THE RESPONSE OF RURAL SETTLEMENT TO A LOCAL HAZARD SYSTEM: A MODEL AND SIMULATION

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ABSTRACT

THE RESPONSE OF RURAL SETTLEMENT
TO A LOCAL HAZARD SYSTEM:
A MODEL AND SIMULATION

By

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A theoretical model of the interaction between the settlement process and a natural event system is constructed, based on empirical and theoretical work in the areas of settlement geography and natural hazards research. Settlement geography lacks a strong theoretical framework, and tends to ignore settlement as a process. No basic generalizations have emerged concerning the interaction of settlement and the environment, and the role of hazard systems in historical processes has yet to be considered. The study focuses upon three important questions: (1) What is the general character of the process of settling a rural agricultural area? (2) How often and with what magnitude do natural events occur? and (3) How does the settler's perception of the hazard system influence the resulting settlement pattern? A verbal model is developed and translated into an interactive computer simulation model. The stochastic simulation is written in the computer language BASIC.

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Dedicated To LARRY NEITHERCUT

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CHAPTER I

A THEORETICAL MODEL OF HAZARD-SETTLEMENT INTERACTION

Introduction

Two specific themes have dominated human geography since its founding: man's spread across the face of the earth making it his home and man's perception of and interaction with his environment. From Aristotle's explanation of the suitability of settling a region as a function of the distance to the equator, to the most sophisticated utilization of LANDSAT imagery, these themes have continually been at the forefront of geographic investigation.

The topics of human settlement and man's relationship with his environment are so basic to the human condition that their timelessness is not particularly surprising. These themes are sufficiently broad to attract the attention of members of other disciplines, yet consistently they have been a major focus of human geographers. Within geography, the interpretation of these themes has varied. Indeed, much of the history of the discipline and the history of geographical ideas in America is embodied in the rise and fall of differing orientations to these themes.

This study is an investigation into an area at the core of these two themes: the relationships between human settlement and the environment. It is an attempt to create a general conceptual model which will explain the basic relationships between the process of man settling the land and the surrounding environment. The final goal of this study is the translation of the model into a computer simulation so that it might be eventually compared with real world settlement processes. The development of a model nearly always requires the focus to be narrowed in the difficult struggle to delineate the workings of a complex system. The translation of the model into a mechanical form, the simulation, understandably requires another degree of specificity. It is, then, the goal of this work to develop and then simulate a conceptual model of the relationships between rural settlement and the most dramatic elements of the environment, natural hazards.

Settlement Geography

While the study of settlement has been a common topic of investigation in geography, the maturity of the pursuit remains at a low level. An indication of this is the relatively recent attempt to establish initial specific definitions in settlement geography and the disagreement which followed (Stone, 1965; Jordan, 1966; Stone, 1966;

Mitchell, 1966). Until recently, much of the work in settlement geography was simply historical narratives of geographical topics. Gentilcore's "Vincennes and French Settlement in the Old Northwest" (1957) provides a good example of this type of work. Attempts at analysis or explanation during this period were usually mechanistic and/or deterministic. An example is McDermott's attempt to explain an advance and retreat of settlement in Northern Ontario solely as a result of changing provincial policies (1961). The emergence of a sound analytic approach in historical geography, primarily through the influence of Andrew H. Clark (Jakle, 1971, pp. 1090-1), brought new depth to the study of settlement. These later studies usually endeavored to reconstruct, through the use of original survey and land office records, the detailed settlement pattern at a number of points in time. This time slice approach allowed interpolation between the reconstructed geographies of the past to show different periods of geographic change. This type of work is best exemplified by Harris' notable <u>The Seigneurial System in Early Canada: A Geographical Study</u> (1966). The weakness of such studies is that the data used to construct the cross sections may not effectively delimit the periods of development or changes within a settlement; perhaps more importantly the idea of process is simply ignored.

There have been few research works devoted to the study of settlement as a process. Bylund constructed a deterministic model of settlement in Northern Sweden which allowed him to simulate settlement by assigning attractive weights to a church, a road and three parent settlements (Bylund, 1960). Hudson, borrowing a theoretical framework from plant ecology has attempted to construct a general location theory for rural settlements (Hudson, 1967; Hudson, 1969). Norton, most recently, has simulated the settlement of Southern Ontario stochastically, utilizing a number of indicators of township character, such as land quality and distance to a regional entry point (1976).

These studies are major contributions to the initial understanding of the process of settlement, yet the major thrust of all of the models has been to predict rather than explain the process. Norton, for example, is not as interested in understanding and being able to explain the workings of the settlement process in Ontario, as he is in being able to develop a predictive tool that could be used to duplicate the process in areas where no land records exist. Indeed, even Hudson's attempt to construct an explanatory theory has been criticized by some who question its universality as well as the applicability of ecological theory (Grossman, 1971). Hudson's theory is based simply on the locational aspects of the settlers, that is their frequency and distance apart. In this way Hudson avoids an explanation of settlement as a human process.

Geographers have long recognized the importance of differing environmental influences on the settlement process, and yet rarely have they attempted to generalize into a conceptual framework the character of these relationships. Griffith Taylor's monograph Canada: A Study of Cool Continental Environments and Their Effect on British and French Settlement (1947) was a landmark study in describing the physical and climatological stage on which Canada was settled, yet it remained a descriptive narrative. Perry explained that one of Taylor's ". . . major interests was in the effect of climatic conditions on settlement in Australia . . ." (Perry, 1966, p. 138), that is, he was interested in the end result, and not in the process which caused the result. Perry's article, encouragingly titled "Climate and Settlement in Australia 1700-1930: Some Theoretical Considerations" is designed to show the ". . . origin of their optimism . . ." and ". . . the general trend of thinking about climate and settlement in Australia . . ." but does not deal with the theoretical consideration of the relationship between environmental hazards and the settlement process (Perry, 1966, p. 139). Indeed, Heathcote's magnificent study Back of Bourke: A Study of Land Appraisal and Settlement in Semi-Arid Australia (1965) is an inspired geosophy of Australian settlement, but again Heathcote does not attempt to elaborate on the general relationships between settlers and a hazardous environment. There have been a number of other studies concerning early settlement and environmental perception. Peters (1969), for example, has shown how early Kalamazoo County, Michigan, was settled in successive stages owing to the settlers' perception of the attractiveness of the prairies. Yet all of these studies suffer from a weakness that Taafe has criticized an earlier period of geography for: "Its failure to lead to cumulative generalizations. What one geographer found out about the effect of environmental features was seldom referred to in the next geographer's study" (Taafe, 1974, p. 5). Clearly then, while much of the recent research in the area of settlement and settlement's relationship to the environment has been quality empirical investigation and landmark attempts at predictive models, there is a distinct lack of attempts to develop explanatory models to describe the actual process in general terms.

Geography and the Man-Land Tradition

The study of man-environment relationships has long been a topic of investigation in American geography. As early as 1864, George Perkins Marsh wrote Man and Nature; or, Physical Geography as Modified by Human Action (1864). James explains that "in his wide reading, especially of the works of Humboldt, Ritter, Guyot, and Mary Somerville, [Marsh] recognized that a 'new geography' had appeared, focusing on the close interconnections between man and his natural surroundings" (James, 1972, p. 195). Marsh was particularly concerned with man's destructive effect upon the environment and in many ways was America's first "conservationist."

The man-environment theme continued to be popular in American geography. It was embodied in the concept that human development and behavior is the result of direct responses to the natural environment. This concept, commonly referred to as environmental determinism or simply environmentalism was taken up by American geography as a guiding philosophy in its early years as a professional discipline. Environmentalism sprang to the forefront of geographic thought as geographers began to search for a professional identity, in part because of the common training in geology of most of the early American geographers. During the first quarter of the century, geographers clutched at the concept of environmentalism to provide them with an identity as well as a philosophic rationale.

The aim of the environmentalists was clear: they strove to explain the relationship between the natural environment and human development and behavior in causal terms. The philosophical background of environmentalism encompassed the geologist's emphasis on the physical side of relationships, the popularity of social Darwinism during the period, and the immature position of the social and behavioral sciences.

The retreat from the mechanistic interpretation of the man-land tradition began in the twenties. This is evident in Harlan H. Barrows' call to redefine geography as "human ecology," or ". . . the mutual relations between man and his natural environment" (Barrows, 1923, p. 5). Barrows went on to argue that "Geographers will, I think, be wise to view this problem in general from the standpoint of man's adjustment to the environment, rather than that of environmental influence" (Barrows, 1923, p. 3). Barrows advocated making the study of man-land relationship not simply a focal point of geography, but its entire definition, giving up other parts of geography to other disciplines. As to historical geography Barrows stated: ". . . it is the special task of the historical geographer to describe and so far as possible to explain this evolution of man's environmental relations" (1923, p. 11).

The dominance of environmentalism and the extreme reactions to it are well known and need not be commented upon in this brief attempt to give a background of the study of man's environmental relationships in American geography. Indeed, as Taafe has pointed out, "regardless of position on an essentially philosophical continuum from determinism to free will, the subject matter emphasis remained the same. Both Barrows and Semple, for example, would study relations between man and his physical environment. Only the verbs they would use in describing their findings would differ" (Taafe, 1974, p. 3).

For the most part, the reaction to environmentalism was to ignore the relationships between man and his environment. The division between the physical and human sides of geography grew. Barrows' attempt to change the focus of geography was ignored, astonishing as it is to us today living in an ecology-era. The rise of the spatial analysis viewpoint supplanted the man-environment theme in geography during the 1960s. More recently, however, with the rise of an environmentally conscious sector of society, the study of man-environmental relationships has seen a revival. The strength of this comeback is based not only on a new awareness on the part of much of the population of environmental problems but also the need for practical applied geographic research in this area. Gilbert White and his students at the University of Chicago brought new life to the study of man-environment relations through their research on human occupance of flood plains. From these studies others naturally emerged dealing with environmental perception, that is, how man perceives his environment. These studies differ greatly from the earlier man-land work in that the emphasis was not on a ". . . fixed external environment but on ways in which men structure their environment in their own minds" (Taafe, 1974, p. 12).

The proposed focus of this study stands firmly on the shoulders of one hundred years of what Pattison has called "the man-land tradition" (Pattison, 1964). "The man-land tradition dwells on relationships; . . ." explained Pattison (p. 215), and while the orientation to these relationships has fluctuated, it has been a major theme in American geography. This study, which seeks to develop a conceptual model of the relationships of settlement patterns and natural hazards is seen as an extension of this historic tradition.

The Problem

Settlement geography, or ". . . the description and analysis of the distribution of buildings by which people attach themselves to the land" (Stone, 1965, p. 347), has only recently experienced initial attempts to develop a theoretical framework. Most of the work on settlement theory has been developed for predictive rather than explanatory purposes. Although the importance of the influence of the environment on the settlement process has long been recognized rarely have these studies progressed beyond basic description, failing to lead to generalizations.

The recent awakening of an environmentally conscious "Ecology" movement has helped to focus new interest on the relationships of man and his environment. With the development of natural hazard research much more is now known about the occupation of hazard zones and the decision making process which affects this occupation. However, natural hazard research has tended to ignore the role of hazards in larger historical processes such as settlement.

Settlement geography lacks a strong theoretical framework, and tends to ignore settlement as a process. No basic generalizations have emerged concerning the interaction of settlement and the environment, and the role of hazard systems in historical processes has yet to be considered. The development of a theoretical model of the relations between the process of settlement and hazard systems is sorely needed.

Questions

The initial decision of this study to investigate the relationship between settlement and the natural environment presented an intriguing if unwieldly problem. What are the influences between the process of man settling the land and the natural environment; what sort of interaction occurs? There are, of course, a myriad of influences. The image of the 1930s Great Plains drought and the widespread effect of this natural hazard on plains settlement patterns was impressive. The depth of recent research in the study of natural hazards and the fact that natural hazards are perhaps the most dramatic and distinctive element of the natural environment encouraged consideration of the relationship between natural hazards and the settlement process.

What are the relationships between settlers, settlement patterns and natural hazards? How does the natural environment through the agent of natural hazards influence or at least create constraints on the decision making of a settler? How do settlers react to varying levels of flooding, for example? These questions and more all seemed to lead to three specific primary questions: How does the settlement of an area occur? How often and with what intensity do natural hazards occur? and How does the settler's perception of the hazard events influence the resulting settlement pattern? It is these three questions that this study is designed to investigate.

In what manner is an area initially settled? There are, of course, a myriad of considerations in choosing a place to settle such as soil quality, distance from transportation lines, availability of services, etc. A number of studies have engaged in attempts to classify patterns of settlement and have stated that initial settlement patterns are usually of a uniform nature. However, specific empirical studies frequently point to the clustering of early settlements (Enequist, 1960) for obvious reasons such as equal perception of land attractivity, kinship ties and economic ties. It was hypothesized that generally as man settles the land one settler will tend to settle near another although these small clusters of settlements might be randomly spaced over an area.

How often and with what intensity do natural hazards occur? In line with the common concept of "100-year" and "1,000-year" floods, it was hypothesized that hazard frequency and intensity is basically a linear relationship between the average occurrence of a specific event and its intensity. That is, the more infrequent a hazard, the more extreme its intensity. Thus the frequency of an event with a specific magnitude in any hazard system may be roughly determined by its relationship with the magnitude of the system's most frequent event. The most frequent event of any hazard system acts as a base index for that system.

