Assessment of the Conflagration Potential of Urban Areas, seeks to develop an empirical system which will not only assess the conflagration potential but designate fire breaks as well.[44] Such a proposal is consistent with the objectives of this paper. It will be remembered that the parameters of concern in the spread of mass fire were as follows:

1 - The concentration of fuel, its density, its configuration, its fuel load, and its nearness to other fuels.

2 - The size of the initial fire area, and its location in reference to the supply of fuels.

3 - The initial fire density, and the configuration it possesses in terms of continuity of fires.

4 - The fuel type of the initial fire as well as the fuel type of the suspected end fire area.

5 - The surface wind, measured in terms of speed, direction in relation to fuel, and relation to upper atmospheric movement.

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[44]B.M. Cohn, p. 30.

6 - The distribution of the initial fire, especially in regards to the area of the suspected end fire.

7 - The atmospheric conditions, in terms of humidity, recent precipitation, prevailing upper strata winds, and climate.

8 - The topography, particularly as regards land forms, which may act as channels for promotion of fire or barriers to it.

Basic Parameters

These parameters were evaluated in light of conventional, conflagratory, and fire-storm types of fire, and from the list were chosen five elements most sensitive to conditions of the conflagratory and fire-storm fire environments. These five, in terms more equatable to the urban environment are:

1 - The construction features of the buildings and structures. This relates directly to the elements of fuel concentration and type.

2 - The configuration and intensity of the initial fires, which is related not only to the reason for fire start, but also to possible delays in alarm, or in control unit arrival at the fire scene.

3 - The intensity of the use of the area, or the density of the buildings. This relates to the "land fuel load" as well as to the element of "individual-fire" barriers and breaks. Congestion and the existence of fire-breeders enter at this level of consideration.

The building fuel load is important as distinguished from the land fuel load expressed above. It determines not only the original combustibility of the structure, but its burning time, probability for creating fire brands and general fuel level.

4 - The wind speed and direction not only determine in large part whether a mass fire will develop as a conflagration or firestorm, but also helps determine the general extent of the end fire.

5 - The fuel type determines the general combustibility of an area and its resistance to ignition. The fuel type may well be important in the designation of certain areas as fire barriers or fire breeders.

The majority of these factors (items 1, 3, and 5) are concerned with the day-to-day condition of the study area, and can as such be termed "static" factors. Since changes in material and structure quite likely occur, these elements are not truly static, yet will be so termed for our purposes. As variables which may be more easily measured they may be used to determine a conflagration or mass-fire hazard. The study by Cohn, Almgren and Curless examines these three factors and arrives at a schedule as shown in Table 9 which incorporates values for the Occupancy Fire Load, the Density of Building Coverage, the Height of Structures, and Construction of Floor, Roof, and Exterior Walls, and a Slope Multiplier.

Hazard Value Per Block

The result of this series of value assignments for hazard is a model which measures the relative hazard value per block. The model (and its value scale) is basically representative of the AIA fire defense grading schedule, yet it does present the concept in a different manner.

TABLE 9

VARIABLES FOR CALCULATING MASS FIRE POTENTIAL

NUMERICAL VALUES FOR HAZARD BY BLOCK

	Occupancy Fire Load	Scale Values
(A)	1 - Vacant or Non-Combustible	0
	2 - Light Fire Load	10
	3 - Moderate Fire Load	20
	4 - Heavy Fire Load	30

	Density of Building Coverage	Scale Multiplier Values	
(B)	0 to 5 per cent	0.0	
	6 to 20 per cent	0.1	
	21 to 30 per cent	0.2	Ground area
	31 to 40 per cent	0.4	covered by
	41 to 50 per cent	0.6	buildings or
	51 to 60 per cent	0.8	combustible
	61 to 70 per cent	0.9	storage
	Over 70 per cent	1.0	

	Height of Buildings	Scale Multiplier Values	
(C)	Vacant Land	0	Approximately
	1 to 2½ stories	1	each 12 ft. in
	3 to 5 stories	2	height counts as
	Over 5 stories	3	one story = 1
			additional point

	Floor Construction	Scale Values
(D)	Fire Resistive or Non-Combustible	0
	One or more Floors all or Partially Combustible	10

"Table 9 continued"

(E) Exterior Wall Surface	Scale Values
Standard Masonry	0
Substandard Masonry	10
Non-Combustible	10
Non-Combustible on Combustible Supports	15
Combustible	30

(F) Roof Construction	Scale Values
Protected Non-Combustible	0
Unprotected Non-Combustible	10
Non-Combustible on Combustible Supports	20
Combustible	30

(G) Terrain Multiplier Slope	Scale Multiplier Values
10 per cent or less	1.0
11 to 20 per cent	1.1
21 to 40 per cent	1.3
41 to 60 per cent	1.6
61 to 80 per cent	1.8
Over 80 per cent	2.0

Source: B.M. Cohn, L.E. Almgren, and M. Curless, A System for Local Assessment of the Conflagration Potential of Urban Areas, Chicago: Gage Babcock and Assoc., Inc., 1965, pp. A24 - A28.

The model requires the estimation of a good many qualitative factors (such as light, moderate or heavy fire occupancy load). The value for density of buildings or construction is intended as a multiplier, giving density, in effect, the highest weighing value of the factors. Such an assignment is consistent with all the concepts we have examined. Symbolically, the model as presented by Cohn, Almgren and Curless takes the following form:[45]

$$((O + F + W)\, H_M + R)\frac{D}{100} \cdot D_M \cdot T_M = R$$

where O is the occupancy fire load value
F is the Floor Construction value
W is the Exterior Wall Construction value
H_M is the Height Multiplier value
R is the Roof Construction value
D is the Construction Density Percentage
D_M is the Density Multiplier
T_M is the Terrain Multiplier
and R is the Final Block Rating

Fire Loading by Use

The authors of this model go to considerable detail in explaining their classifications of such qualitative terms as negligible, light, moderate, and heavy (as found in part A, Table 9). Indeed, an understanding of various fire loads typically found with certain land uses may be extremely helpful to us here. A negligible fire occupancy load rating usually implies a vacant area, or a structure with essentially non-combustible contents. Examples would include:

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[45]*Ibid.*, p. 31.

"Machine Shops and Metal Working
Storage of Metal Implements of Machinery
Boiler Houses, Power Houses
Brick Storage, Stone Crushing
Water Treatment and Sewage Disposal Plants"[46]

Light fire loading would commonly include these land uses:

Apartments, Houses, Hotels, Hospitals,
Libraries (metal shelving), Telephone Exchanges,
Funeral Parlors, Halls, Gymnasiums,
Schools, Laboratories, Offices, Police and Fire Stations

Moderate fire loading is characteristically found in these land use types:

Bowling Alleys, Theaters, Churches, Restaurants
Department Stores, Retail Stores and Shops
Drug Stores, Laundry and Dry Cleaning Shops
Most Manufacturing Plants

High fire occupancy loading is typified by the authors as including:

"Aircraft Hangars, Petroleum Refineries,
Whiskey Warehouses, Paint Factories, Stock Yards
Rubber Tire Storage, Warehouses
Crowded Department Stores, Feed Mills
Textiles, Clothing and Mattress Manufacturing and Storage."[47]

These categories, as assumed by the authors, are consistent with the AIA fire defense schedule, as well as with the standards published by the National Fire Protection Association (NFPA).

Relative Potential Rating

The model for measuring the conflagration potential of each block is valuable primarily because it allows a fire hazard evaluator to rate areas of the city relative to their location and degree of hazard. The application of such a model should provide a municipality with reasonable

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[46] Ibid., p. A24.

[47] Ibid.

estimates of the relative potential for mass fire spread as well as areas of confinement. The model is intended to be used as a block by block measuring device, yet could be applied in a sampling design to a large, relatively "homogeneous" land use area as discussed above. In any case it is important to remember that such subjective evaluatory methods should be viewed in a relative manner, comparing block ratings to other blocks. Cohn, et al., caution that the ratings should not be viewed "as individual absolute measures. On the basis of the ratings alone it cannot be predicted, for instance, which or how many buildings in a specific block might be destroyed in a conflagration, nor can the ratings be used to predict the actual extent of a conflagration which might occur some day in the future."[48] The model ideally identifies potential, and rates severity of mass fire hazard. Since the comparisons within the model are primarily on the basis of the fire loading evaluation, the model does not imply a measure of the speed with which a fire might spread through the block. This shows instead the "propensity of the block for simultaneous burning of several buildings, i.e. a conflagration" or fire storm.[49]

The result of an application of this model to each block in a community would be a rating for each block. Presented in map form, with gradients applied for differing hazard ratings, the data would pictorially represent different hazard potential areas. These relative assignments of ratings, when coupled with assumptions of fixed climatic conditions and standard atmospheric flows, could be grouped into ranges which would broadly define the potential for mass fire. Cohn, Almgren, and Curless applied the following breakdown in a general case:

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[48] Ibid., p. A9.

[49] Ibid.

"Blocks with ratings up to 20: No group fire or conflagration potential, but possibility of (conventional) fire spreading to adjacent buildings.

Blocks with ratings of 21 to 40: Low potential for group fires and conflagrations, but moderate to high probability of (conventional) fire spreading to adjacent buildings.

Blocks with ratings of 41 to 70: Moderate potential for group fires and conflagrations.

Blocks with ratings over 70: High potential for conflagration.

Blocks with ratings of 15 or less are classified as firebreaks."[50]

In the determination of block ratings, it will be common to find a wide variance in all the elements within each block. Averaging must, of course, occur. The authors provide one example which may be valuable.

"Of the 1-2 story buildings in a certain block, the ground floor area of 10 per cent is warehouses . . . (negligible fire load); 40 per cent is apartment housing (light fire load); 30 per cent is in retail stores (moderate fire load); and 20 per cent is in lumber yard (heavy fire load).

10 per cent x 0 (rating)	=	0
40 per cent x 10	=	400
30 per cent x 20	=	600
20 per cent x 30	=	600
TOTAL		1600

1600/100 = 16 = block rating

The average occupancy rating for that (evaluatory) portion of the block (rating procedure) is 16 . . . "[51]

This averaging routine is carried out for each of the elements of the model, and might result in the example continued below. The buildings and structures are divided into groups determined by height, with ratings determined separately. The height-separate ratings are then accumulated and grouped to derive the block rating.

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[50] Ibid., p. A10.

[51] Ibid., p. A23.

TABLE 10

BLOCK RATING MODEL APPLICATION

	Category		1-2 Stories	3-5 Stories	Over 5 Stories
(O)	Occupancy Fire Loading		16	13	10
(W)	Exterior Wall Construction		7	0	0
(F)	Floor Construction		4	8	0
(H_M)	Height Multiplier	(x)	1	2	3
(R)	Roof Construction		26	24	0
(D)	Construction Density Percentage	(x)	43	43	14
	TOTALS		2279	2838	420
	Total/100		23	28	4

Totals of Columns = 55
(D_M) Density Multiplier (x) 0.8
(T_M) Terrain Multiplier (x) 1.0
Result 44

(R) Final Block Rating = 44

$$((O + W + F)\ H_M + R)\ D/100 \cdot D_M \cdot T_M \cdot = R$$

$$(55) \qquad (0.8) \quad (1.0) \quad = 44$$

Source: B.M. Cohn, L.E. Almgren, and N. Curless, A System for Local Assessment of the Conflagration Potential of Urban Areas, Chicago: Gage Babcock and Assoc., Inc., 1965, p. A. 33

The system is relatively straightforward. Since it describes the block in terms of mass (fire loading, structural size, etc.) in relation to the total space available, it could become an important tool for the fire evaluator.

Application of the Model

The authors, Cohn, Almgren, and Curless, made no attempt to describe a typical rating for varying land uses, yet they do imply that since the various parameters do vary with variance in land use, the model will impute generally basic differences in rating between land use types. A few examples of blocks studied by the authors may be relevant.

Case 1: This block consists of single-family, one- and two-story wood frame dwellings. The buildings cover approximately 25 per cent of the area of the block, and the terrain slope is less than 10 per cent. The buildings have a light fire load, and have combustible exterior walls, floors, and roofs.

The fire hazard rating for this block is 16, placing it well below the group fire potential category, but not low enough to quality as a fire break.

Case 2: This analysis area contains a high-rise residential development, such as that found in an urban renewal area. The high-rise units are integrated with scattered 2-story townhouse developments. Construction is fire resistive in all cases. The 2-story townhouses comprise a light fire load. The over-5-story high-rise buildings have a light fire occupancy load, a large number of openings in the masonry walls and a fire resistive roof and floor rating.

The final "ratings of blocks of this nature seldom exceed 10, reflecting their exceptionally low potential for a mass fire."[52] In addition, these blocks generally qualify as fire breaks.

Case 3: This case involved an intensely built up block composed of commercial and industrial uses. It has a density of nearly 95 per cent. One- to two-story buildings occupy about 10 per cent of the block area, with a generally moderate fire load, masonry walls, and combustible floors and roofs. The 3 to 5 story buildings are generally a moderate to heavy fire load, with roofs non-combustible but unprotected. Two 6-story warehouses of heavy fire loading but non-combustible protected roofs, floors and exterior walls cover 40 per cent of the block area. The application of the model would yield results of _6_ for the 1 to 2 story buildings, _30_ for the 3 to 5 story, and _36_ for the over-5-story buildings, for a total of _72_ for the block. This places this block in the category of _high_ potential for mass fire.[53]

These examples would seem to indicate that the density of development of individual blocks or analysis areas plays an important part in the determination of the rating. This is indeed a valid conclusion. The determination of density figures varies widely in actual practice, primarily around the pros and cons of including streets and alleys in the calculations. Since streets vary widely in width, as do building

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[52] _Ibid._, p. A38.

[53] _Ibid._, pp. A37-A39.

set back lines, and the calculation of barriers to fire spread is included in the second portion of the fire assessment model, the determination of total block area is taken to include that area within lot lines and to include the alleys as an integral part of the block. Within this defined block area buildings, combustible storage and parking lots are taken as the basic elements for deriving a density figure.

Numerous special conditions can, of course, exist which do not easily fall within the category of buildings for the determination of fire load, construction and height. The storage of highly flammable materials above or below ground presents a fire hazard rating much in excess of that which is derived from the model. These blocks, whether used for above-ground storage of flammable liquids or gases, subject to flooding by these fuels, or for the storage of explosives are assigned a standard fire hazard rating of 150.[54] The concern for these areas is reflected in the intense research carried on by the NFPA in its preparation of standards.

Lumber yards are generally treated as combustible buildings, with each 12 feet in height counted as a story. Automobile parking is considered as a one-story building of light fire loading, unprotected non-combustible walls, floors, and roof and of 40 per cent density. In addition, properties with superior protection are treated as 1-story buildings, fire resistive, with a light fire loading.

Potential for Firebreaks

Up to this point we have discussed the potential for mass fire within blocks or analysis areas. To relate these specific units to the

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[54] *Ibid.*, p. A30.

entire urban fire area, we must determine where these units might combine to form contiguous rating groups, and where limits to these contiguous groups might be found. The effectiveness of the limits for attenuating differing degrees of fire size is a vital concern also. Our problem, then, involves the determination of potential fire breaks and a model for "testing" their effectiveness.

Area and Firebreak Typology

In the determination of potential fire breaks, we must turn to our previous allocation of ratings of fire hazard for each block. These ratings have been grouped in categories of:

Firebreaks

No Mass-fire potential

Low mass-fire potential

Moderate mass-fire potential

High mass-fire potential

In addition to these ratings assigned on a block-to-block basis, the community is composed of numerous open spaces. Cohn, Almgren, and Curless determined that open areas of a minimum width of 120 feet would be referred to as potential primary fire breaks. These open spaces could include "freeways, railroad rights-of-way, rivers or bodies of water, parks," or private open spaces.[55] Thus, potential primary fire breaks might be defined as permanently open spaces not less than 120 feet wide, or as previously mentioned, blocks having a fire hazard rating of 15 or less. These blocks must be a "minimum of 300 feet" in width. Cohn, et al.,

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[55] Ibid., p. A41.

further define secondary fire breaks as being composed of open spaces not less than 80 feet in width or of blocks with a fire hazard rating under 20 and no less than 300 feet wide.[56]

The basic strategy of the model begins by the mapping of all seven of the above area types. This involves the creation of designated multi-block areas for high potential hazard, and for moderate conflagration potential. The addition of potential fire breaks to the mapping process should result in a division of the community into separated, aggregate areas of high and moderate mass-fire potential, divided by lines of open space. The end goal is the creation of a series of fire-potential-free paths running across the community, connecting with open spaces of *no-potential* blocks to isolate the high and moderate potential areas. The result at this point will be a map delineating potential fire breaks, not only of open-space nature, but of no-fire potential blocks. These "strips" will undoubtedly vary in width. The test for effectiveness of breaks need only be applied to areas less than 500 feet in width, since in the opinion of Cohn, Almgren, and Curless this is the maximum width required.

Radiating Surface Area

The elemental parameter in the determination of the effectiveness of a fire break is the *radiating surface area*. The shape of the radiating surface, its orientation to the exposed subject fuel, as well as its distance to that fuel are all crucial determinants of the critical parameter level. Much fire engineering is devoted to this subject, especially in *Fire Technology*, a publication oriented specifically to the fire

[56] *Ibid*., p. B2

protection engineer.[57] In the instance of building fires, with the conditions of fire frontage facing a potential fire break, three surface shapes are of concern. The square radiating area, the rectangular area, and the exceptionally long horizontal rectangular radiating area are each created by a specific combination of the fuel array, the organization of window openings in the fire structure, the length of the building and the wind pattern. The wind factor demands an element of adjustment, since average wind conditions vary widely in communities. Cohn, Almgren, and Curless state that:

> "The calculation of total radiating area, which is necessary to find the required distance separation for an acceptable fire break, is the most complicated step... in the method..."[58]

Figure 2 presents a rough means of determining the required exposure distance for an acceptable fire break. It is based upon the radiating surface area of a fire under three levels of normal wind condition, assuming the wind is blowing toward the exposed building. This is the basic element in testing the effectiveness of a fire break under the assumptions of conflagratory conditions along one edge of the break.