What is the relationship between the settlement process and natural hazards? A settler's perception of the hazard is the key to answering this question. The perception of a hazard was hypothesized to be dependent upon three basic assumptions: (1) Infrequent intense hazards of cataclismic proportion are primarily dismissed as flukes, or occur so rarely in a person's lifetime, if ever at all, that the hazard does not produce a significant level of behavioral adjustment on the part of the settler, either in reaction to the hazard itself or to the prospect of future hazards of the same type. That is, in response to a "freak" forest fire, a homeowner will rebuild his house rather than move. (2) Frequent hazard events of low intensity such as an August dry spell, or below zero weather in the north, are perceived to be simply a part of a broader existence. Such events are unconsciously accepted, may be implicitly planned for, and often help define the cultural niche in which they occur. (3) Moderately frequent hazard events of moderate intensity contribute to the greatest perception of a hazardous situation. Moderately frequent hazards were thought to contribute to the accumulated perception of hazard more so than quite frequent or quite infrequent events and because of their intensity are most likely to initiate an adjustment in response to the hazard, thus affecting the process of settlement.

The next chapter of this study provides a general background on settlement geography and traces the development of theory and definitions of settlement geography. Chapter Three charts the development of natural hazard research and focuses on a general systems model of hazard zone occupance. Chapter Four puts forth the model of settlement/hazard interaction, and Chapter Five documents the translation of the model into a computer simulation. The concluding chapter discusses the model, and the importance of theory in the development of simulation models. A user's guide to the simulation appears as Appendix A.

CHAPTER II

SETTLEMENT GEOGRAPHY AND THEORIES OF THE SETTLEMENT PROCESS

The Scope of Settlement Geography

While the study of settlement is an ancient pursuit, settlement geography as a specific focus within professional geography is of a more recent origin. German and French geographers of the Nineteenth Century were responsible for the first modern work in this area, influenced by Carl Ritter's early studies of human geography. Stone (1965) has explained that much of the early research in settlement geography was done by Germans in two specific areas, "house type (including distribution, architecture, and building materials) and urban centers" (Stone, 1965, p. 349).* As early as 1891, F. Von Richthofen lectured in Berlin on settlement geography; A. Meitzen published his four volume summary of settlement research in 1895 which classified all of the German settlements, thereby establishing villages as a key focus of settlement geography

*Much of the following discussion is taken from Stone (1965) and Kohn (1954).

(Meitzen, 1895). Meitzen also stressed form as the important element of settlement classification.

O. Schlüter, often looked to as the founder of the field of settlement geography, rose to a leadership role near the turn of the century. His definition of the field was a broad one. Stone paraphrased: "To location, size, and growth of settlements and their relationships to nature he added the study of internal structure, external form and appearance, and areal arrangement as well as historical, economic and cultural conditions (including arbitrary choices by people)" (Stone, 1965, pp. 349-50). Schlüter made a distinction between form and process, and Stone suggests that he was probably the first to explain that the major concern of settlement geography is with the resulting phenomena of people's activities and not the people themselves.

The German definition of settlement geography continued to be quite broad. A good deal of confusion has arisen from an emphasis on form and process at all scales. As recently as 1961, a German settlement text defined the study of rural settlement to include ". . . the study of man's use of plants and animals to procure food and clothing, of an economic area larger than the dwelling, and of direct relationships between the economic area and the dwelling" (Stone, 1965, p. 351).

The development of French settlement geography was similar to the German experience, yet notably different in its much narrower definition of the field. Vidal de la Blache, the founder of modern human geography in France, had a strong influence on early settlement work, and it was one of his students, Albert Demangeon who dominated the development of settlement geography in France for the first third of this century. Demangeon's major work on this topic described the major distributional characteristics of settlement throughout the world (1927).

Early French settlement work was focused principally on settlement form. This narrower scope contrasts with the broader German interpretation. Stone notes that more recent work in France has tended to rely on a broader definition, yet with continued emphasis on the dwelling.

Elsewhere in the world, definitions and themes in the study of settlement vary widely. In Belgium, M. A. Lefèvre, a student of Demangeon's, has stated that the focus of settlement geography was the definition, classification, and explanation of house type distributions. She also emphasized the process of settling as a part of the analysis of form. In Scandinavia, settlement studies seemed to stress the <u>process</u> of settlement, and investigations into delimiting the succeeding stages of settlement. Early English settlement studies were dominated by analyses of house types, morphology of villages and field patterns.

The development of settlement geography in North America has been slow and restrained. Few definitions of the field have appeared and little attention has been given to the development of a theoretical framework. The first notable settlement work done in America was Isaiah Bowman's "pioneer belt" studies (Bowman, 1931; Bowman, 1932; Bowman, 1937). Bowman's science of settlement was designed to be an interdisciplinary investigation of areas for potential colonization, and was quite popular during the 1920s and 1930s. Particular attention was given to different processes of settlement and areas which had recently been or continued to be settled. The semi-arid belt of the Great Plains and the cool margins of the northern forests were popular areas of investigation. G. T. Trewartha narrowed the focus somewhat explaining that settlement geography was the study of house types and ". . . the characteristic grouping and arrangement of these buildings into colonization or occupance units called settlements; . . ." (Finch and Trewartha, 1936, p. 620). Trewartha defined "house" loosely, including any building that people live or work in.

A major assessment of settlement geography was included in the 1954 Association of American Geographers volume American Geography: Inventory and Prospect (James and Jones, 1954). Kohn states in the second paragraph of this assessment that, "in general, settlement geography has to do with facilities men build in the process of occupying an area" (Kohn, 1954, p. 125). Kohn divides the study into two halves, the examination of the process of occupying pioneer areas and the examination of settlement form and features. He sidesteps the first approach mentioning Bowman's work, and explains that there is "a growing interest" in the latter approach. In Kohn's review of what he calls "studies of specific facilities and their grouping" he considers (1) studies of architectural style; (2) studies of roads and properties; and (3) studies of settlement ensembles. Clearly then, he felt that geography was moving away from studies of process towards a narrower view of form and classification. And yet, Kohn is quick to point out:

> Geographers do not examine architectural styles, roads and properties, and settlement ensembles only for the sake of identifying new categories or developing new classifications. To be sure, there was a time when geographers, newly aware of the possibilities of detailed field mapping, limited themselves to the study of shapes. But in recent decades, studies of the facilities which men build have been undertaken for one of two purposes. One is for the light they throw on historical sequence--studies of origin; the other is for the light they throw on functional relations--studies of functions (Kohn, 1954, p. 136).

Yet Kohn encourages the classification work nonetheless, at the expense of the analysis of the development of the styles, and properties and ensembles.

As to "The Prospect For Settlement Geography" and "Special Problems to be Solved," Kohn suggests "the comparative study of settlements in different cultural areas . . ." and ". . . compilation of world maps showing the areas of individual farmsteads and the areas of compact farm villages, and of various combinations of these basic types" (p. 138). Kohn begins his article despairing that ". . . no analytical framework has been developed for settlement geography comparable to the principles of location in industrial geography . . ." (p. 125). His suggestion for further research would certainly not aid in the development of such a framework.

Kirk H. Stone recognized the great confusion which had arisen from the multiplicity of definitions and the extreme breath of settlement geography, and attempted to begin an initial ordering of the field with "The Development of a Focus for the Geography of Settlement" (1965). Stone explains that there is not only disagreement within the discipline internationally, but also etymologically. To create order out of chaos, Stone suggests a number of specific definitions:

> It is suggested that the geography of settlement be defined as the description and analysis of the distribution of buildings by which people attach themselves to the land. Further, that the geography of settling designate the action of erecting buildings in order to occupy an area temporarily or permanently (p. 347).

Stone then continues the emphasis of settlement geography on the dwelling and includes other buildings which are a direct ". . . tangible expression of man-land relationships . . ." (p. 347), such as barns and equipment sheds. "But excluded as a central subject of settlement geography are elements of the landscape such as functions of people, fences, land use, and lines of circulation and communication; these are considered whenever essential to the analysis of distributional patterns of buildings, but as central topics they are assigned to other divisions of geography" (Stone, 1965, p. 347).

Stone recognizes the difference between urban land and rural settlement. "It is suggested that the geography of rural settlement be defined as the description and analysis of the distribution of buildings by which people attach themselves to the land for purposes of primary production" (p. 347). This definition implies that the principal activity in an area of rural settlement might be farming, mining, trapping or fishing, and that the people would live in small (less than 200 buildings) clusters of individual dwelling units. Stone defines urban settlement as the larger grouping of buildings dominated by secondary and tertiary activities.

Terry Jordan responded to Stone's article in "On the Nature of Settlement Geography" (1966). He has two specific criticisms. Jordan complains that Stone's emphasis on ". . . the description and analysis of the distribution of buildings by which people attach themselves to the land . . ." (Jordan's italics, p. 26) ignores building types, including their design and construction materials. He argues that traditionally this has been a part of settlement geography. Secondly Jordan objects to Stone's emphasis on buildings, an emphasis that would leave the study of fencelines to agricultural geography but give barns to settlement geography. This division, he suggests, is an attempt ". . . to draw too short a circumference around settlement geography, . . . to mark its borders too sharply" (p. 26).

As an alternative definition Jordan has offered ". . . the study of the form of the cultural landscape, involving its orderly description and attempted explanation" (1966, p. 27). He elaborates on "the form of the cultural landscape":

> It is synonymous with settlement morphology and includes (a) vertical arrangements and dimensions (such as the number of stories in a house), (b) horizontal arrangements and dimensions (such as the distribution of buildings, the floor plans of houses, or the pattern of fences and fields), and (c) the material composition (such as brick vs. wood in house construction or line hedges vs. wire fences) (1966, p. 27).

Jordan argues that it is the emphasis on form which is the primary element of settlement geography. The confusion and lack of agreement on definition is due, he feels, to a lack of recognition of the ". . . fundamental, central role of form in settlement geography . . ." (p. 27).

Stone replies (1966) in an effort to clear up what he sees as a misunderstanding. Stone explains that his article was designed as a "development of a focus" while Jordan's was a comment on the "nature of settlement geography." Stone is trying to produce a lowest common denominator for the study area to forge an agreement on its core theme. Jordan, Stone explains, is concerned with the peripheral boundary definitions. Stone is quick to add that by ". . . the description and analysis of the distribution of buildings by which people attach themselves to the land . . ." (p. 208) he meant that description includes classification of house types, form and construction materials. If fences are important to an explanation of the distributional pattern of buildings Stone assures Jordan that that is quite an acceptable topic. Again, Stone had endeavored to establish the basic core of investigation. He explains Jordan's definition as one which attempts to delineate the circumference of the field.

More insightful perhaps is Robert D. Mitchell's letter to the editor of the Professional Geographer in the same issue as Stone's reply (1966). Mitchell wonders if the study of form is not a shallow basis for a definition of rural settlement geography. "Function must be added to provide reasons for form and distribution. That is only part of the problem. What would Messrs. Jordan and Stone do with process, the 'settling' behind the 'settlements?'" (Mitchell, 1966, p. 198). Indeed, enough attention has been given to whether fence types are part of settlement geography, and little thought has been given, since Barrows, to the process behind this form. It would seem that an understanding of process is important before an analytical framework may be developed for settlement geography "comparable to the principles of location in industrial geography . . ." (Kohn, 1954, p. 125).

American settlement geography, then, has characteristically focused on form and description, a narrower view than that taken by geographers in other countries, the Germans for example. Settlement geography has become synonymous with rural settlement geography in light of the major developments of urban and economic geography based on central place theory. For the purposes of this study, Stone's original definitions, though unfortunately linked to descriptive studies of distribution and form, will be used to encourage a codification of terminology. Therefore, in this study ". . . settlement refers to one or more buildings at a place and settling designates the action of erecting buildings in the use of an area" (Stone, 1965, p. 348). If settlement geography is ". . . the description and analysis of the distribution of buildings by which people attach themselves to the land" (Stone, 1965, p. 347), the study of the process of settlement and the human behavior characteristics of such a process must be included within such a definition.

Development of a Theoretical Framework for Settlement Geography

Settlement geography with its ancient heritage and modern variances has long lacked a theoretical framework. This has been an oft noted and despaired fact. Yet within the last two decades a few initial attempts have been made to develop a conceptual framework for the study of settlement. Most of these have been attempts to create models which might predict settlement form, but not explain the process itself.