A set of physical variables are found in the analysis of the exposed surface area as well as the fire surface area. Cohn, Almgren, and Curless determined a series of critical levels for each of these parameters and found those in the following list subject to simple

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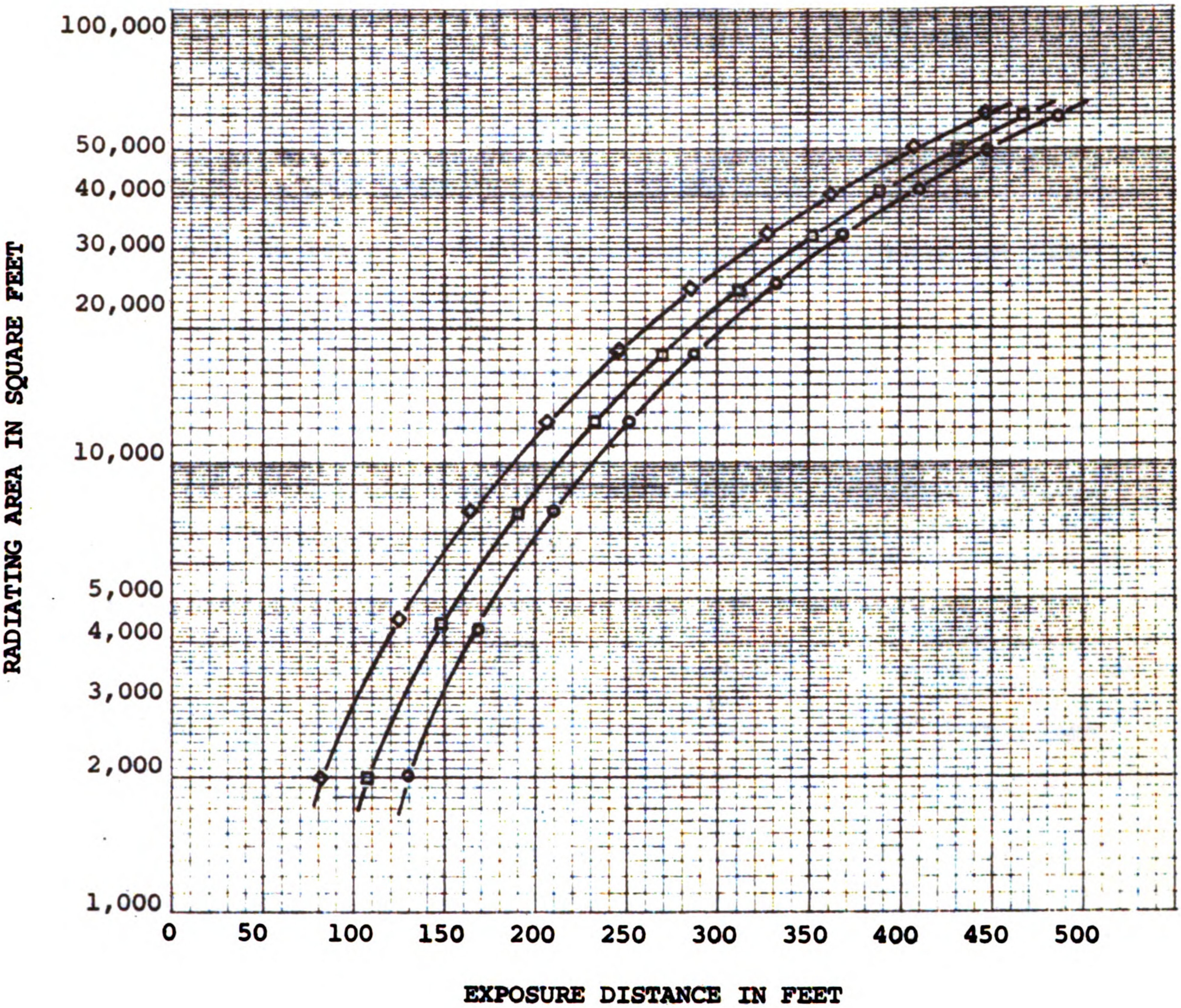
[57]One example of particular interest is an article by H.E. Anderson, "Fire Spread and Flame Shape", Fire Technology, Vol. 4, No. 1, February, 1968, pp. 51-57. The author states that "in laboratory tests, the size of a flame front can significantly effect the rate of fire spread")p.51). He adopts an analog approach in testing, and concludes that "we can expect a fire moving up a 30° slope to be about five times faster than one backing down the slope. Wind tunnel tests have shown that fires with flames inclined 30° from the horizontal will have rates of spread nearly 18 times faster than those for similar fires with no wind present." (p. 56).

[58]Ibid., p. 33.

Figure 2

Radiating Area vs. Exposure Distance



NOTE:

1 = Light Wind Conditions —◇
2 = Average Wind Conditions–□
3 = High Wind Conditions —○

Source: B.M. Cohn, L.E. Almgren, M. Curless, A System for Local Assessment of the Conflagration Potential for Urban Areas, (Chicago: Gage Babcock and Associates, Inc., 1965), p. 32.

measurement or derivation. The analysis of these parameters is, of course, applied to both sides of the firebreak. In simple statement, the parameters are:

1 - The Height of the Buildings

2 - The Amount of Wall Openings or Windows

3 - The Roof Construction of the Buildings

4 - The Set Back of the Buildings from the Exposure Lot Line

5 - The Exposure Width of the Building

6 - The Width of Vacant Areas

The application of these elements to the buildings on either side of a potential fire break will form the first portion of a modeling sequence to determine the effective radiative surface of that segment of analysis.

Structural Surface Model

The model developed by Cohn, Almgren, and Curless uses a set of multipliers based on a combination of the elements of roof construction, height of building, and amount of wall openings. Table B-12 presents this multiplier set for fire classifications by roof construction. A comparison between the multiplier values for Class 1 fire resistive roofs and Class 5 peaked wood roofs indicates the importance placed upon roof structure and fuel type as a measure in the attenuation of fire, and the consequent restriction of radiative area.[59] The specific multiplier which applies to the building under analysis is applied to the building width to yield the radiating area of a potential fire in that building. If the building is set back from the lot line, a Factor of Contribution is applied to the radiating area to modify for the effect of increased distance. The result is the adjusted radiative area. In simplified notation, the model takes the following form:

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[59] _Ibid._, p. A46.

$$\begin{matrix} H \\ O \\ R \end{matrix} \quad (M), \text{ where } \quad (M \cdot W \cdot C)\left(\frac{W}{W+V}\right) = A_F$$

where H = Height of Building in Stories
O = Degree of Wall Openings
R = Roof Classification
M = Derived Multiplier (Table B-12)
W = Building Width in Feet
C = Contribution Factor Derived from Set Back Distance
V = Width of Vacant Area in Feet
and A_F = Adjusted Radiative Area in Square Feet

In addition to determining the area of the radiative surface, Cohn, et al., found it important to determine the shape of the area as well. This was accomplished by

$$\frac{A_F}{W} = F$$

where A_F = Final Adjusted Radiating Area in Square Feet
W = Building Width in Feet
F = Average Flame Height in Feet
V = Width of Vacant Areas in Feet

Apply $\frac{W+V}{F}$ = a ratio on the order of

1 to 1.5	=	square shape
1.6 to 8	=	rectangular
Over 8	=	long rectangular

This derivation of the area of the radiative surface as well as the shape of the surface allows the evaluator to determine the required effective fire break or exposure distance from Figure 2. In addition, Table B-13 presents the material in Figure 2 in a tabular form.[60]

Several of the parameters of the model require examination at this point. The classification of an exposure surface by the amount of openings

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[60] Ibid., p. A51.

it presents is a very important element in evaluating the potential for ignition. The degree of exposure given to interior fuel loads by window openings is the chief element in determining their probability of ignition by radiative heat. The primary source of radiative heat is visible flame; hence, the amount of flame which breaks out of its closed "interior" fuel environment through windows and other wall openings is the basis for our concern with radiative area. Since buildings and structures vary widely in the amount of openings in their walls, a subjective classification is perhaps the most workable for our evaluatory efforts. The report by Cohn, Almgren, and Curless classifies openings in the terms of none, few, average, many, all. The determination is basically the estimation of what portion of that wall will not shield exposed buildings from radiative heat for any length of time.

A classification of none for "wall openings" implies a protected masonry wall with no doors, windows or wood frame combustible elements. Frontage walls with the standard NFPA (and fire hazard rating) classification of non-combustible or combustible are classified as all openings. This is due to their suspected inability to stand for any prolonged period of fire life.

Application of the Model

In the previous section on the estimation of conflagratory hazard within blocks, three cases or examples were discussed. Case 1 involved a residential neighborhood of single-family, one- and two-family homes, of wood-frame construction. These dwellings comprised 70 per cent of the frontage on the 650 foot sample block, or 455 feet of building width. Roofs were predominantly peaked to 15 feet, and of wood construction.