Erik Bylund's 1960 article "Theoretical Considerations Regarding the Distribution of Settlement in Inner Northern Sweden" (Bylund, 1960) was the first attempt at generalization in settlement study. His work in the central Lappland area of northern Sweden on historical settlement before 1807 led him to construct four simple models of the way settlement moved in "waves" in this area (Figure 1). Each of these models relies on the assumptions of equal physical conditions and that further areas will not be settled until those closest to the "mother settlements" have been occupied. In an endeavor to add a degree of reality to his deterministic model, Bylund assigned attractive weights to a road, a church, and the parent settlement. These models rely on a process Bylund calls

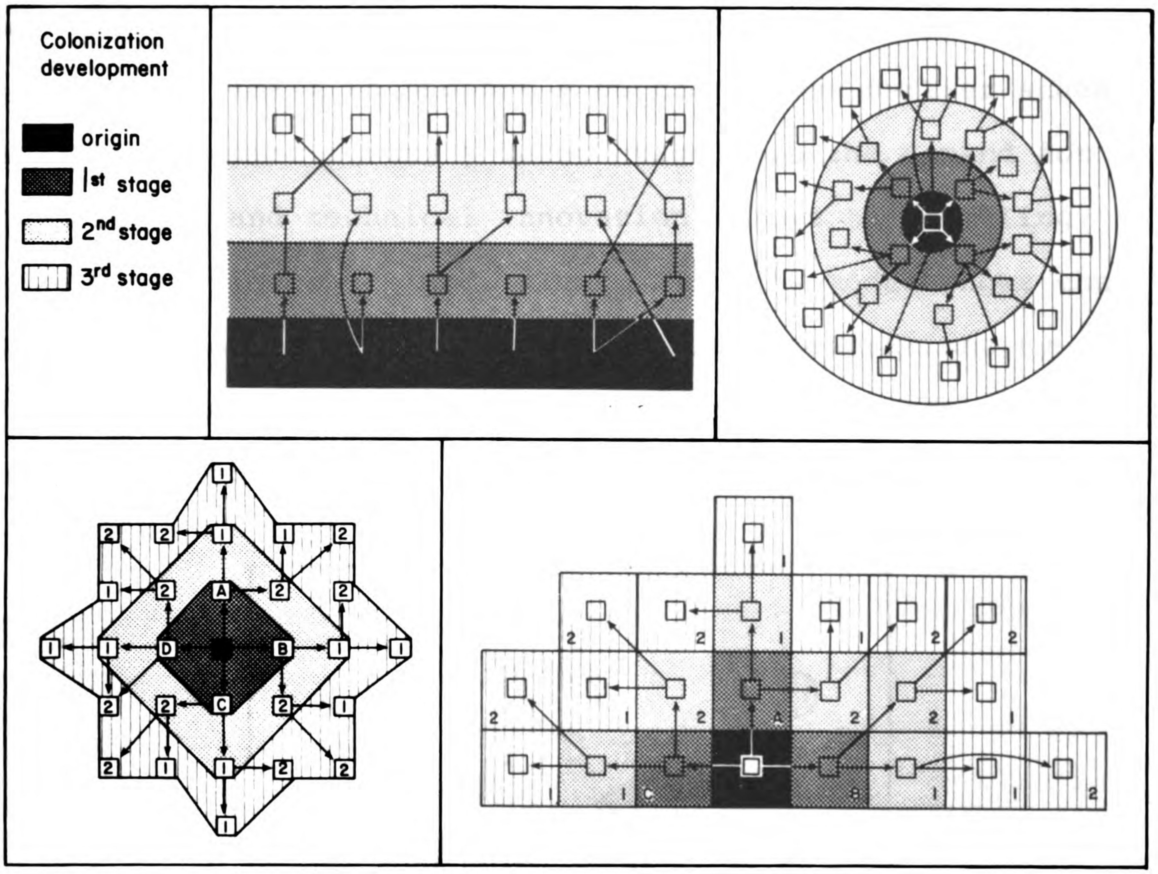

Fig. 1.--Bylund's Four Theoretical Models of Settlement Development (after Bylund, 1960).

clone colonization, whereby a few pioneers initially locate in a region and further settling is carried out by their sons and daughters, and the next stage by their sons, etc. Bylund's final model, as illustrated in Figure 2, makes an initial attempt at the identification of stages in the settling of an area. He suggests that wasteland, or land parcels too small to support a settler at an earlier stage will be occupied during a later stage when the demand for land rises, and technical innovation allows the settling of smaller pieces of land. Thus, Bylund's model shows the settlement of the interstices of earlier generations by later settlers who are produced from all settlements not simply the most recent. Bylund ends with:

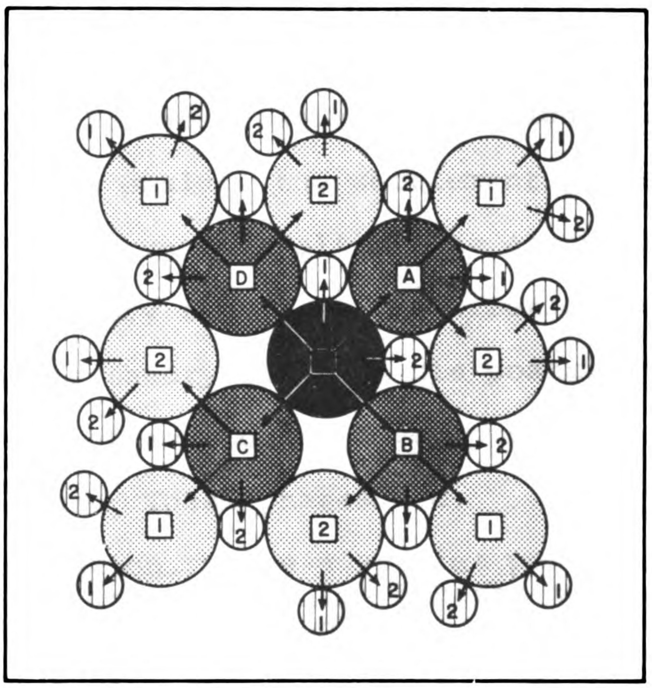

Fig. 2.--Bylund's Refined Model of Settlement Development (after Bylund, 1960).

> In order to adapt the models still better to reality, attention of course, must also be paid to other facts which have not been discussed or considered here; amongst other things, the natural advantages of the settlers' lands, which vary as between each other, e.g., concerning the occurrence of good soils or of profitable fishing lakes. It is, however, obvious, that the very complicated pattern of the spread of settlement does not in every case admit of explanation by physico-geographical conditions alone, however important these may otherwise be (Bylund, 1960, p. 231).

John Hudson is the major innovator in the area of theoretical settlement geography. His dissertation entitled Theoretical Settlement Geography was completed in 1967, the major points of which are embodied in his article which followed two years later "A Location Theory for Rural Settlement" (Hudson, 1969). Hudson presents a theory which attempts to explain the changes of rural settlement over time. In the construction of his theory, Hudson relies on concepts from central place theory, diffusion studies, ecological distribution laws and morphological laws. The model attempts to emulate the settlement process and he specifically addresses himself to the assumption of central place theory that farm distribution is uniform.

Hudson's theory rests on his postulation of three specific phases of settlement development which are based in plant ecology. These phases are:

1. Colonization, where a species penetrates a new region, and extends its habitat outside the limits of its old region.

2. Biological renewal, where a species regenerates through an increase in numbers, encouraging short distance dispersal filling the interstices of previous areas.

3. Competition, where weak individuals are pushed out due to the limitations of the environment, the pattern stabilizes as density increases.

It is the first stage which is of the greatest interest here. Colonization is primarily associated with the spread of settlement into a yet unsettled area, or new environment. The characteristics of this new environment may be best interpreted, Hudson feels, by utilizing a number of concepts from ecological modeling. He explains that the density of human settlement at any one point can be thought of as a function of m environmental parameters, from which there may be derived a group of n statistically independent variables. If we think of each of these variables as vectors in n-dimensional space (n-space), each vector is by definition orthogonal to all others. These n variables may take on widely varying values reflecting different environments and the differing levels of the m environmental parameters. Given the values of these variables, we may imagine a form or volume delimited in this n-space by the intersection of n-planes defined by the value of each vector. This hyper-volume is defined as Niche space, or N. Hudson calls it the "fundamental niche of the population" (Hudson, 1969, p. 367). "Each vector in this space has n components, defining a certain combination of values of the environmental variables. It is a familiar fact that there exist vectors $(x_{i1}, x_{i2}, x_{i3}, \ldots x_{in})$ that are too extreme to permit human settlement" (p. 367).

These vectors represent hazard environments which might be too cold, too dry or too hot for settlement.

An important concept is that niche space is not a tangible mappable space. Ecologists speak of biotope space (B), which is a mappable physical representation of the varying levels of the variable of niche space (see Figure 3). A function may be defined that translates niche space to biotope space: Φ (x_1, x_2, x_3, . . . x_n). It is not necessarily a single valued function; though permissible levels of n variables may exist, there is no assurance that these variables actually have physical manifestation in an area. Crudely, it might be a nice place to settle, but perhaps no one has chosen to do so.

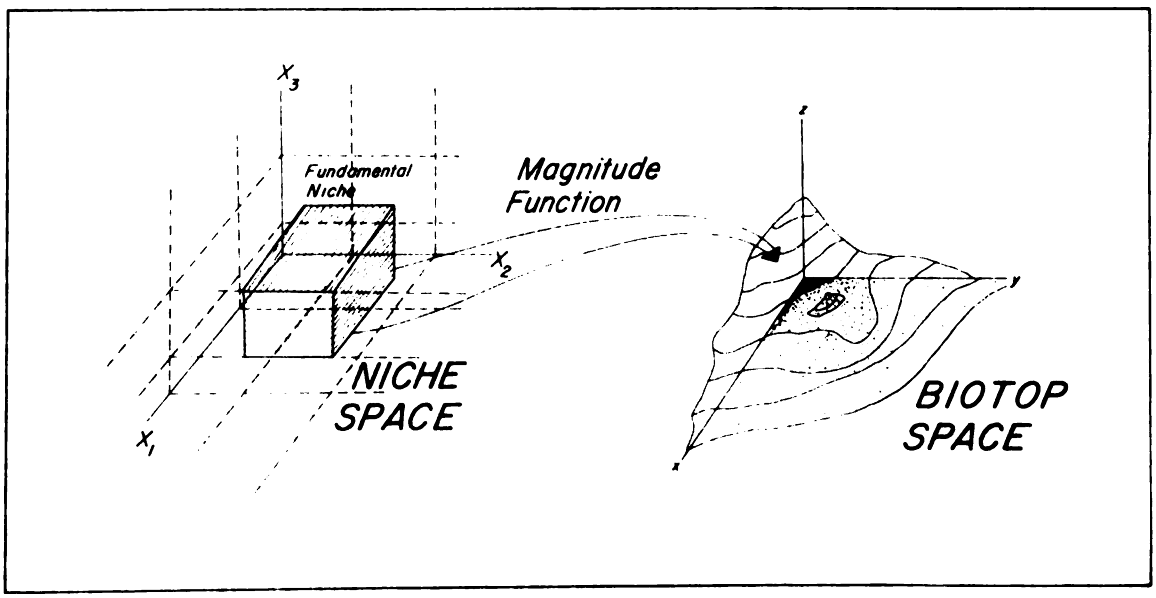

Fig. 3.--The Magnitude Function, f(x1, x2, x3) Determines the Density, (z), of Settlement in Any Area, dB, of the Biotope (after Hudson, 1969).

To illustrate the difference between niche and biotope space, and their boundaries Hudson explains:

> Limits in the niche are counterparts of distributional boundaries (regions) in the biotope. An example of a limiting value on a variable in the niche space is minimum farm size--the size beneath which agricultural operations are economically unfeasible. Tree line, on the other hand, is a boundary in the biotope space, corresponding to some phytophysiological limit in the niche space (Hudson, 1969, pp. 367-8).

It is important to note that these vectors do not have an equal influence on settlement. Indeed, gradients are quite important. "In general the function Φ defines a mapping that determines the density of settlement in the biotope space and is called the magnitude function" (p. 368). The different components of the function exert varying weights on its outcome. This function provides the density of settlement for an area, but not its pattern of settlement.

Spread, Hudson's second phase, is similar to Bylund's recognition of another new stage where numbers increase and a filling of the gaps occurs. This process produces an increased density, that is, the magnitude function allows the biotope to grow vertically. Citing Bylund and other studies of larvae spread, Hudson accepts the assumption that successive generations show a limited spread away from the parental settlement. Yet Hudson is quick to point out that spread is not the only source of growth, as Bylund suggests, but also includes continued in-migration from outside the area. "More important geographically, there is no reason to expect this new immigration to cluster around the settlements of the pioneers" (p. 370). This all suggests to Hudson a "greater regularity in the spacing of farmsteads, rather than clustering" (p. 370). Hudson feels that it is spread which encourages a cluster in settlement pattern and colonization which encourages regularity.

Competition occurs when the biotope is completely settled. Weak individuals are forced out and the pattern begins to stabilize. This process of competition tends to produce greater regularity in the pattern and in turn produces one condition for the development of a uniform network of central places.

Hudson compared his model with actual settlement patterns from six Iowa counties. He concluded that in the early stages of settlement when the density of settlements is low and unsettled areas are common, the location of settlements is essentially independent of one another. As density increases competition increases and the settlement pattern changes from the clustered to a more regular pattern. Hudson therefore sets a constraint upon the assumption of central place theory that rural farm patterns are regularly spaced, by maintaining that a certain degree of competition is necessary.

A fascinating recent study by Norton (1976) is one of the first efforts to develop a stochastic simulation model of settlement. Norton endeavored to simulate population levels by township for southern Ontario utilizing the variables availability, distance to the nearest entry point, land quality and potential of each township. Norton's stated aims include an attempt ". . . to isolate the principal variables involved in the process of settlement, to construct settlement patterns for periods for which data are limited, and to produce patterns which might have developed given particular processes" (Norton, 1976, p. 270). That is, Norton is not only interested in the influence of the variables on the settlement process, but also in creating a predictive tool to simulate the settlement of areas and periods where data do not exist. Norton is also interested in being able to ask "What if . . ." questions.

Norton's location process involves the calculation of an index of attractiveness (A_i) for each township utilizing the four variables of township character. The probability of a township receiving a settler may be then calculated from the index of attractiveness. No attempt was made to differentiate between locations within a township. Norton's function is based on four variables:

$$A_i = A_i\ (I_i,\ S_i,\ Q_i,\ V_i)$$

where: A_i = the attractiveness of the ith township

I_i = the index of availability of the ith township

S_i = the distance between the ith township and the nearest entry point

Q_i = a measure of the land quality of the ith township

V_i = a measure of the potential of the ith township

Norton's attractiveness function is quite similar, though he does not point this out, to Hudson's magnitude function. Norton's variables can be seen as representing a four-dimensional niche space and the attractiveness function translates this into the probability of density in biotope space. Recognizing the potential differing influences of these variables, Norton simulated the settlement process many times changing the input of each variable. The general form for the calculation of attractiveness values that Norton used was:

$$A_i = h \cdot I_i^a \cdot S_i^b \cdot Q_i^c \cdot V_i^d$$

where the constant h is assumed to be equal to one, the attraction being scaled in a similar manner for all townships. The letters a, b, c, and d represent exponential constants, and it was these constants that Norton varied to change the influence of each variable. Arbitrarily, Norton decided that the exponents could take the values of 0.0, 0.5, 1.0, or 1.5. Given four variables with four possible exponential weights there were a possible 256 different simulations that Norton ran in an effort to determine the levels of influence of each of these variables. This is a specific recognition of the importance of gradients in n-space as pointed out by Hudson. The probability of the ith township receiving a settler (P_i) was determined from:

$$P_i = A_i / \sum_{i=1}^{m} A_i$$

where m is the number of townships available for settlement. An assumption of Norton's model concerning the calculation of the index of availability is of particular interest here. In determining the availability of a township Norton decided that there was a maximum density of one settler per 100 acres. He calculated the number of available 100 acre locations at the beginning of each time period. To find the availability index he used:

$$I_i = T_i - O_i$$

where: I_i = Index of availability for the ith township

T_i = Total number of 100 acre locations in the ith township

O_i = Number of occupied 100 acre locations in the ith township

Initially then, O_i equals zero; when maximum density occurs the value of O_i equals T_i, and I_i equals zero. Norton's major assumption then, is that "as the number of available lots in a township declines the attractiveness declines, so that with no lots remaining the attractiveness is zero" (Norton, 1976, p. 274). This is identical to assumptions made by Hudson in the construction of his simulation:

(1) The probability of a settlement occurring in an area, a, is a function only of the size of a, not its location in the study area;
(2) the number of settlements in any small part of the study area is independent of the number falling in any other area;
(3) the probability of more than one settlement occurring in a, approaches zero as a approaches zero, faster than a does (Hudson, 1969, p. 374).

These assumptions, that are based on the central place theory premise of uniform dispersal of farms, are seemingly based on the specific North American experience and need to be examined further.

Grossman (1971) objects to Hudson's use of biological theory and argues that Iowan farmers with their high degree of individualism and their complex and diversified origin are unrepresentative of rural settlers. The implications of Hudson's and Norton's assumption are that an area will be completely settled at a broad scale, and the next stages of settlement will fill in the large gaps. Hudson suggests that ". . . it seems likely that new settlement would be somewhat repelled by the earlier settlement, under conditions of contiguous landholdings of approximately equal size typical of most homesteading in the United States" (Hudson, 1969, p. 370). This contradicts Bylund's observations of settling in Sweden where he has talked of clone colonization. That is, settling that occurs in waves out from a focal point or focal region. Grossman's studies of clustered settlement in Nigeria have urged him to argue against the universality of Hudson's assumptions of dispersed farmsteads.

The difficulty with the assumption of unclustered settlement is that time after time empirical studies have shown that for one reason or another early settlements are clustered (Bylund, 1960; Peters, 1969; Grossman, 1971). This might be explained by a common perception of the regions by settlers, by an extreme vector limit in niche space or a physical constraint of the region.

> It must be remembered that not always the best areas, even according to contemporary appraisal, were those first occupied. Settlers, in small numbers and with limited techniques at their disposal, are attracted to those areas which they are capable of managing and controlling. The physical characteristics of these areas are certainly closely relevant to this, but the concept of manageability is important especially where, for example, the control of water (power) supply, or the regulation of drainage, or the clearance of vegetation is involved (Paget, 1960, p. 325).

In Norton's model the simulated patterns which best fit reality are quite clustered. Not surprisingly there are clusters of settlement in the areas we now call Windsor, Niagara, Toronto, Kingston and near Montreal. How did these results occur given Norton's initial calculation of an index of availability? The influence of the other variables was to counteract his assumption of availability. For example, one of the variables used, Distance to the nearest entry point (S_i), was the straightline distance between each township and the nearest entry point. The entry points used were the Detroit River, Niagara, York (Toronto), Kingston and the Quebec border (near Montreal). Indeed, Norton found this variable to be the most influential in the sense that of the 256 simulation runs, the patterns which most closely matched reality had used an exponent value of 1.5 for the distance variable, while the other variables generally had exponents of less influence.

In his conclusion Norton recognizes that "Gentilcore noted that, during the early years of settlement, location was dependent upon the entry points and the availability of surveyed land" (Norton, 1976, p. 286). Indeed, Norton grudgingly admits that "the lot availability variable, . . . is formulated assuming a linear relationship between the available lots and the township attractiveness. This is possibly unrealistic as townships with a minimal number of lots remaining might prove very attractive as they represent available land within developed areas" (p. 286). In fact, not only does initial settlement in south Ontario reflect the date that land was surveyed, that is, land was settled as it was surveyed, but also that "the pattern begins as a series of cores and subsequently develops throughout the area, emphasizing several of the early cores" (p. 286). This seems identical to Bylund's observations in Sweden and to the idea of clone colonization, and thus directly contradicts the availability assumption that both Hudson and Norton made.

An important building block of the model which will be formulated in this study is the recognition that early settlement tends to be clustered. This clustering may be a result of the movement of a settlement frontier, of a common perception as to the suitability of settling a certain type of land, e.g., river valleys, of clone colonization, of similar cultural origin, or of the proximity to entry points, military outposts or capital cities. In any event the suggestion that the settling of an area is an inverse function of number of settlements already there displays unfortunate ignorance of the importance of cultural ties, behavioral adjustment and environmental perception.

CHAPTER III

NATURAL HAZARD RESEARCH AND MODELS OF MAN-HAZARD INTERACTION

The Development of Natural Hazard Research

Natural hazard research is a relatively recent development within geography. Although its origins may be traced back to Barrows and his interest in human adjustment to the environment (1923), natural hazard studies did not come into full bloom until a few decades later. "Natural hazards are those elements in the physical environment, harmful to man and caused by forces extraneous to him" (Burton and Kates, 1964, p. 413). Natural hazard research focuses on the interaction of man and nature, and the governing human-use system and natural event system. Thus natural hazard studies do not restrict themselves simply to the characteristics of natural events, but search out the relationships of the events and the human occupation of the affected area. This research is concerned with the question "How does man cope and adjust to the risk and uncertainty evident in hazardous geophysical systems?"

Early natural hazard research was limited to studies of flood hazards, and even today more is known about man's relationships with floods than any other hazard. The earliest work done in the area of flood hazard was carried out in the 1920s and 1930s when Congress delegated the Corps of Engineers to investigate the manageability of the country's river basins for reasons of flood control as well as irrigation, hydroelectricity, and navigation. Many of these initial reports were quickly adopted. Because of their appearance during the Depression, the proposals were designated public work projects. Geographers were actively engaged in these projects. Gilbert White, the founding figure of natural hazard research, was spurred to survey the alternatives involved in attempts to reduce flood loss. His Human Adjustment to Floods (1942) was the first in a continuing series of hazard related monographs by White and his students to emerge from the University of Chicago Department of Geography in its Research Paper series.

In 1936, following a series of damaging floods, Congress authored the Flood Control Act of 1936. This act declared Congress' intent to grant financial support to any flood control project whose financial benefits outweighed its cost. Twenty years later, having spent five million dollars, a geographic investigation was organized to determine the changes in urban flood plain occupation that had resulted from these programs. The investigation focused on seven representative sites. The variety of adjustments utilized at these sites in response to the flood hazard were classified as actions that were designed to (a) modify the cause of the hazard; (b) modify the losses caused by the hazard; or (c) distribute the losses. A number of disconcerting conclusions emerged from the investigation (see: White et al., Changes in Urban Occupation of Flood Plains in the United States, 1958). While flood-control measures had increased, so too had the amount of flood damage. The general goal of reducing flood damage had not been realized and there had been increased human occupation of the flood plains. The study also showed that the federal government's emphasis on flood-control and upstream management excluded other possible adjustments. It was clear, then, that the federal programs had failed, and that there was a critical need for increased understanding of human occupation of flood-prone areas (White, 1973).

A number of studies were begun on other aspects of floods as a natural hazard. Agricultural use of flood plains was reviewed by Burton (1962), coastal flooding along the eastern seaboard by Burton, Kates and Snead (1969), efforts to improve flood damage estimation and the evaluation of flood control efforts by Kates (1965), and methods for handling flood losses by Burton (1965). These studies established natural hazard research as a viable sub-field within geography. Five principal areas of investigation were developed as a result of these studies and continue as a basic description of natural hazard research. These areas are: (1) assessing the extent of human occupation of hazardous regions; (2) identifying the complete range of adjustments to the hazard; (3) the investigation of human perception and evaluation of hazards; (4) describing the hazard adjustment adoption process; and (5) estimating the optimal group of adjustments, and their social and environmental consequence (Burton, Kates and White, 1968).

Much of this new wave of hazard research was characterized by a healthy amount of interdisciplinary research work. Engineers were involved in analyses of structures and their flood resistivity. They were frequently the most responsive group in applying the lessons of geographic investigations. The Army Corps of Engineers was often involved as well as hydrologists from the U.S. Geological Survey. Economists were needed in advanced cost-benefit analyses, and investigations into the economic effects of zoning controls. Psychologists were drawn into the foray to help explain risk behavior and the perception of uncertain environments. From the beginning, natural hazard research has been unique in geography for its practical, applied value--a characteristic becoming more and more prized--and the degree of input by geographers in a broad interdisciplinary research effort.

By 1969, the importance of natural hazard research was recognized in a number of major ways. The International Geographic Union Commission on Man and Environment committed itself to hazard research as one of their two major areas of development in the following three years. The Commission played an important role in encouraging and coordinating hazard research around the world. Equally indicative of hazard research's acceptance within the world was an international seminar on flood problems held in Georgia, USSR, for three weeks in the fall of 1969. White commented soon after the conference that it was of special interest to geographers for two reasons. "It was the first systematic recognition by the United Nations community of the importance of dealing with water-resources management in a way that takes account of the full range of alternatives open to man. It also brought into the discussions the findings and methods of analysis of geographers in close association with hydrologists, engineers, and economists" (White, 1970, p. 440). The seminar was sponsored by the Soviet Ministry of Reclamation and Water Management with the Georgian Scientific Research Institute of Hydraulic Engineering and Reclamation, and the United Nations' Transport Division of the Economic and Social Affairs Department. Twenty-eight countries were represented with participants from UNESCO and WHO and an array of Soviet research institutes. Among other topics, attention focused on the range of alternatives for managing flood damage, and there were proposals for continued international collaboration. Geographers from a number of countries held a central role, both as United Nations' consultants and as authors of papers chosen for discussion (White, 1970).

Recent developments in natural hazard research are indicative of a broadened, more advanced research effort. Investigations have branched out into a myriad of hazards other than floods including droughts, hurricanes, tornadoes, avalanches, earthquakes and tsunamis. Besides the cross-section studies of one hazard, investigations of all the hazards of an area, that is a regional hazard ecology, emerged (e.g., Hewitt and Burton, 1971). Behavioral science methodology became a prominent tool in the investigation of hazard perception and behavioral responses to hazards. Studies such as Saarinen's use of the Thematic Apperception Test in his analysis of Great Plains farmers' perception of drought (1966), and Sims and Bauman's use of sentence completion tests to contrast tornado perception in Alabama and Illinois (1972) were landmark works. These studies borrowed standard techniques from psychology and utilized them in ground-breaking research in the areas of environmental perception and natural hazards. Perhaps the single most important development in hazard research is the recognition of the key role of environmental perception in the adjustment process.

The importance of perception became clear in the re-evaluation of the government's flood policy in the late 1950s. Much of the failure of the programs was seemingly due to the obvious differences in hazard perception by different respondents, such as between resource managers, a home owner or shopkeeper for example, and flood research scientists or hydrologists. To better understand the process of human adjustment to flood hazards it was clear that more needed to be known about hazard perception. Early investigations of attitudes toward flood hazards and hazard perception were reviewed by Burton and Kates (1964). The key to natural hazard research then became twofold: it was, of course, particularly important to understand the behavioral aspects of human occupation of hazard zones, but an emphasis on hazard perception and its relationship with the behavioral adjustments was a prerequisite to understanding this behavior.

Models of Human Adjustment to Natural Hazards

In an attempt to understand the relationships between hazard perception and adjustment adoption, a number of conceptual models have emerged. These models are rudimentary attempts at developing an explanation of the basic relationships involved in the decision making process of hazard adjustment. The assumptions of the earliest flood control projects were based strictly on economic optimization. The cost-benefit analyses were based on an optimizing model which assumed complete knowledge of the hazard, and optimal economic adjustments on the part of the resource managers. The limitations of this model are obvious. A modified model, which White has called a ". . . subjective utility model," relaxes the complete knowledge assumption (White, 1973, p. 199). This model recognizes the subjective role of environmental perception and the subjective evaluation of the possible results of any adjustment. However, this model retained the optimization assumption such that if a resource manager's perception of a hazardous area might be ascertained, it would be feasible to predict his behavior. The model assumed that a person would undoubtedly optimize the benefits of his/her environment within the personal constraints imposed by the role of perception.