(Table 18). Since these dwellings are of wood construction, the wall opening category is stated as all. By the application of the model, the adjusted radiative fire area is found to be approximately 22,000 square feet, and of a long rectangular shape. In an area of average normal velocity winds, the required separation distance (see Table B-13) is 265 feet.[61]

The crucial test of this procedure occurs in the comparison of the derived figure for required effective separation distance and the actual separation. If the required distance is at least equal to the actual distance, the Cohn, Almgren, and Curless report would designate that area as a primary fire break. In all cases, the maximum required distance of any structural type in a block is the distance used as the required "block" distance. Where the actual separation is at least two-thirds of the required distance for separation "that increment should be considered a secondary fire break."[62]

The end result of the procedure embodied in this model is intended to be a comprehensive examination of the micro-environment of mass fire--or at least the potential for the group fire. Fire is itself a very transitory element; in that it is an emergency event, it is totally dynamic in both its ignition and spread. The preparation for controlling mass dynamism such as a mass fire must examine static elements as inputs to the spread. As inputs, these elements are defined as parameters, and hence our involvement with physical structure leads us to a required analysis of the arrangement, concentration, and composition of structure as a fuel--a basic element in the triangle of fire.

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[61] Ibid., p. B35.

[62] Ibid., p. A50.

The methods for computation of block mass-fire hazard and determination of fire spread limits have considered the building as the major fuel element in urban areas. This does not imply an ignorance of vegetative fuels nor of volatile storage fuels, but rather a concern with the more "usual" urban environment. We have discussed building density, height, and volume, and briefly alluded to building arrangement and separation. Building separation normally refers to the average distance separating the walls of adjacent buildings. This separation generally decreases as building density increases. The arrangement of these individual separations is of considerable importance for the period immediately following first ignition. If the initial fire spreads past this first separation, its perimeter increases exponentially, presenting larger control fronts. Thus, a description of the arrangement of buildings within each block may be in order.

The fire hazard models ignore an explicit parameter of arrangement for two reasons. First, the explicit presentation of arrangement is found implicitly in the parameters of percentage developed and density. Second, the conflagration limit model includes a provision for building set back (hence frontage arrangement) as a multiplier value. An unstated assumption of the models' formation may relate to the scale of the expected mass fire and the reliance on block and areal concepts of spread.

CONCLUSIONS

The stated objective of this study was an examination of the critical parameters in the spread of mass fires within an urban area. Such an examination must be made in terms of the urban environment as well as the fire research environment. The differences in scale of fuels as well as fuel reactions to ambient conditions are inherent in modeling ventures, and must be applied to the "real" area. If this is not possible realistically, it must be accomplished symbolically.

The models which were examined in the fourth chapter were not an explicit outgrowth of the specific parameters examined in Chapter Three. The models were easily adaptable, however, because it was based on a theory of fuel state and ambient dynamics. Because the models recognize the unique character of each sub-area of each urban area and rely on basic concepts of fuel loading and disbursement, they arrive, I believe, at a very simplified, workable predictor of potential hazard. Their simplicity <u>cannot</u> be used as a criticism of their comprehensiveness. A model is, by definition, a simplification of a real state. In that the model purports only to rate <u>potential</u> for disaster, it is a success. Attempts to discredit such a modeling approach to study as having failed to predict the area of spread or pattern of spread, fail in themselves by a lack of understanding of the basic purpose of the study. That purpose is merely the identification of potential.

Such an argument is not a weakening of a position of advocacy for the model, but rather a round-about means at describing the necessarily stochastic nature of non-deterministic modeling. It must be understood that when research deals with a dynamic process, such a fire spread, it must consider a random element of variability as inherent in all its parameters. The element of probability must be considered not only in the expression of potential for fire breeding, spread, and delimitation, but also as implicit in the model's structure and parameter definition. To attempt removal of the stochastic element and substitute precise historical conditions ipse dixit, in effect creates a deterministic model of a non-certain situation. Such determinism, by relying on non-stochastic descriptors of past elements, is forced to ignore parameters of the immediate situation. The result is a model which steps beyond its stated constraint, yet fails to achieve its explicit objective.

The outcome of the discussion concerning the parameters of the model in Chapter Four was essentially a relation of the importance of the fire spread parameters to the existing fire environment. The model is basically expressed as a description of mass and space in a special environment. Such terms are by no means strange to the urban planner and designer. The treatment of mass as a fuel and space as a channel of heat flow are somewhat alien to the planner, however. The designer is unaccustomed to having his well-structured setting of buildings and space referred to as fuel loads and fire breaks. Such a discrepancy in language has been the precise target of this study. Unless the urban planner is inclined to an understanding of the problems faced by disaster experts, he may well be working at cross purposes with them.

Disaster is not just a pre-occupation of men waiting-for-the worst. A re-examination of Table B-1 will impress upon the reader the magnitude of loss by mass fire. Many of those cities mentioned had excellent fire control teams, and perhaps acceptable conditions for the normal attenuation of conventional fire spread. Yet something went wrong.

Planning the form of a community is especially serious in the light of threatened disaster. Interest in mass-fire protection was intense immediately following World War II. An important conclusion drawn from the records and analysis of bombing surveys stated that the major destroyer was fire; fire storm and conflagration. The advent of the nuclear weapon has not changed this. Small fire breaks did not stop the spread of mass fire. Areas of low-density buildings actually fed fires, and allowed conflagrations to sweep across cities. The reaction after the war was a loud cry for the acquisition of large, thousand-yard wide areas of open land throughout the urban areas, set off to act as fire breaks. This meant the linking of existing parks and reservations with each other and with water courses, preserving hill barriers and hastening the clearance of areas for a very broad freeway rights-of-way. These elements are a part of the overall pattern which some schools of planning have advocated for decades.

The problem is still based upon economics, however. It is difficult, if not impossible, to convince people to pay for something which may not happen at all, or to sell their land when it is returning a profit. This is no new problem. The answer may well lie in the multi-use concept of land development. Under such a concept, land is explicitly acquired for some purpose, while creating benefits for an additional number of other purposes which are more difficult to value or to "sell" to the public. An examination of the critical parameters of the previously derived models may lend several clues to such multi-uses.

The need for more improved enforcement of building regulations may be recognized in governmentally spurred programs of industrialized building methods, federal construction-loan requirements, review of architectural and site design, and special materials research programs. These program types are not new; in fact, they are all operative or proposed. The degree of local involvement may be a crucial element. If responsible planning-oriented officials within local government understand the needs of mass-fire attenuation, and the areas of potential hazard within their community, they may be able to creatively enforce and regulate programs. This is, of course, an idealistic concept and perhaps oriented toward the use of administrative law. The thought of well-directed, responsible, comprehensively motivated planning on the part of local officials is nonetheless attractive.

The use of open space as a means of attenuating spread is a fortunate by-product of much recent development. The creation of freeway rights-of-way across urban areas has become a reality, yet these large 'divided' areas of the community are frequently without sufficiently wide (150 feet minimum) areas which might qualify as fire breaks. The institution of multiple-use open space is especially important in such areas. A primary use of these areas is most likely to involve recreation or transportation, yet it could just as easily involve purification lagoons for water and sewage treatment plants, industrial "park" areas, shopping center parking, airport or heli-port landing sites, or university campuses. Whatever the primary use, its accomplishment satisfies a major parameter in the halting of mass-fire spread.

Planning is of necessity a futuristically oriented activity, and presents no assurances that expenditures today will be relevant in the

30- to 50-year future. The use of multiple-use tactics are, therefore, all the more attractive in that they require relatively little explicit expenditure for projects which are viewed by the public as of too small a probable occurrence. The planning of yet undeveloped areas of the community is no less vital an area of concern for the disaster planner.

During World War II, numerous urban areas were the targets of incendiary and high explosive bombs. One of the hardest hit cities was Hamburg, Germany. It was subjected, in 1943, to a two-day firestorm of astounding proportions. The records of the fire protection service of that city were preserved intact by Dr. Hans Brunswig, Fire Chief. In a recent translation he states that

> "For three decades, city planners and architects have been discussing such ideas as 'relaxation,' the 'city in rural surroundings,' and 'satellite cities.' Their goals are based on sociological and hygenic grounds, and they have been able to realize these ideas many times in the last ten years of reconstruction. These trends are consistent with effective fire protection, regardless of whether a fire originates in war or peace."[63]

Dr. Brunswig undoubtedly has a great regard for the effect of passive urban form on the spread of mass fire. In 1966, he observed with regret and concern that many of the structural and land development preventative measures "for achieving structural fire protection have not yet become self evident conclusions...[64] The importance of examining urban fire environments on a block basis was further emphasized, in his statement that

> "If individual fires...are not properly fought..., or if these forces are unable to effectively combat these fires because of unfavorable structural and design characteristics,

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[63]Dr. Hans Brunswig, Practical Experiences of Fire Protection Services, Part 1, Trans. by Curtis E. Harvey and Wilham C. Truppner, Institute for Defense Analyses, June, 1966), p. 134. (My emphasis).

[64]Ibid., p. 163.

> the danger of the fusion of these fires into a row fire emerges. Row fires in turn can create block, area, and city fires.,... pushing fire fighting services from an offensive to a defensive position."[65]

The relevance of the loss of an offensive position in regard to any emergency or disaster must be evident. The crucial part played by a passive element of design (an element which can be controlled) must be recognized, dealt with, and improved. The importance of an elemental parameter is no less great because that parameter requires much public coordination and action, nor because that parameter is critical to an event which may never occur.

There can be little doubt that an urban planner trained in several analytical fields of survey and technical research; devoted to the concepts of public interest, welfare and safety; and well aware of the needs (the intimate needs) of each public service operation of the community could perform a vital service to that community. There are few such men available, however. The demands upon a physical planner's time may well force him to treat dispassionately all but his own physically-oriented land use plans. The socially oriented planner may well reject totally all concern with land use planning and effective privision of non-welfare oriented public services. In the end, the only persons concerned with public safety from fire may be fire safety personnel, the budget officer, and the insurance companies. In effect, this situation frequently exists today.

Planning's concern in the fire realm has been with the distribution of fire houses, the passing (not enforcement) of building codes and zoning ordinances, and the promotion of subdivision design techniques which ignore,

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[65] Ibid., p. 391. (My emphasis).

if anything, the total fire potential of the community. Safety standards, to a large extent, have been depressed, ignored, or changed to effect the same private interests which inevitably develop the community in uneconomical as well as unsafe forms.

Several questions which were unanswered in this paper might be asked here. Is zoning, as now practiced, an effective tool in grouping land uses in non-hazardous configurations? Is it being used to its full force? Are communities really getting their moneys worth when they allow extensive, hard-to-service development? Why hasn't a strong relationship developed between working urban planners and the technically oriented, expert groups concerned with public finance, fire safety, water quality, and the like? Can the planner, trained as a generalist, hope to effectively communicate with specialists in fire control, etc.? Is non-contact with service bureaus of the city government in effect non-support and thence opposition to those agencies? Can the blame for non-enforcement of building and housing codes be laid to the planner in part?

One area of concern is of course the financial arena. Many planning ventures of the past have been predicated wholly on the provision of federal and state monies. Since financial concerns underwrite much of the efforts toward data collection, it would seem only elemental that agencies seek out all available funds. In the instance of some federal programs, local planning agencies have entered into stage programs, and produced as a final result yet another paper plan. The continuation of the planning process, and perhaps even the imaginative expansion of the process have not frequently occurred.

Cynically speaking, what has not transpired is the dedication of planning effort to the provision of public safety from fire, with notable exceptions. The question is why. The answer may well be that local planning agencies fail to recognize that pre-planning for fire occurrence is not merely a matter of deriving ratios of equipment to population, but a whole series of needed enforcements of ordinances, codes, and statutes already on the books and all regarding as primary tools of the urban planner. The answer may well have to come from local fire officials who are able to swing sufficient public attention toward the possibility of fire spread. Scare tactics may well be abhorred, yet effective. In any instance, they are much desired over the real thing.

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APPENDICES

A. THE MECHANICS OF FIRE
AND FIRE SPREAD

B. DATA AND SUPPLEMENTARY
INFORMATION

APPENDIX A

THE MECHANICS OF FIRE AND FIRE SPREAD

Research by private and public organizations concerned with fire behavior and control has resulted in a large body of knowledge on the behavior of fire in urban and forest environments. Much of this has been contributed and sparked by the Forest Service of the Department of Agriculture and the National Fire Protection Association, (NFPA), but the experiences of municipal fire departments have also been invaluable. Foresters and wildlife managers have come to regard fire as an essential tool in certain stages of silviculture, in land improvement, and in fire hazard pre-planning. Much of their experience is directly applicable, or at least interpretable, to the urban situation.

Much of the available knowledge concerns small-scale fires, and those of low intensity. In such cases, the available fire control efforts are sufficient, and the combined elements of fuel, weather, and topography have not favored fire spread. In the urban environment, single-structure fires are also the most common in occurrence. Because of this, research on mass or large-scale fires has had to be conducted on a modeling basis, either in the open or in laboratory environments. Modeling situations are vital, for they permit close control and the measurement of experimental options, and can thereby allow accurate analysis of basic fire characteristics . As in all modeling situations, the validity of the extrapolation of small-scale data to a large-scale occurrences is open to question.

The propagation of certain fire characteristics has been shown to be at least partially dependent upon the size or scale of the fire itself.

Because some of these relationships are too vague to be detected in small fires, or because they may not be present at all, it would seem scientifically valid to expect a series of thresholds in fire scale at which relationships would occur.

It has generally been conceded by fire researchers that fire behavior at any one point is highly dependent upon fire action at all other areas in the fire. This has been referred to as a "pattern phenomenon."[1] Since fire behavior is also largely dependent on the state of the environment in which burning occurs, it is vital that a fire researcher concern himself with both the fire's "pattern" behavior and the environment's effect on that behavior. In other words, a fire must be considered as an element in an environmental system. The end result of such a relationship is the conclusion that large-scale inferences cannot be strictly drawn from small-scale fire occurrences without allowances for the fire environment, and its effect on fire growth.

Fire Environment

The environment of a fire is a crucial element to its propagation, further spread, and control. It is commonly described in terms of the relationships between factors of air flow, fuel nature, and topographic fire surface. As in all environments of a dynamic nature, it is never fixed, but may vary in numerous ways--among them space and time.

The descriptive size of a fire's environment is of crucial importance, for it may both limit a fire or be a cause for its further violent expansion. As with all real environments, the fire environment is

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[1] Clive M. Countryman, Mass Fires and Fire Behavior, (Berkeley: Pacific Southwest Forest and Range Experiment Station, United States Forest Service), p. 4.

three dimensional, extending vertically as well as horizontally. Countryman has described two broad types of fire environment, which he has termed closed and open.[2] Inasmuch as we are here primarily concerned with the urban situation, this is a vital distinction. A closed environment would normally isolate the fire from conditions outside its immediate envelope. A fire burning inside a building might well operate independent of conditions outside the building. The environment within the building is characterized by the arrangement of fuels, and their characteristics. The movement of air and the degree of moisture within the building might well be the function of the heating and ventilation system of the building. The environment of the fire is confined to the closed space of the building. In general terms, however, the fire environment of the city or urban area is not confined. Rapid and full changes can occur in fuel conditions, weather behavior and air movement. Topography may play a big part. By and large, the city is an open environment. A fire situation will be influenced easily by conditions outside its immediate environment.

It should be understood that a fire, originally started and furthered by a closed environment, may break out of that environment. In such a situation, the outside conditions can influence the fire's spread to other fuel, and to enlarge it in both size and intensity. As we shall see later, the point at which a fire escapes its closed environment and enters the open urban area may be the turning point in the development of a mass-fire.

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[2] *Ibid.*, p. 7.

Elements of Fire Environment

The three major elements of the fire environment, and the factors which influence the degree of fire spread are fuels, air mass, and topography.[3] The study of mass fire must include these three variables, and focus primarily on their interrelationships in the fire environment. The manner in which they affect fire characteristics and behavior is the substance of the majority of fire research, and of this paper.

Fuel

For our purposes, fuels may be described in terms of:

1. The type of fuel
2. The distribution of fuel
3. The exposure of the fuel
4. The environmental conditions surrounding the fuel.

These elements are not complete descriptors of and by themselves. The interrelationships between these characteristics play a vital role also, and must therefore be considered. Such interplay among the descriptors would include:

1. The variance of fuel characteristics with the time of day, week,or year.
2. The variance of fuels in regard to geographic location, both locally and nationwide.

For our purposes, it may seem clumsy to speak of the urban area in terms of "fuel." Yet in the fire environment, that is exactly what

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[3] *Ibid*., p. 9.

structures, buildings, and natural cover comprise.[4] The type of fuel which is found in the fire environment is of crucial importance. The emphasis of this paper, however, is directed more toward the arrangement of fuels, and so must devote only limited space to fuel types. Much scientific research is being conducted with the fuels of fire, yet it is on a level of chemical and physical research which places it beyond our scope. The varying degrees of combustibility of different fuels are of importance to the concepts of this paper, but will not be discussed further here.

In any one instance, fuel will be found in varying degrees of density. The degree of continuity with which a fuel is spread over an urban area will influence strongly the likelihood of fire spread. In any one urban environment flammable fuels may be spread continuously over an area, only sparingly with non-flammable areas between, or may completely surround non-flammable or bare areas. The factor of "continuity" of spread as such is very important in the urban fire environment.

Also important to the distribution of fuels is the concept of arrangement of fuel particles. This refers not only to the horizontal arrangement of fuel, but to the vertical as well. Fuels may be closely packed or in a very loose configuration. Finally, the amount of fuel which is found in an area must be considered. Allied with this factor is the consideration of proximity to different non-fuels.

One major difference between urban fuels and wildland fuels is that in the urban fire environment fuels are distributed among non-fuels.

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[4] R.H. Renner, S.B. MArtin, and R.E. Jones, Parameters Governing Urban Vulnerability to Fire from Nuclear Bursts, Phase I, (San Francisco, United States Naval Radiological Defense Laboratory, June 30, 1966), p.151.