Neither of these models, however, were particularly helpful in explaining the behavior actually observed. While it was obvious that people in hazardous areas recognized differing levels of hazard from one part of the area to another, this recognition was not necessarily translated into a behavioral response. It was not uncommon for people to return to areas where they experienced high personal damages and extreme financial loss rather than move elsewhere close-by where they recognized that the danger was less. The models failed because of their key dependence on the optimization assumption. The need to adequately explain the behavior of occupants of hazard zones, and predict the behavioral response of these occupants to changes in policy required the creation of a new model.

White has explained that "the obvious direction in which to move was the model of bounded rationality . . ." (White, 1973, p. 200), as developed by H. S. Simon (Simon, 1957). Kates' work in Lafollette, Tennessee (Kates, 1962) helped develop a model of bounded rationality for hazard decision making. Kates investigated the behavior and expressed perceptions of residents of a Tennessee river valley. He endeavored to find out how people perceive hazards, how they perceive the range of adjustments open to them and what factors might explain the varying perceptions of the same environment. White presents "a rough model of decision" (1973, p. 201) that illustrates the early attempts to create a model of the decision making process. This model recognizes the inputs of the environmental system and the social system on the decision maker (see Figure 4).

The most recent version of a model of natural hazard decision making and behavior is found in Kates' "Natural Hazard in Human Ecological Perspective: Hypotheses and Models" (1971). Kates explains that:

> . . . it is only now that we can begin to structure a primitive general framework of human adjustment to natural hazard, in which we try to preserve its human ecological perspective. In this perspective,

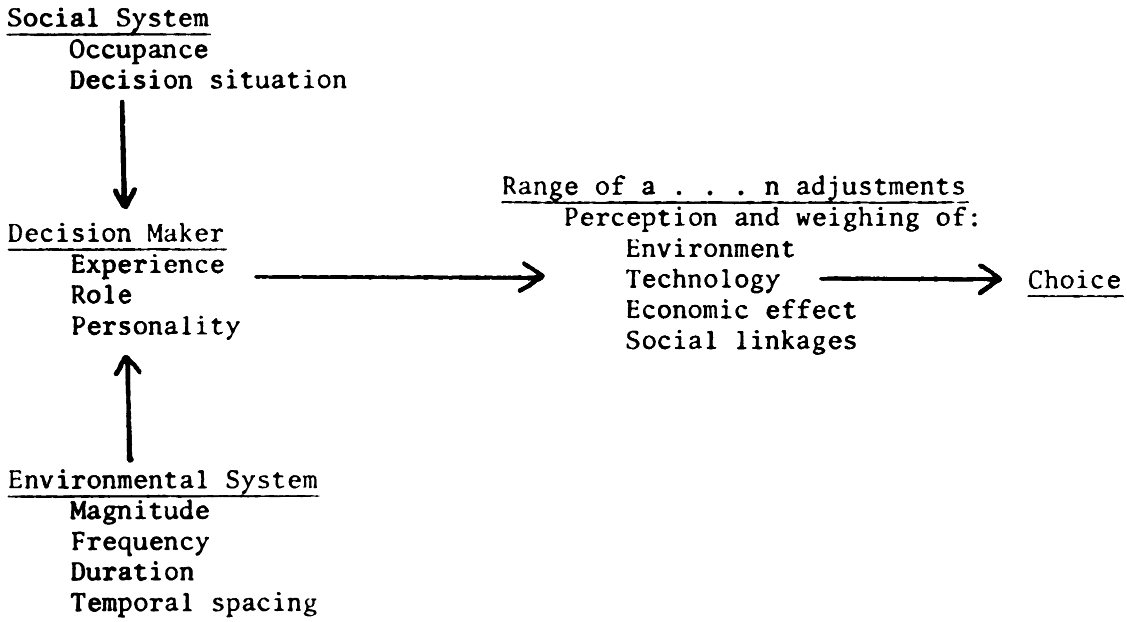

Fig. 4.--A Rough Model of Decision (after White, 1973).

> with its focus on man as the ecological dominant, the interactions between men and nature tend, over the short run, to be stable, homeostatic, and self-regulating and, over the long run, to be dynamic, adaptive, and evolutionary in the direction of increasing control over nature's resources and buffering from nature's hazards (Kates, 1971, p. 438).

Kates' purpose is to present a basic systems model of the short-run process of adjustment. He lists a number of basic hypotheses which sum up the present state of knowledge of hazard research and help provide a basis on which the model may be built. These hypotheses help explain the nature of natural hazards, adjustments to the hazards and the individual choices made by those involved. These hypotheses are listed below under Kates' sub-headings.

A. Man-nature interaction. A natural hazard is a result of the interaction between a human-use system and a natural system. It is a result of the basic process of man pursuing that which is beneficial and avoiding that which is hazardous. Clearly there are conflicts in perceived benefits, and frequently people accept hazardous situations knowingly due to their perception of net personal benefit.

B. Techno-social stages. Adjustments to hazardous situations may be categorized into three techno-social stages. Each of these stages has a preferred group of adjustments, and a distinctive choice process, primarily determined by cultural characteristics.

Folk or pre-industrial adjustments are characterized by mystical or unrational behavior or have been built into the culture as a stress relieving system (e.g., see Hsu, "The Cultural Ecology of the Locust Cult in Traditional China," 1969). These adjustments require alteration of human behavior rather than control of the natural system. They require little capital, and may be implemented by small groups or individuals.

Modern technological or industrial adjustments are characterized by a very limited number of actions relying on technological efforts to control the workings of the natural system. They are capital intensive and require community-wide action.

Comprehensive or post-industrial adjustments are characterized by features of both of the previous stages allowing a greater flexibility of action. They allow a variety of capital inputs and individual involvement and organization.

C. Hazard Differences. Given the above stages of hazard response, the character of the hazards themselves necessarily varies. That is, given different levels of cultural and technological development, the hazardousness of different natural systems varies. Four specific attributes of hazards are key to these differences. It is the variation of these attributes which gives rise to different adjustments. Three of these attributes are characteristics of the event itself: frequency of occurrence, magnitude of event, and suddenness of the onslaught of the phenomenon. The fourth attribute is whether the hazard is intrinsic to the purpose of the human occupation or is not related to this activity.

D. Decision maker differences. The choice of adjustment process may vary given a specific hazard, between decision makers. The choices may be individual or collective ones. While the "management unit" may differ, from a house to a city, ". . . the ways in which choice of adjustment is made does not fundamentally differ" (Kates, 1971, p. 440).

E. Individual differences. All individuals who choose an adjustment to a hazard perceive the hazard and are aware of a range of adjustments. These adjustments are evaluated with reference to their economic benefit, feasibility and social suitability. And yet, while the decision process is similar, each perceives the hazard differently, is aware of a different range of adjustments and uses different criteria in the evaluation of the adjustments. Perception of the hazard may vary according to: the characteristics of the hazard, personal experiences with the hazard, and individual personality factors.

The general outline of Kates' model appears in Figure 5. The model is ". . . only a small slice of the global system for which the above hypotheses represent the first step towards a theoretical formulation" (Kates, 1971, p. 443). The model is of a system at a single cross-section of space and time. That is, at a specific place for a specific moment, man and nature interact through their governing systems to produce a natural hazard. This hazard produces a specific set of hazard effects. The adjustment process governs the choice of adjustments that modify the natural event system, modify the human use system or modify the hazard effects through emergency adjustments. A more detailed representation of the model appears in Figure 6. To provide a greater understanding of the model as a whole each element will be discussed in terms of its relationship with the other elements.

Important characteristics of the human use system include descriptive data concerning human occupation of

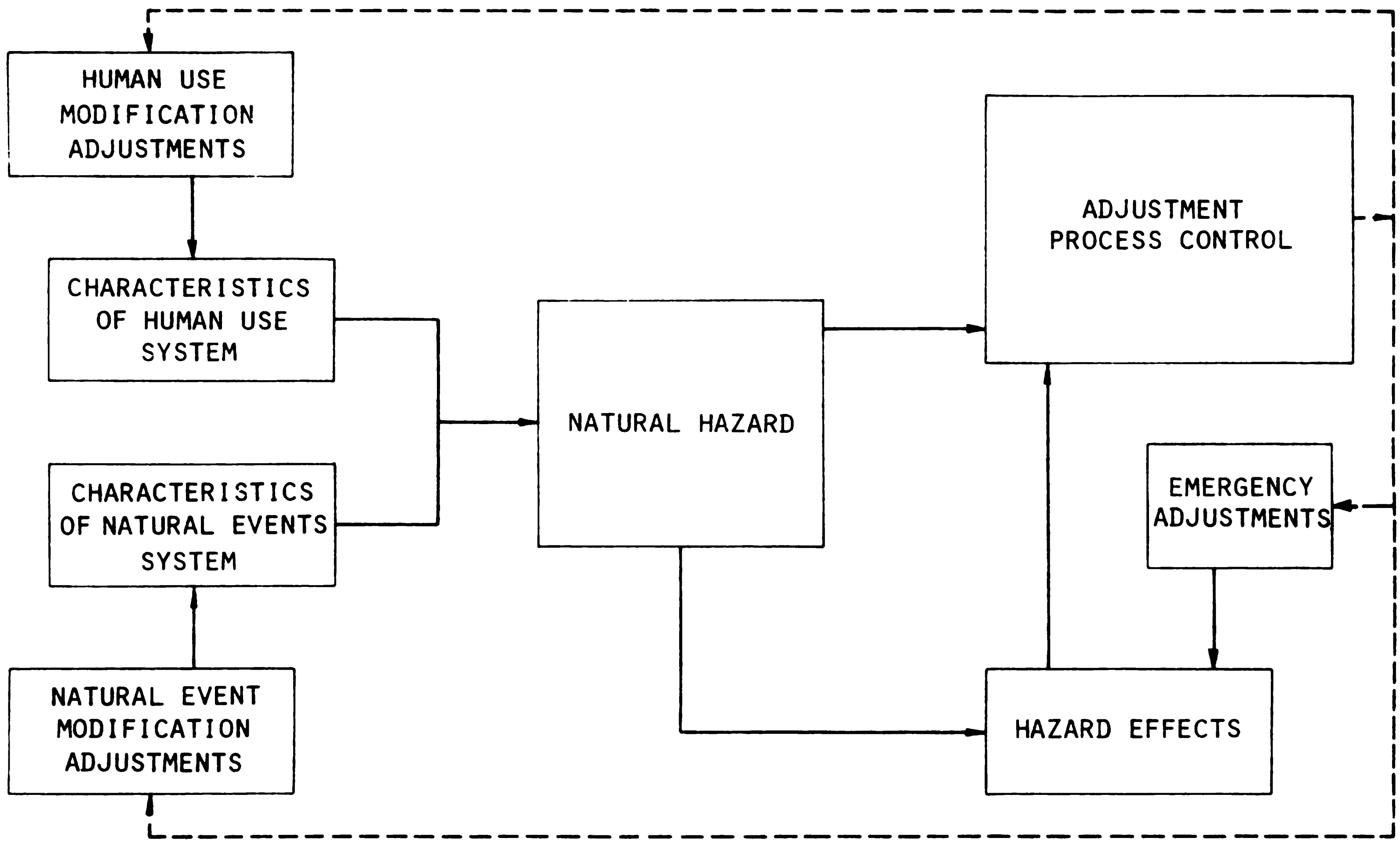

Fig. 5.--Human Adjustment to Natural Hazards, Outlines of a General Systems Model (after Kates, 1971).

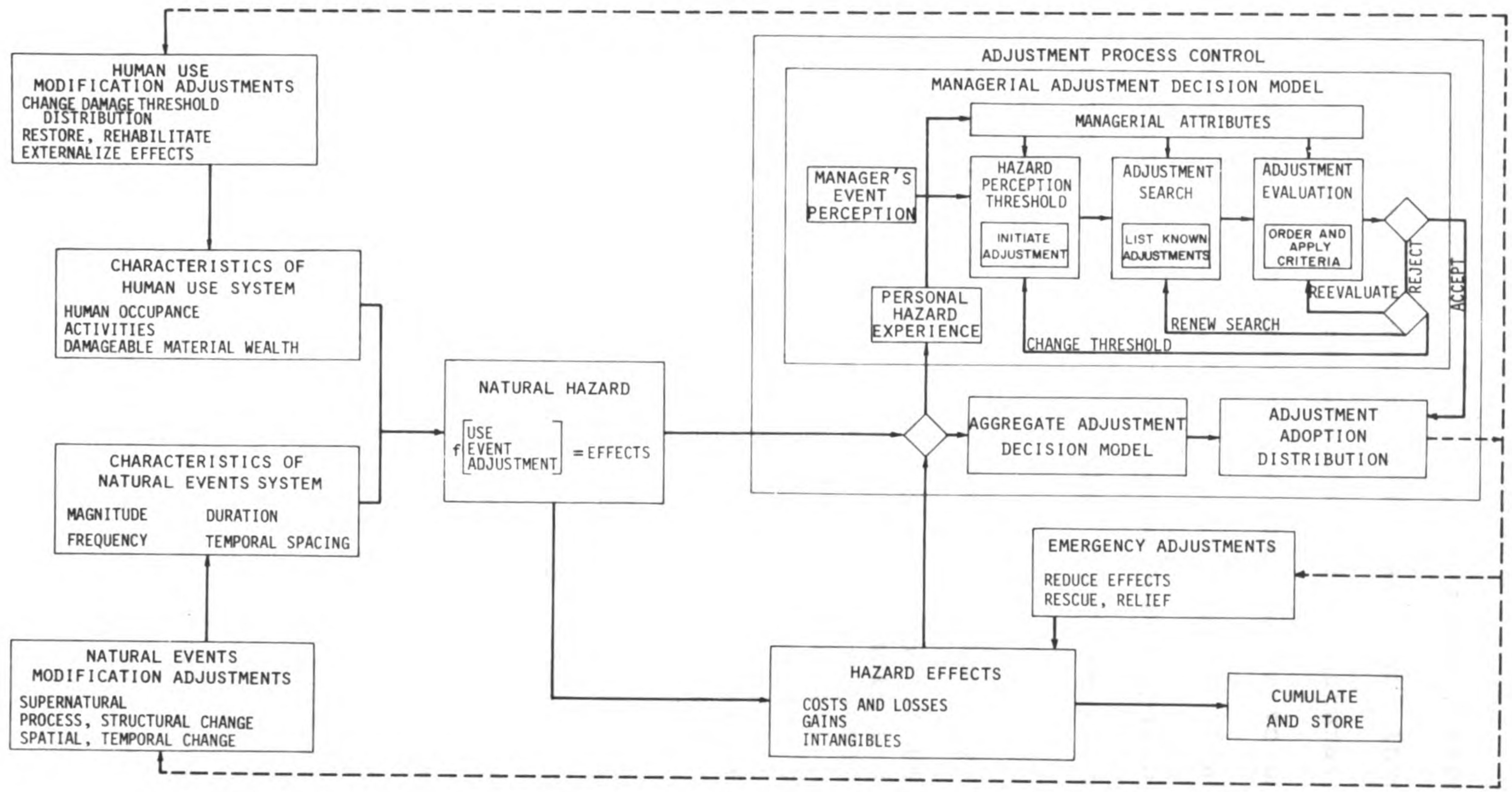

Fig. 6.--Human Adjustment to Natural Hazards (after Kates, 1971).

the hazard area: the number of people, age and sex breakdown and temporal parameters (e.g., seasonal occupation). The type of activity involved is, of course, important as it relates to the occupation of the area and inventory of damageable material. Characteristics of natural event systems include the magnitude, expressed in volume, energy, or dimension; frequency, expressed in terms of an average recurrence period; duration; and temporal spacing, described by the patterns of events, whether they are random, clustered or uniform.

A natural hazard is a state threatening to man

> . . . compounded of an expectation of the future occurrence of natural events which impinge on a human use system that is provided, through adjustments, with a certain capacity to absorb these events. In the context of the model, natural hazard takes on meaning as a set of functional statements that relate for each level of assumed adjustment, for each set of human uses, and for each pattern of event occurrence, a set of possible hazard effects (Kates, p. 445, 1971).

Hazard effects are not necessarily felt, and certainly are not necessarily all bad. Whether the hazard is felt or not is due partly to the character of the hazard itself (its magnitude, for example) and also the types of previous adjustments. The effects of some hazards are welcome to some individuals, as are snow blizzards to ski resort owners.

The presence of any hazard demands the natural human response to minimize its influence and isolate its effects. This basic decision making process has been the focus of natural hazard research for many years. An early version of a decision making model was developed by White (1961) for hazard and resource related decisions. This model has been discussed above and is based on H. A. Simon's notions of "bounded rationality" and "satisficing" (Simon, 1957). Kates' model, and specifically the sub-system model "Adjustment Process Control," is the most recent refinement of hazard decision making theory.

The model of adjustment control assumes that each resource manager has a threshold of hazard perception below which an adjustment is not perceived as necessary. This threshold is a result of his perception of the hazard system, his past experience, access to information, etc. The threshold may, of course, vary, as do the factors which influence it. If the hazard threshold is reached, a review of possible adjustments is instituted by the resource manager. The evaluation of possible adjustments is carried out utilizing four basic criteria: (1) the suitability of the adjustment for the environment, (2) its technological efficacy and feasibility, (3) its long-term economic benefits, and (4) its conformity to social acceptability. These criteria need not be of equal importance, and may vary greatly between cultures. The application of the criteria is primarily a function of the characteristics of the human use system. Based on the criteria, a decision is made to adopt, or not to adopt. A rejection is fed back into the evaluation process. Simon's concept of "satisficing" explains that, rather than optimizing a choice or situation, people will often "satisfice" it. That is, rather than find the optimal adjustment for a hazard, a resource manager will simply search for a satisfactory adjustment. Thus, adjustment rejection may affect the evaluation process such that an individual might relax his standards of acceptance to find a satisfactory solution.

Regardless of the hazard, adjustment adoption frequency appears to be a function of hazard frequency. While variation in adoption is related to frequency, the greatest variation occurs in areas of intermediate frequency. In areas of low frequency, people adopt few if any adjustments; with high frequency, widespread adoption occurs.

There are three types of adjustments, those that: (1) modify the natural event system, (2) modify the human use system, and (3) post-event emergency adjustments.

Kates' model is a general one which yearns to be applied in various field situations to further test his assumptions, and elaborate on the model itself. For the purposes of this study, however, Kates has not simply created a foundation of natural hazard theory, he has also provided a general framework which attempts to model the interaction of a human-use system and a natural event system which in their combination have produced a natural hazard. The purpose of the present work has been to construct a narrower model of the process of settlement and its interaction with natural hazards. The similarity of purpose is clear. This study will go from the general to the specific and attempt to model a specific human-use system--the process of agricultural settlement--and its relationship with a natural event system.

CHAPTER IV

THE DEVELOPMENT OF THE MODEL

Geographic models come in many shapes and sizes. Chorley and Haggett, in Models in Geography (1967), point out the many different roles that a model may play. They explain that models may be used as explanatory, psychological, normative, organizational or constructional devices. Given this vast array of functions which a model may perform, it is difficult to arrive at a satisfactory definition (see Harvey, 1969, pp. 144-47). The definition of a model then, is necessarily linked to its designated function. It is the purpose of this study to develop an explanatory model which embodies the theory of the system it is intended to represent.

Opinions vary concerning the utility of geographic models, as does the appropriateness of their use. It is clear, however, that many things can be gained from the development and use of models, if only developed as theoretical exercises or pedagogical tools. The purpose of this study is the development of a theoretical model which will explain the process of interaction between rural settlement and a natural hazard system. As the world's population

grows, so too does world hazard zone occupation. Also, as the historical record grows longer, natural hazard researchers are becoming aware of previously unknown hazard zones. Because real, as well as known, hazard zone occupation is on the rise throughout the world, the understanding of the human mechanisms which contribute to this increasingly dangerous situation is of the utmost importance. This study is an initial attempt to develop a theoretical model which might aid others in the analysis and control of hazard-zone occupation. In this chapter the individual elements of the model are identified and their relationships are described verbally and symbolically. In the next chapter, the verbal model is transformed into a computer simulation so that the actual process may be represented dynamically.

The Settlement Process

An important component of the interactions between settlement and natural hazards, is the process of settlement itself. For the purposes of this model, settlement has been restricted to rural agricultural settlement. The act of settling the land is thought of as a process which has occurred in the past, without the myriad of electronic influences of the Twentieth Century. There are, of course, isolated areas of the world where television and bulldozers do not reach, and this limitation is not designed to exclude them. However, it is perhaps necessary to stress that this model is born out of a larger interest in the early colonization and settlement of North America. The model is designed to represent that type of settlement which is characterized by single-family dwellings, each located on the land that is farmed, usually approximating 160 acres. These definitions are likely to be considered by many as the stereotypic characteristics of early white settlement in the Midwest region of the United States. Undeniably this is so, and yet the model is not meant to be a regional one, and clearly there are other areas of the continent where these conditions also appeared.

A large amount of confusion has been interjected into settlement studies due to unclear explanations of the scale at which the analysis has taken place. To avoid this confusion, a few more declarations are necessary. This study is in no way related to the distribution of villages, or hamlets or any other low-order central places that are commonly associated with agricultural production. It is expressly concerned with single-family agricultural units which may or may not be contiguous holdings. Much of the confusion in the investigation of random vs. regular vs. clustered settlement patterns is seemingly due to this same scale problem. This is a result, at least in part, of the dual central place theory dicta of regular spacing of farmsteads and the regular development of a central place network. There is a large gulf between patterns of individual farmsteads, and patterns of hamlets or villages. It is clear that there are a number of stereotypic agricultural settlement types including, in North America at least, the New England village with a commons and central church site, and the southern coastal dispersed plantations and farms (Trewartha, 1946). The distinction between these types of settlement patterns are often more clearly drawn by historians than geographers. A historian is seemingly more apt to recognize the influences on the evolution of different settlement patterns because of his more frequent concern with historical processes. Ernest Paget, a geographer, has explained:

> In Canada, for example, the French Canadians adopted nucleated settlement patterns with their primary aim of reestablishing socio-religious and mainly self-sufficient communities. These were, and still are, markedly different from those elsewhere in Canada where the primary aim was economic, in the creation of rural townships with scattered farmsteads. In the latter, emphasis was on farming efficiency and social problems were correspondingly more difficult to overcome; in the former the emphasis was on social efficiency (as they saw it) with its requisite groupings (Paget, 1960, p. 325).

Frequently geographers, in their quest to determine the character of a pattern, lay a grid on a map and aggregate the number of settlements per cell. Yet any description of a pattern as random or uniform is grid specific, for a pattern at one grid size could be random, and clustered at another size. Hudson states that,

> Distributions are random, regular, or clustered only with respect to a given quadrat size and the size of study area in the case of cell count analysis,

> and with respect to study area size in near-neighbor analysis (Hudson, 1969, p. 377).

Hudson has explained that the density of settlement in an area can be thought of as being dependent on m environmental variables. These variables may be transformed into n components which represent the m variables, yet are statistically independent. That is, each of the n components represent basic factors of the original environment, and none measure any characteristic or phenomenon measured by another. These components are thus independent and orthogonal in n-dimensional space. Each of these components is represented by a vector in n-space, the volume represented by the intersection of the component values represents niche space (N) for a particular area. A magnitude function may be seen as transforming niche space (N) into a mappable abstraction of N called biotope space (B). It is biotope space which represents the density of settlement; it is here where settlement-limiting vectors in N are translated into actual boundaries. Thus, a hazardous environment, stricken by drought for example, might be represented by an influential component whose value is quite low. The representation of this limitation might create a settlement boundary in biotope space.

Hudson also explains that the magnitude function determines the density of settlement in biotope space (dB) but not the pattern of that settlement. However, a number of Hudson's hypotheses and conclusions deal with the concept that there is indeed a relationship between density and pattern. That is, Hudson tried to show that the greater the density, the greater the regularity of settlement. As a corollary, Hudson showed that the less dense the biotope the greater the degree of clustering. During periods of little competition, that is low density, clustering is encouraged. These periods commonly occur early in the settlement history of an area, in the stage Hudson has called "colonization." This study is exclusively devoted to the initial period of settlement of an area when the environmental character, that is, the niche space, is still in the process of being thoroughly evaluated through the settlement process.

A basic assumption of this model is that in the early stages of the settlement of an area, people tend to settle in a clustered manner. Varying biotope density (dB), cultural ties, channel migration, and environmental perception as well as more deterministic influences, such as transport and service centers, all contribute to clustered settlement in early settlement stages. The density of settlement, as expressed at a point in the biotope by the magnitude function, is not a strict determination, for while the environmental parameters may allow a specific dB, a variety of real world influences may determine the density to be much less than dB. This is a small yet key point, seemingly ignored by previous works in settlement geography too caught up with geometry, e.g., Hudson (1969). A key difference between the early colonization stage where clustering tends to dominate and the later competition stage where regularity dominates settlement patterns is not simply the result of time-space geometry but of distinct human-related influences such as information availability, experience, and cultural development.

On the whole then, a new settler is more likely to choose a place to farm nearby other already established settlers. A symbolic representation of the settlement process is shown in Figure 7.

The Natural Event System

The characteristics of natural hazard systems may vary between localities as well as between types of hazards. It is a difficult endeavor to attempt to generalize concerning the important characteristics of hazardous events. Natural hazards include drought, hail, flood, hurricane, tsunami, earthquake and tornado, and clearly the geophysical systems ruling the occurrences of these events are widely disparate. However, probability theory has been effectively used in the analysis of these systems.