Therefore, a discussion of fuel must consider non-flammable areas. Urban fuels are primarily located in either structures or vegetation. Structural fireloads are usually the heaviest, containing the larger volume of fuel. In the majority of urban fire environments, fuels are primarily found between ground level and the second story.[5]

The exposure of a fuel is of prime importance in the study of fire spread. As will be discussed later, radiative energy is a major factor in the spread of flame. As far as "interior" fuels are concerned, their location within a structure, the amount of opening in a structural barrier, the height of the structure above the ground, and the shape of the structure are all critical factors in the amount of radiative heat energy reaching the fuel. In the urban fire environment, elements which will most commonly limit exposure of exterior fuels would include structures and buildings, other fuels (such as vegetation, trees), and topography.[6]

The environmental conditions of the fuel and of its surroundings are usually described in terms of several generalizations. These treat the age of the fuel, the temperature of the fuel and of the air, the moisture content of the fuel and of the air, and the wind conditions in the immediate area of the fuel. Most of these ambient conditions are weather dependent, and can therefore be described in terms of weather variations, such as seasonal cycles, annual cycles, and day-night changes. These include changes of a local nature as well as climatic cycles.[7]

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[5] Ibid., p. 157.

[6] Ibid., P. 161.

[7] Ibid., pp. 162-165.

Air Mass

The air mass which surrounds a fire environment, and is part of it, is perhaps the most variable of the elements. The air mass may interact with both the topography and the fuel near the surface of the earth. There are, of course, several variables which are critical in defining the air as it affects a fire. Among these factors are:

1. The temperature of the air mass, specifically at the varying levels above the fire.
2. The stability of the air mass, and the presence or absence of winds at the varying altitudes.
3. The degree of precipitation in the air.
4. The humidity of the air in the fire environment.
5. The amount of wind in the fire area.
6. The atmospheric pressure in the fire environment.
7. The presence of local conditions such as ground fog.

In reality, when we speak of the air mass, we are referring to the meteorological conditions in the fire area. Each of the elements given above, which are atmospheric descriptors, can be shown to have various degrees of effect on fuel conditions, fire spread, and fire termination.

The temperature of an urban area (which conceivably forms the total urban fire environment) is instrumental in determining the amount of moisture the air is capable of holding before precipitation occurs. The latitudinal location of a city, its basic topography, and its distribution between land and water are all contributing factors to this temperature. Besides daily temperature variances, of course, annual variations are important to the fire environment.

The relative humidity of the air is a vital parameter in the fire environment. Very moist air has been verified to contain up to 4% water by volume.[8] The effect of humidity on fire, however, is largely of an indirect nature. The moisture content of many fuels is very closely associated to the relative humidity. In forest fire research, it has been found that relative humidity may be taken as a fairly reliable indicator of fire hazard.[9]

The major meteorological factor in fire spread is generally considered to be wind. Reports of major urban conflagrations have frequently cited wind velocity, presistence, and instability as the major problem in confining the fire. Quite apart from its role of supplying oxygen to a fire area, wind can drive burning firebrands far ahead of the control lines to start new spot fires.[10] Apart from surface winds, upper strata currents may affect the development of large fire convection columns, thereby changing the energy release pattern of a high intensity fire.[11] The indirect effects of wind must, of course, include a drying effect on the moisture content of fuels through the evaporation process.

The effect of wind in urban fire environments may be partially due to the shape of the urban area. One source states that the winds in urban fire areas are strongly influenced by:

1. The arrangement of buildings and structures on the ground, the resultant artificial topography. Such structures must also be thought of in terms of "fuel piles."
2. The height of structures, and the variations in these heights.
3. The density of urban structures, creating a "uniform"

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[9] Countryman, p. 14.

[10] Ibid.

[11] Ibid.

plain of heat-producing units, or perhaps a spotty pattern which would influence ground convection currents.

4. The distance between structures.
5. The size of structures, in terms of their physical dimensions, and of their shape.
6. The arrangement of the ground-surface, and the changes in elevations caused by man-made structures or natural land forms. Such "shapes" would create channels of wind flow, both in normal and fire environments.
7. The texture or perhaps grain of the urban area, in the reference of a frictional surface which would slow air movement, creating disruptions of smooth patterns, and micro-air environments.
8. The topography of the surrounding region, which would determine the manner in which air flows were directed at the urban area, and from which direction and altitude. This would also contribute to the meteorological factors, describing the humidity, moisture content, and temperature of the air.[12]

It should be vital to an understanding of a specific fire environment to determine wind patterns. Winds in an urban area are generally set by the overall regional atmospheric conditons, yet are strongly influenced by the urban form. Of prime concern to the fire environment is the rotational pattern of wind. Such rotation may be started where ordinary surface and low-level winds are retarded by structures, vegetation, or land forms, or where there are local thermal sources.

Topography

The third of the major fire environment descriptors is topography.

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[12]Renner, p. 146.

It can be said to have both a direct and an indirect effect upon the spread of fire. In the general case, fires spread more rapidly up a slope than on level ground. This is primarily due to the heating effects of fire radiation on up-slope fuels, and the effect of wind which is generated by the fire in uphill heating.[13]

Conversely, the spread of fire downslope is less than that on level ground, due to the same factors of lessened radiative heating and wind. Rarely in an urban area, however, is a simple slope situation found. The usual topography consists of short, broken slopes. In these areas, fire is generally considered to move slowly, and with a more erratic behavior. It should be emphasized that the effect of windflow may greatly increase or decrease the spread of fire over all forms of topography.

Importantly for the fire environment, topography affects local weather and micro-climate. The greatest effect here may be in the thermal differences found on slopes of differing sun orientation. Such thermal variations might well affect the fuel found on that slope.[14] Likewise, the channeling of windflows may be quite important, resulting in increases in wind velocity in restricted valleys.

In a description of the topography as an element in the fire environment, we are concerned with four factors. These include:

1. The type of surface, that is, land or water.
2. The degree of angle of steepness of the slope.
3. The direction of slope of the land.
4. The elevation of the land in reference to the general area.[15]

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[13] Countryman, p. 13.

[14] Ibid., p. 14.

[15] Renner, p. 100.

Clearly, there are certain topographic surfaces which cannot be thought of as fuels (i.e., concrete in the normal sense), but their existence as non-flammables is equally important when considering fire spread. Such surfaces may provide fire-breaks, or gaps in a continuous area of fuels. The dimensions of such gaps will be of vital importance in the following chapters.

The slope of the topography is an all important variable in fire control as well as fire spread, for it can be an effective block to water supply as well as a barrier to fire spread. Certainly the orientation of slopes is vital in foreseeing the path of possible fire spread, especially if natural boundaries to fire spread are formed by slope ridge lines.

The Mechanics of Fire Spread

The spread of fire through a complex of fuels is a process involving stages of both ignition and combustion. The crucial point for all discussions concerning fire spread is the point separating non-ignition and ignition of a fuel. The line separating these two stages can be drawn easily only when the fuel being consumed is arranged in a discontinuous pattern. When fire is burning through a continuous fuel array, the point of ignition may well be obscured by the rapid and changing advance of fire. In nearly all cases, however, the unignited fuel is heated to its point of ignition by conduction, convection, and/or radiation from the heat of combustion of ignited fuel.[16] The importance of each of the three modes of heat transfer is dependent upon the fire environment; that is, upon the elements of fuel, topography, and the air mass.

The process of conduction, which involves "body-to-body" contact between fuels plays little part in the spread of fire through discontinuous fuel arrays. The urban fire environment presents, for the most part, a discontinuous fuel array. The element of conduction would remain a minor factor in the mass spread of urban fire, therefore, since discontinuous fuel arrays must rely upon means of heat transmission which are not dependent on physical continuity.

In the presence of large non-fuel separations between fuel elements, the dominant means of heat transfer is radiation. This is likewise true in cases of "downward propagation" of a fire. In such instances, the exposure of a fuel to the heat source is a critical factor

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[16] Ibid., p. 247.

[17] Ibid., p. 248.

in ignition. Importantly for our purposes, distance from the heat source is also vital.[17] The method of heat convection has in the past been the cause of fire spread in many major disasters. The transmission of heat through bodies of highly heated air accounts for much upward fire spread. Convective currents have frequently carried burning solid fuel, or fire brands, long distances to create new fires. In the case of convective transfer, exposure and position of the unignited fuel in relation to the fire source is the prime factor in determining ignition.

In the discontinuous fuel array, then, there may be a clear distinction between ignited and unignited fuels. Likewise, the time and point of ignition can be easily marked. Both these factors are vital to the control of fire spread. We shall later examine this facet of fire control in greater detail.