In the analysis of natural systems, probability theory is primarily concerned with the probabilistic structure of events that are characterized by a very limited existence on a time or space continuum. That is, these natural events are discrete events with a momentary or

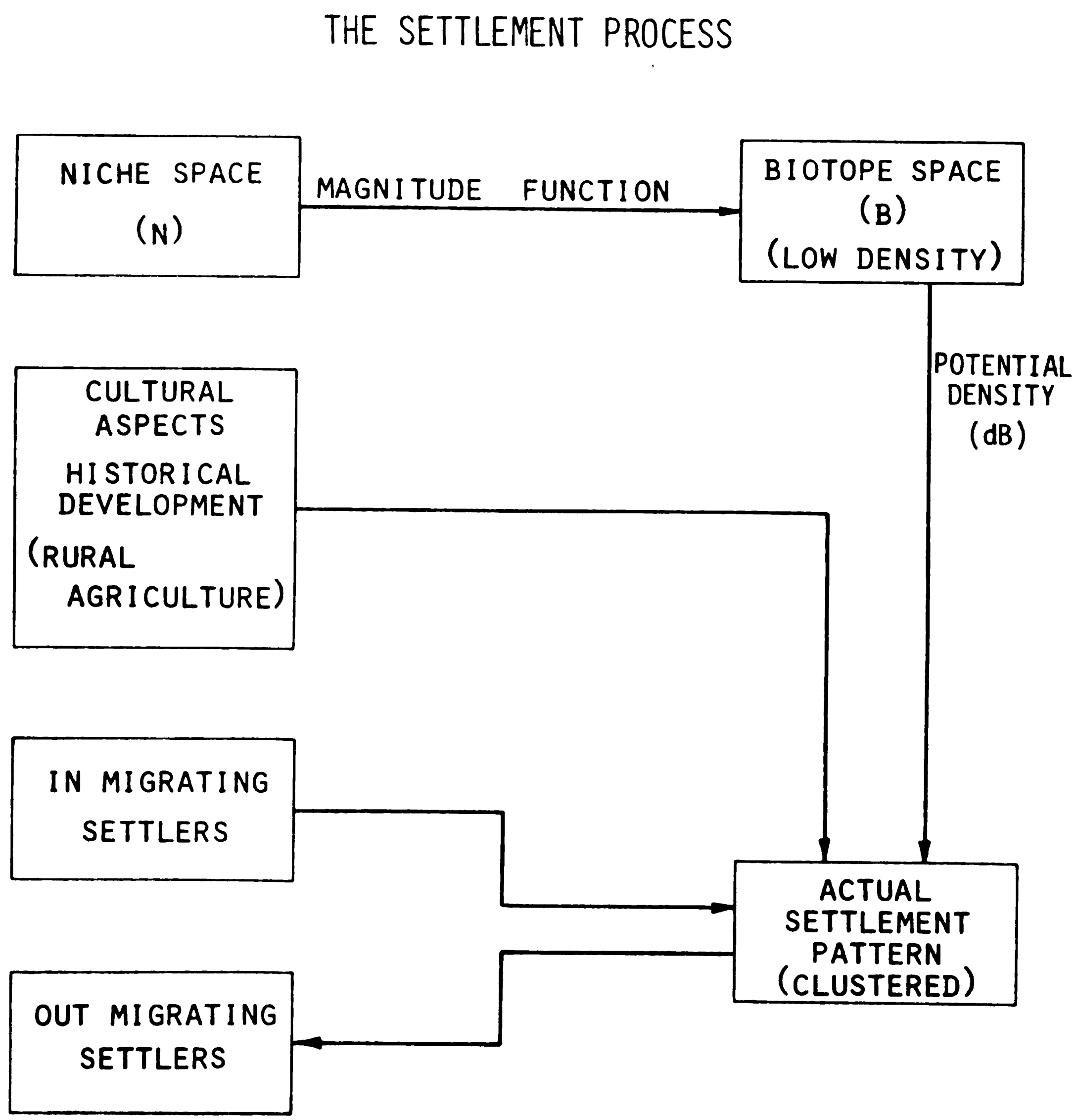

Fig. 7.--Model of the Settlement Process.

limited duration in time. These discrete phenomena might include annual maximum of river height, monthly low temperature, and annual frequency of hail storms. The principal focuses of probabilistic analysis of discrete natural event systems are the frequency and the magnitude of these events. Hewitt reviews the multiplicity of uses of probability theory in the analysis of natural event systems in "Probabilistic Approaches to Discrete Natural Events: A Review and Theoretical Discussion" (1970).

A number of theoretical approaches to the magnitude and frequency of natural events have been developed. All of these techniques are designed to establish the relationship of the events' frequency and magnitude over time. The great majority of this type of analysis has been limited to the study of flood frequency and peak stream discharge, and will be explained in that context. Perhaps the best known and most widely used is the Theory of Extreme Values, as developed by E. J. Gumbel (1958).

The Theory of Extreme Values explains that at any given gauging station, a discharge of a given magnitude will eventually be exceeded. While past records will always be broken, the probability of the occurrence of a specific discharge decreases as the magnitude increases. That is, low stream discharges occur more frequently than high discharges. The theory explains that no matter how severe a flood, for example, the future will see one higher;

the more severe, the longer the wait might take. There is an important point here: a distinct inverse relationship exists between discharge (magnitude) and occurrences over time (frequency). Dury has stated,

> . . . statistical analysis of actual records and statistical reasoning about the results of analysis show that the observations reduce themselves to order when their magnitudes are plotted against their frequencies (Dury, 1969, p. 35).

The Gumbel technique is widely used in flood frequency analysis for its predictive value. This method requires the highest stream discharge at a specific point to be recorded each year. These peak levels are called floods and comprise the annual series. The series is then ranked in descending order. The recurrence intervals (RI), or the average frequency of occurrence, for each level of discharge may then be calculated using the formula

$$RI = \frac{N + 1}{r}$$

where N is the number of floods in the annual series, and r is the ranking of a given discharge.

The discharge levels are then plotted against the calculated recurrence intervals. Specially-designed Gumbel graph paper may be used, but logarithmic-probability or semi-log paper are just as likely to work (Benson, 1962, p. A-7). The plotted data are apt to approximate a straight line depending on the type of paper, the geographic region, and other factors. The purpose of this type of analysis is to enable the researcher to determine the recurrence interval of a given discharge. A line may be either drawn on the graph by eye or fitted mathematically. It is important to realize that the recurrence interval is simply the average interval of time between two successive events of a given magnitude. It does not mean that a discharge with an RI of 50 years occurs every 50 years. Indeed, it is quite possible for two "50-year floods" to occur in succeeding years. Furthermore, Dury explains, ". . . some 50-year spans must inevitably include 100-year floods (on the average, one such span in two), 500-year floods (one in ten), and 1,000-year floods (one in twenty)" (Dury, 1971, p. 151). An example of a flood frequency graph is reproduced in Figure 8.

The Gumbel technique has shown that the mean flood has a recurrence interval (RI) of 2.33 years. The median flood has an RI of 2.0 years, that is, it can be expected to be exceeded or equaled, on the average, 50 percent of the time. The most probable annual peak discharge has a recurrence interval of 1.58 years. The probability of a discharge occurring in any given year is simply the reciprocal of the recurrence interval. That is, if a discharge has an RI of 50.0 years, its probability of occurrence during any given year is .02 or 2 percent.

The shape of a curve created by plotting discharge against average frequency on regular graph paper is usually

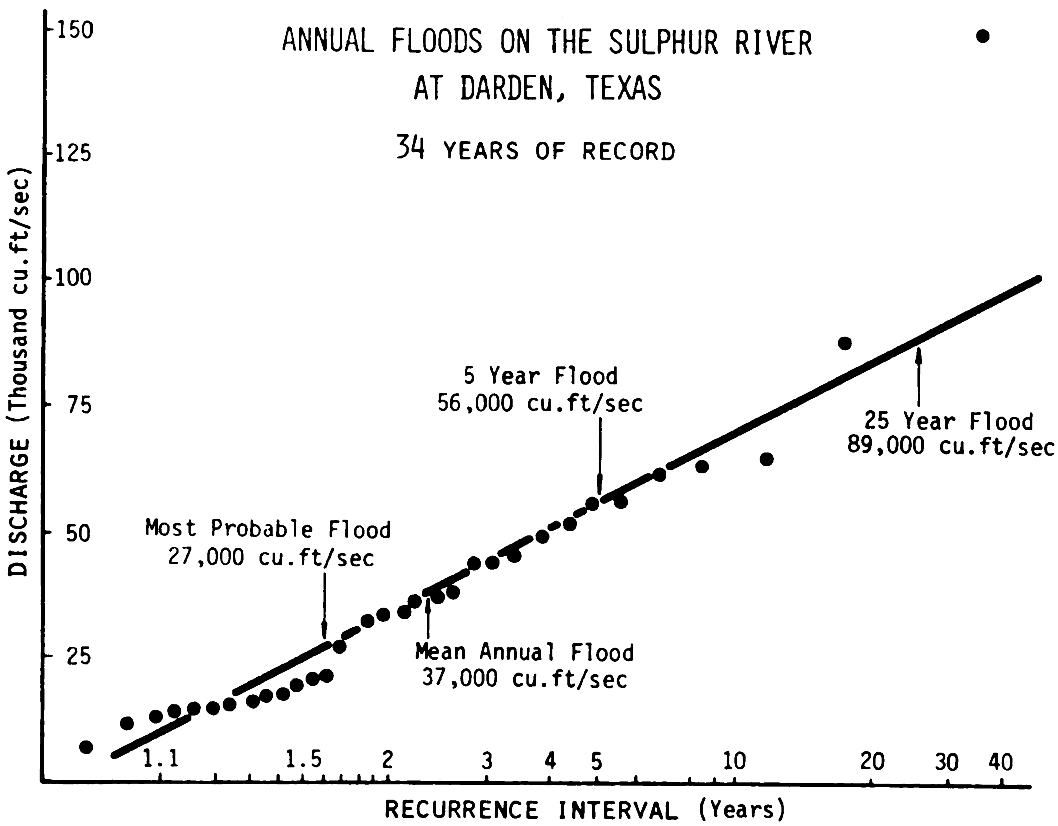

Fig. 8.--An Example of Gumbel Analysis (after Dury, 1969).

a shallow sloping curve similar to the cumulative frequency curves of the lognormal and Gumbel distributions. The lognormal distribution is a continuous frequency distribution which is widely acknowledged as representing the frequencies of a wide range of natural event systems (American Insurance Association, 1956; Benson, 1962; Hewitt, 1970). Wolman and Miller have stated that ". . . the frequency distributions of the magnitudes of many natural events, such as floods, rainfall, and wind speeds, approximate log-normal distributions, . . ." (Wolman and Miller, 1960, p. 54).

It is a basic assumption of this model that the sole natural hazard experienced by the settlers' in their day to day existence is flooding, and that the annual peak discharges are lognormally distributed. A symbolic representation of the natural event system is found in Figure 9.

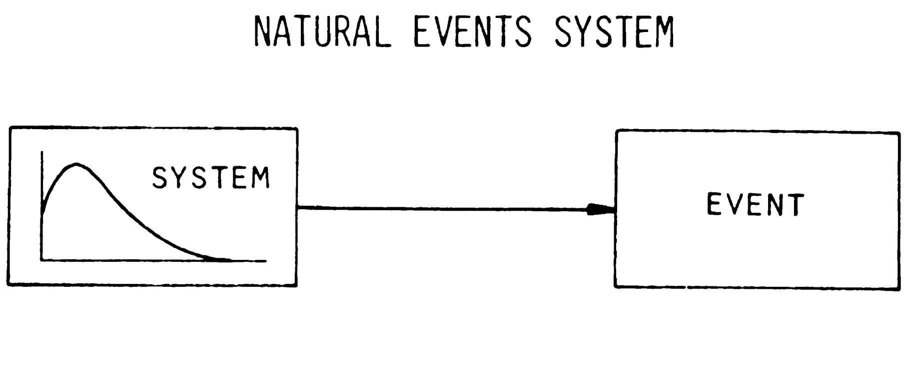

Fig. 9.--Model of the Natural Events System.

The Human Response

Human adjustment to the presence of natural hazards has long been the major focus of hazard research. Many of the studies in the natural hazard area have inventoried possible adjustments, analyzing the effectiveness of certain adjustments or analyzing the adjustment adoption process. It is, therefore, of particular importance in the development of a model of settlement and hazard interaction, that the process of adjustment evaluation and choice by the settlers be defined. What are the behavioral relationships between the settlement process and natural hazards?

There are a myriad of influences on the adjustment adoption process. Many of them have been touched on in an earlier chapter. However, four major factors need to be discussed here: economic status, adjustments available, perception, and experience. The material wealth of an individual can affect his access to information, his security against serious financial loss and can widen the range of possible adjustments. However, as important as wealth may be as a factor influencing the adjustment process, for the purposes of this model, it is assumed that the individual wealth of all the settlers is the same. Because the model intends to replicate the function of a rural historical process, it was felt that not only would wealth vary little from settler to settler, but that also its influence would be less in a rural, less-developed region.

The available adjustments factor is obviously important in the adjustment process. Flood damage to a farm can be anywhere from light to devastating. Good soil can be washed away, buildings knocked down, crops destroyed, equipment and fences lost. It has been shown that flood damages, as flood magnitudes, are lognormally distributed (American Insurance Association, 1956), and thus it is assumed that the larger the flood the larger the loss to the settler. Of Kates' three techno-social stages discussed above, early agricultural life may be considered similar to the Folk and Pre-industrial stage and, as such, the available adjustments relied on change in the human use system rather than the natural hazard system. These adjustments required low capital investment and were implemented on an individual basis. The adjustments open to an early settler were quite limited. The settler, through crop diversity, plot distribution, and surplus production, could absorb some of the hazard damage. He could simply accept the loss and hope to do better next year, but really little else. As Brooks has explained:

> When the climatic conditions become such that farmers can no longer raise their crops their resources completely vanish and the breaking point of their social fabric is at hand. Peasant farmers and unskilled laborers are usually left with but two alternatives: remain and risk famine and death, or flee to a region better supplied with the necessities of life (Brooks, 1971, p. 40).