From the above discussion, it can be discerned that the three methods of fire transfer are based on two processes. These are heat-transfer and mass-transfer. The two are quite dissimilar. As a fuel element burns, the heat that is generated is given off in several ways. As we have seen, radiation of heat from the flame is a dominant means, and is governed by the temperature and scale of the flame. Radiative heat is omni-directional from the flame zone. When radiant heat strikes an unignited fuel, it is absorbed by the fuel and raises the temperature of the fuel. The remainder of the radiant heat is absorbed by non-combustible surroundings, or by the ignited fuel itself. In the study of fire spread, we are primarily concerned with the amount of heat absorbed by the unignited fuel. This amount can be generally said to be determined by geometric factors, that is distance from the heat source and the amount of exposure of the fuel to the flame source. Generally speaking, the nearer a fuel to the heat source, the greater the contributed amount of radiant heat to that fuel. Likewise, the nearer a fuel is to a heat source, the greater the amount of high intensity surface exposure.[18]

The radiant energy which is emitted into the immediate air mass contributes to the direct transfer of energy in molecular motion. The resultant motion is released in turbulent eddies and currents of air directly above the flame of the active fire. The result of the turbulence of air above a flame is a "plume" of heated air and burning gases commonly termed a "convection column." Frequently this very buoyant column transports solid, incompletely burned fuel far above a fire, out of the convection current. In the event these solid brands continue active burning, and land elsewhere, they create a new fire. The superheated gases and air, however, also carry great potential for starging fire.

In the event the convection column comes into contact with an unignited fuel, it envelops the exposed surface of the fuel with a heated layer of air, raising the temperature of the fuel. The fuel itself is heated by molecular transfer through conduction. The degree to which the fuel absorbs the heat of the column is dependent upon the temperature difference between the two elements, the surface characteristics of the fuel, the transfer nature of the fuel, and the nature of the flow of the heated gases past the fuel.[19] Since the flow of the buoyant convection column will be greatest in a vertical direction, unignited fuel above the fire source will be greatly affected by this means of heat transfer. The importance of topography should be self evident at this point.

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[18] Ibid.

[19] Ibid., p. 249.

The spread of fire by the transfer of mass plays an important part. Mass transfer is usually associated with (1) the flow of burning liquid fuels downhill, (2) the flow or emission of burning gases, and (3) the transfer of burning solid fuel. The importance of these means of spread lies in the manner in which they are carried away from the fire. Burning solid and liquid fuels travel by the force of gravity. All three forms of matter may be forcibly ejected from a fire by explosion of a container, or by the explosion of hot gases. Both burning solids and gases may be carried by the buoyant action of heated air.

The slope of the ground will determine much of the direction and extent of fire spread by solid or liquid transfer. The stability of the air mass and the disturbance caused by the convective column can carry burning fuel many miles. The horizontal wind velocity within the fire environment is a large factor in determining the distance over which brands can travel.[20]

The spread of fire, then, is more than just a function of simple elements of distance between fuels. It is a complex interaction of all the elements of the fire environment, and of the determinants of fire intensity.

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[20] *Ibid.*, p. 251.

APPENDIX B

DATA AND SUPPLEMENTARY INFORMATION

TABLE B-1

SELECTED FIRES AND CONFLAGRATIONS SINCE 1910

United States and Canada

Year	City	Remarks	Monetary Loss
1911	Bangor, Maine	55 acres of buildings	$ 3,200,000
1913	Hot Springs, Ark.	518 buildings	2,250,000
1914	Salem, Mass.	1600 bldgs., 6 killed	14,000,000
1917	Atlanta, Ga.	1938 buildings	5,500,000
1918	Minnesota Forest Fires	4000 bldgs., 559 killed	25,000,000
1922	New Bern, N.C.	1000 bldgs., 40 blocks	1,500,000
1923	Berkeley, Calif.	640 buildings	6,000,000
1925	Shreveport, La.	196 buildings	1,000,000
1930	Nashua, N.H.	350 buildings	2,000,000
1933	Auburn, Maine	250 buildings	1,500,000
1934	Chicago, Ill.	Stockyards	4,617,000
1934	Nome, Alaska	20 city blocks	2,000,000
1935	Los Angeles, Calif.	222 bldgs., forest fire	3,620,000
1941	Jersey City, N.J.	Waterfront	5,000,000
1945	Alton Bay, N.H.	215 buildings	200,000
1947	Texas City, Texas	Waterfront, 468 killed	67,000,000
1947	Maine Forest Fires	1200 dwellings	30,000,000
1956	Malibu, California	140 bldgs., forest fire	-,---,---
1959	Roseburg, Ore.	110 bldgs.	10,000,000
1961	Los Angeles, Calif.	505 buildings	30,000,000
1965	Louisville, Ky.	Industrial, 12 killed	10,000,000

Source: Fire Protection Handbook, Twelfth Edition, 1962, N.F.P.A., pp. 1=59, 1-63.

TABLE B-2

RANKING OF PRINCIPAL FACTORS CONTRIBUTING TO SPREAD

OF CONFLAGRATION IN THE UNITED STATES AND CANADA

Period 1901 to 1925	Percent of Total
1 - Wood Shingle Roofs	25.4%
2 - Inadequate Water Distribution System	13.0
3 - Inadequate Public Protection	13.0
4 - Wind Velocity Greater than 30 m.p.h.	12.5
5 - Lack of Exposure Protection	10.2
6 - Delay in Giving Alarm	2.8
7 - Congestion Reduced Fire Fighting Access	2.8
8 - Failure of Water Supply	2.8

Period 1926 to 1961	
1 - Wind Velocity Greater than 30 m.p.h.	15.3%
2 - Inadequate Water Distribution System	12.2
3 - Lack of Exposure Protection	11.1
4 - Wood Shingle Roofs	9.2
5 - Inadequate Public Protection	8.4
6 - Unusually Hot or Dry Weather	8.4
7 - Delay in Fire Discovery	5.3
8 - Delay in Giving Alarm	5.0
9 - Congestion Reduced Fire Fighting Access	4.6
10 - Forest or Brush Fire Entered Town	3.8

Source: Fire Protection Handbook, Twelfth Edition, 1962, N.F.P.A., p. 1-64.

TABLE B-3

CHANGE IN RANKING OF FACTORS BETWEEN TIME PERIODS

1901 - 1925 and 1925 - 1961

Those Increasing in Importance in Spread of Conflagrations

1. Lack of Exposure Protection
   10.2% to 11.1%

2. Wind Velocity Greater than 30 m.p.h.
   12.5% to 15.3%

3. Delay in Giving Alarm
   2.8% to 5.0%

4. Congestion Reduced Fire Control Access
   2.8% to 4.6%

5. Unusually Hot or Dry Weather
   8.4%

6. Forest or Brush Fire Entered Town
   3.8%

Those Decreasing in Importance in the Spread of Conflagrations

1. Wood Shingle Roofs
   25.4% to 9.2%

2. Inadequate Water Distribution Systems
   13.0% to 12.2%

3. Inadequate Public Protection
   13.0% to 8.4%

4. Failure of Water Supply
   2.8% to less than 1%

Source: *Fire Protection Handbook, Twelfth Edition, 1962,* N.F.P.A., p. 1-64.

TABLE B-4

COMPARATIVE FIRE STATISTICS

FOR THE UNITED STATES

1966 and 1967

	1966	1967
Alarms per 1000 population	20.1	20.0
Fires per 1000 population	10.8	10.4
Losses per capita	$5.60	$5.90
Buildings fires per 1000 population	4.2	4.1
Average building fire loss	$1241	$1342

Source: "Fire Record of Cities, 1967," Fire Journal, Vol. 62 #4, July 1968, p. 35.

TABLE B-5

COMPARATIVE FIRE STATISTICS

FOR THE UNITED STATES

BY CITY SIZE

	Under 20,000	20,000 and over
Alarms per 1000 population	16.6	20.0
Fires per 1000 population	11.6	10.4
Fire losses per capita	$8.24	$5.90
Building fires per 1000 population	4.8	4.1
Average building fire loss	$1605	$1342

Source: "Fire Record of Cities, 1967," Fire Journal, Vol. 62 #4, July, 1968, p. 36.

TABLE B-6

POTENTIAL FIRE AREAS - 1967

(Cubic Feet)

Fire Area (Cubic Feet)	# of Fires Involving Less than 80 Per Cent of Potential Fire Area	# of Fires Involving More than 80 Per Cent of Potential Fire Area	# of Fires Extending to Other Properties
Under 50,000	3	2	1
50,000 to 99,999	2	11	0
100,000 to 249,999	8	45	12
250,000 to 499,999	16	55	13
500,000 to 999,999	16	44	11
1,000,000 to 1,999,999	10	16	11
2,000,000 and over	13	14	8
TOTAL	68	187	56
Area not Reported	9	27	7
Extinguished by Sprinklers	8	0	0
Area not a Factor or No Data	34	0	0

ource: Warren Y. Kimball, "Control of Large-Loss Fires," Fire Journal, November , 1968, Vol. 62 #6, p. 73.

TABLE B-7

WATER APPLICATION RATE

GALLONS PER MINUTE PER 100 CUBIC FEET OF FIRE AREA

Water Density Applied Per 100 Cubic Feet of Fire Area, GPM	Number of Fires Reported - 1967	
None	2	0.5%
Under 0.10	33	8.3%
0.10 to 0.24	48	12.1%
0.25 to 0.49	65	16.4%
0.50 to 0.74	36	9.1%
0.75 to 0.99	27	6.8%
Total Under 1.00	211	53.3%
1.00 to 1.49	27	6.8%
1.50 to 1.99	13	3.3%
2.00 to 2.99	24	6.1%
3.00 to 3.99	11	2.8%
4.00 and over	6	1.5%
Total Over 1.00	81	20.4%
Fires where not a factor	10	2.5%
Fires where data not available	94	23.8%
Total Reported Fires	396	100.0%

Source: Warren Y. Kimball, "Control of Large-Loss Fires," Fire Journal, November, 1968, Vol. 62, #6, p. 74.

TABLE B-8

WATER SUPPLY DEFICIENCIES - 1967

Cause	No. of Reported Occurrences
Inadequate supply at hydrants	27
Small dead-end mains	5
Water storage depleted during fire	4
Private water supply inadequate	4
Public and private water storage quickly exhausted	1
Valve closed and pumps not operating	1
Valve partly closed	1
Closed valve reduced pressure	1
Valve found closed when fire started	1
Low pressure	1
Water lost through large pipes in fire building	1
Failure to start fire pumps	1
Failure of power to city pumps	1
Building standpipe inadequate	1
Small, low-pressure main	1
Volume adequate for only one hydrant	1

Source: Warren Y. Kimball, "Control of Large-Loss Fires," Fire Journal, November, 1968, Vol. 62, #6, p. 77.

TABLE B-9

MUTUAL AID RESPONSE - 1967

Number of Outside Fire Departments Responding	Number of Fires
1	35
2	36
3	30
4	24
5	23
6 - 9	38
10 or more	10
Total with Mutual Aid Response	216
No Mutual Aid Used	164
No Data	16
Total Reported Large Loss Fires	396

Source: Warren Y. Kimball, "Control of Large-Loss Fires," Fire Journal, November, 1968, Vol. 62, #6, p. 76.

TABLE B-10

REQUIRED FIRE FLOWS UNDER AMERICAN INSURANCE ASSOCIATION STANDARDS - 1967

Population of Community	Required Fire Flow (gpm)	Required Fire Flow (mgd)	Duration (hours)
1,000	1,000	1.44	4
1,500	1,250	1.80	5
2,000	1,500	2.k6	6
3,000	1,750	2.52	7
4,000	2,000	2.88	8
5,000	2,250	3.24	9
6,000	2,500	3.60	10
10,000	3,000	4.32	10
13,000	3,500	5.04	10
17,000	4,000	5.76	10
22,000	4,500	6.48	10
27,000	5,000	7.20	10
33,000	5,500	7.92	10
40,000	6,000	8.64	10
55,000	7,000	10.08	10
75,000	8,000	11.52	10
95,000	9,000	12.96	10
120,000	10,000	14.40	10
150,000	11,000	15.84	10
200,000	12,000	17.28	10
Over 200,000	12,000 plus 2,000 to 8,000 gpm additional for a second fire for a 10-hour duration		

Source: James F. Casey, Ed. The Fire Chief's Handbook, New York: Reuben H. Donnelly, Corp., 1967, p. 66.

gpm = gallons per minute

mgd = million gallons per day

TABLE B-11

THE RECOMMENDED AREAS SERVED FOR HYDRANTS

(AIA) - 1967

Fire Flow Required (gallons per minute)	Average Area per Hydrant (square feet)
1,000	120,000
2,000	110,000
3,000	100,000
4,000	90,000
5,000	85,000
6,000	80,000
7,000	70,000
8,000	60,000
9,000	55,000
10,000	48,000
11,000	43,000
12,000	40,000

Note: 1 acre = 43,546 square feet

Source: James F. Casey, The Fire Chief's Handbook, New York: Reuben H. Donnelly, Inc., 1967, p. 67.

TABLE B-12

MULTIPLIERS FOR BUILDING CHARACTERISTICS

Class 1 Roof Construction - Fire Resistive, 2-Hour or Better

Story Height	WALL OPENINGS None	Few	Average	Many	All
1	.4	1.8	3.6	7.2	12
2	.7	3.6	7.2	14	24
3	1.1	5.4	11	22	36
4	1.4	7.2	14	29	48
5	1.8	9	18	36	60
6	2.2	11	22	43	72
7	2.5	13	25	50	84
8 & Over	2.9	14	29	58	96

Class 2 Roof Construction - Noncombustible or Fire Resistive

Story Height	WALL OPENINGS None	Few	Average	Many	All
1	10	11	12	14	18
2	10	12	14	17	27
3	10	13	15	21	35
4	10	14	17	24	44
5	10	15	19	28	52
6	10	15	21	32	60
7	10	17	23	35	69
8 & Over	10	17	24	39	77

Class 3 Roof Construction - Wood, Flat or Peaked Up to 15 Feet

Story Height	WALL OPENINGS None	Few	Average	Many	All
1	30	31	32	34	38
2	30	32	34	37	47
3	30	33	35	41	55
4	30	34	37	44	64
5	30	34	39	48	72
6	30	35	41	52	80
7	30	36	43	55	89
8 & Over	30	37	44	59	97

TABLE B-12 Continued

Class 4 Roof Construction - Wood, Bow String Truss or Peaked 16 - 25 Feet

Story Height	WALL OPENINGS				
	None	Few	Average	Many	All
1	45	46	47	49	53
2	45	47	49	52	62
3	45	48	50	56	70
4	45	49	52	59	79
5	45	49	54	63	87
6	45	50	56	67	95
7	45	51	58	70	104
8 & Over	45	52	59	74	112

Class 5 Roof Construction - Wood, Peaked 26 Feet and Over

Story Height	WALL OPENINGS				
	None	Few	Average	Many	All
1	60	61	62	64	68
2	60	62	64	67	77
3	60	63	65	71	85
4	60	64	67	74	94
5	60	64	69	78	102
6	60	65	71	82	110
7	60	67	73	85	119
8 & Over	60	67	74	89	127

Source: B.M. Cohn, L.E. Almgren, M. Curless, <u>A System for the Local Assessment of the Conflagration Potential For Urban Areas</u>, (Chicago: Gage, Babcock and Associates, Inc., 1965), p. A48.

TABLE B-13

REQUIRED SEPARATION DISTANCES IN FEET

Average Wind Velocity →	Low (7 mph or less)			Normal (18 mph or less)			High (31 mph or less)		
Shape of Radiating Area →	Square	Rectangular	Long Rect.	Square	Rectangular	Long Rect.	Square	Rectangular	Long Rect.
ADJUSTED RADIATING AREA, SQ. FT.									
1500							120		
1600							120	120	
2200							130	130	120
2300				120			130	130	120
2600				125	120		140	135	125
3200				135	130	120	150	145	135
3800	120			145	140	130	160	155	145
4100	125	120		150	145	135	165	160	150
5000	135	130	120	160	155	145	180	170	160
6000	150	145	130	175	170	155	190	185	170
7000	160	155	140	185	180	165	200	195	180
8000	170	165	150	195	190	175	210	205	190
9000	180	175	160	205	200	185	220	215	200
10,000	190	185	165	215	210	195	230	225	205
11,000	200	195	170	225	220	200	240	235	215
12,000	210	200	180	235	225	205	250	245	220
13,000	220	210	185	240	235	215	260	250	230
14,000	225	220	195	250	245	220	270	260	235
15,000	235	225	200	260	250	225	275	265	240
16,000	240	230	205	265	260	235	280	275	250
17,000	250	240	210	275	265	240	290	280	255
18,000	255	245	220	280	270	245	295	285	260
19,000	265	255	225	290	280	250	305	295	265
20,000	270	260	230	295	285	255	310	300	270
21,000	275	265	235	300	290	260	320	305	275
22,000	285	270	240	310	295	265	325	315	280
23,000	290	275	245	315	305	270	330	320	285
24,000	295	285	250	320	310	275	340	325	290
25,000	305	290	255	325	315	280	345	330	295
26,000	310	295	260	330	320	285	350	335	300
27,000	315	300	265	340	325	290	355	340	305
28,000	320	205	270	345	330	295	360	345	310
29,000	325	310	275	350	335	300	365	350	315
30,000	330	315	280	355	340	305	375	355	320
32,000	340	325	290	365	350	315	385	365	330
34,000	350	335	300	375	360	325	395	375	340
36,000	360	345	305	385	370	335	405	385	350
38,000	370	355	315	395	380	340	415	395	355
40,000	380	365	320	405	390	350	425	405	365
42,000	390	375	330	415	395	355	435	415	375
44,000	400	380	340	425	405	365	440	425	380
46,000	410	390	345	430	415	370	450	430	390
48,000	420	395	355	440	420	380	460	440	395
50,000	425	405	360	450	430	385	470	445	400
52,000	435	415	365	460	440	395	475	455	410
54,000	440	420	375	465	445	400	485	460	415
56,000	450	430	380	475	450	405	490	470	420
58,000	460	435	385	485	460	415	500	475	430
60,000	465	445	390	490	465	420		485	435
62,000	470	450	400	500	475	425		490	440
64,000	480	455	405		480	430		495	445
66,000	485	465	410		490	440		500	450
68,000	495	470	420		495	445			460
70,000	500	480	425		500	450			465

Source: B.M. Cohn, L.E. Almgren, M. Curless, A System For The Local Assessment of The Conflagration Potential of Urban Areas, (Chicago: Gage Babcock and Associates, Inc., 1965), p. A51.