Thus, after the settler has absorbed as much of the hazard's damage as he can sustain, there is little else he can do but move. It is a basic assumption of this model that there is one specific behavioral adjustment that affects the process of settling and the resultant settlement pattern, and that is for the settler to move away. To move is clearly an individual adjustment and may require little capital.

Perception is particularly important to the process of adjustment evaluation and adoption, and has been touched on above. Major questions in the construction of the model are: (1) How do the settlers perceive the flood hazard? (2) How do the varying frequency and magnitudes of the hazards affect the perception? and (3) How do these perceptions influence the actual choice of adjustment, that is, the actual behavioral response? A popular assertion in hazard literature is that there is a strong relationship between the numbers of adopted adjustments and the frequency of flood, drought, and frost events (Kates, 1962; Saarinen, 1966; Burton, Kates and Snead, 1969). However, these were recent studies of modern hazard zone occupance and adjustment in North America where the number of available adjustments are quite large, whereas in early rural agricultural areas this was clearly not the case.

Some researchers have suggested that the most adjustments are adopted in areas of moderate hazard frequency (Heijnen and Kates, 1972). Indeed, White and Haas, in the most recent statement of hazard research, Assessment of Research on Natural Hazards (1977), have written:

> Individuals with no experience of the hazard may be slow to accept information about its probability. It is difficult for individuals who have not lived in an area where houses slip and crack under landslide conditions to grasp the likelihood that their own house may be subject to such destructive forces on an outwardly placid hillside. At the other extreme, there is evidence that individuals subject to frequent hazard experience may tend to minimize its impact, as in the case of residents of cities with frequent heavy snowfalls.
>
> In the intermediate range are individuals who are subject to an extreme event from time to time, as in the case of flood plain occupants who experience a flood every five or ten years. They are likely to show a greater awareness of risk and keener perception of the range of alternatives that are open to them (White and Haas, 1977, p. 100).

The idea of discrete categories of relationships between men and hazards, and what men think and do about the hazards was first suggested by Kates (1963) and Burton (1962). It is not uncommon to rebuild communities in the same place after complete devastation by a flood, excusing the event to a quirk of fate, or dismissing the hazard as an act of God. It is also common for people to accept very low magnitude-high frequency events and to build the adjustments into the normal social system. It is the medium intense events which occur only occasionally that seem to evoke the greatest adjustment, adjustments that are outside the normal day to day social system. For the purposes of the model, events of medium magnitude and medium frequency are perceived by settlers as being more hazardous and result in more behavioral adjustments than do extremely frequent or extremely infrequent events.

A similar concept has developed in the field of geomorphology that has been revolutionary in the analysis of natural event systems. Wolman and Miller investigated the question of the relative importance of extreme or catastrophic events, and more frequent events of less magnitude, in terms of their effectiveness in actual work done in geomorphic processes. "It was widely believed that the infrequent events of immense magnitude are most effective in the progressive denudation of the earth's surface" (Wolman and Miller, 1960, p. 54). However, the authors recognized that frequency, not simply magnitude, was an important factor. They concluded that "analysis of the transport of sediment by various media indicate that a large portion of the 'work' is performed by events of moderate magnitude which recur relatively frequently rather than by rare events of unusual magnitude" (Wolman and Miller, 1960, p. 72).

A major conceptual founding stone of this model is that hazardous events of a medium intensity, which occur relatively frequently, are perceived by the settlers as more hazardous than either frequent, or infrequent catastrophic events. Events of great magnitude are dismissed as flukes, and ". . . even though they may have suffered severe losses, hazard-zone residents tend to return to their original locations" (Mitchell, 1974, p. 322). Extremely frequent hazardous events go nearly unnoticed, accepted as a part of the daily existence. The settlers' perception tends to emphasize the medium intense experiences, ignore the least intense, and rationalize the most intense.

This idea is based on the concept of a standardized perceived hazard system. All hazard systems have their own base index as defined by the most common (and least intense) event, and this index is recognized and accepted by occupants of the hazard zone. A two-inch snow storm in Miami is perceived as a much different hazard event than a two-inch snow storm in Minneapolis. Thus, the actual perceived degree of hazardousness may only be explained in terms of the index event. In effect, then, a standardized hazard system may be visualized where a medium-intense event is perceived with the same degree of hazardousness in Miami and Minneapolis.

Experience, too, is an important factor in a settler's adjustment process. Kates and Burton have shown that the greater the experience with a hazard, the more one is certain of another occurrence. Experience then is really an accumulated hazard perception. The recency of a hazard event is important to the level of this accumulated hazard perception, for as Wolpert has explained in "Migration as an Adjustment to Environmental Stress" (1966), a natural human coping mechanism will attempt to ease the stress created by the hazard. This sense of stress clearly would be a part of any accumulated hazard perception. With each new hazard event we can assume that the accumulated sense of hazard will grow, but that over time this stress will be relaxed by an internal coping system. In another article, "The Behavioral Aspects of the Decision to Migrate" (1965), Wolpert has suggested that what is sometimes called the "mover-stayer decision," be ". . . reduced to the single dimension of time--when to move" (p. 163). He suggests that stayers be considered as movers who have postponed their decision to migrate. The settlers, then, are on a continuum of accumulated perception. When the total reaches a specific threshold, the settler ceases to postpone the adjustment, and moves.

A symbolic representation of the model's assumptions concerning the adjustment adoption process is shown in Figure 10.

Having identified all of the individual elements of the model, an integrated representation of the model as a whole appears in Figure 11. This figure provides an adequate explanation of the functional linkages of the model. However, the model itself is synergistic, and thus cannot be fully explained nor understood at the level of

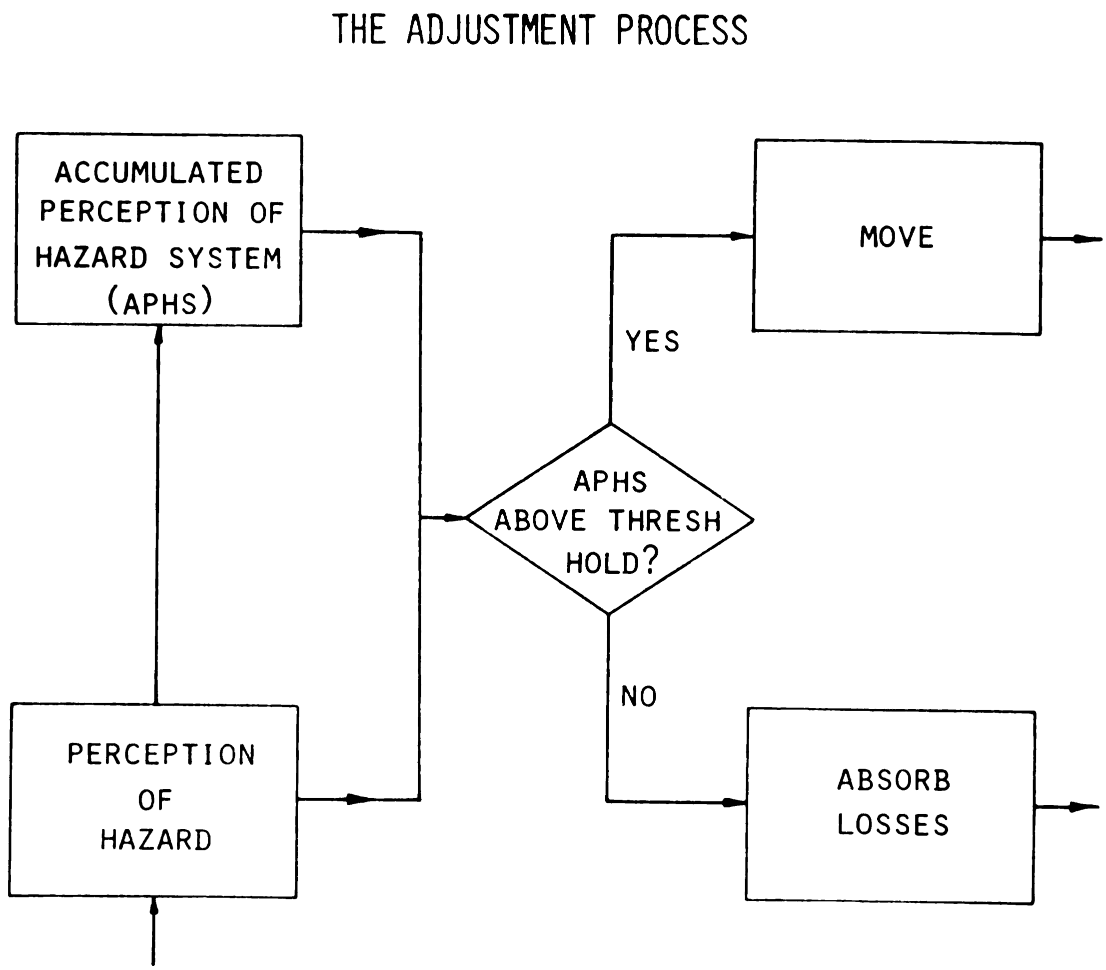

Fig. 10.--Model of the Adjustment Process.

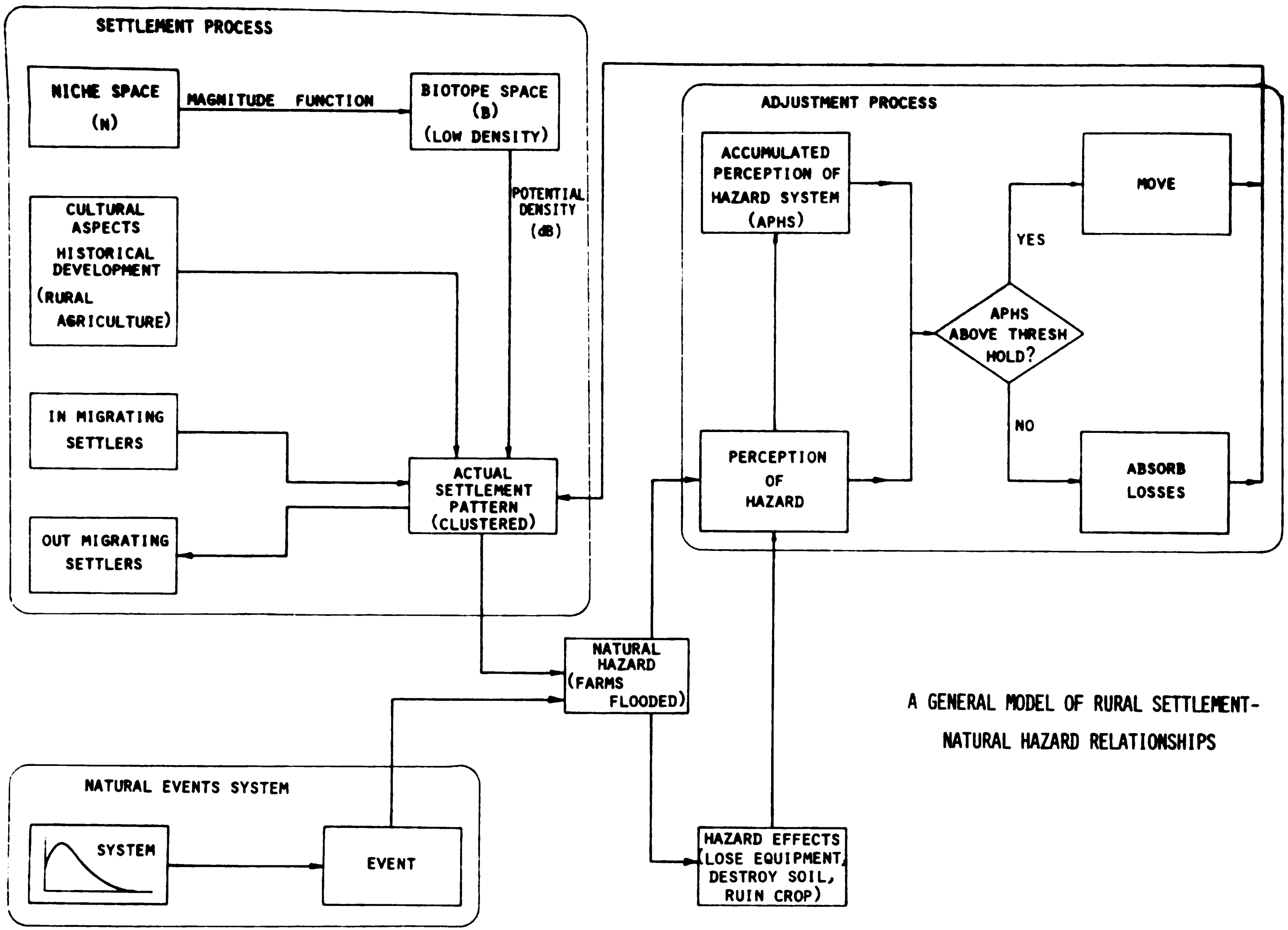

Fig. 11.--A General Model of Rural Settlement--Natural Hazard Relationships.

boxes and arrows. The model is intended to explain the workings of a dynamic system. This process therefore can only be truly modeled in a dynamic way. The translation of the model into a computer simulation is the goal of the next chapter.

CHAPTER V

A COMPUTER SIMULATION MODEL: SETSIM

Computer simulation was first used in geographic research by Hägerstrand in his investigation of innovation diffusion in Sweden (Hägerstrand, 1952; Hägerstrand, 1965). Computer simulation has since become an accepted tool in theory development and the investigation of geographic processes, though its use in human geography has largely been limited to the areas of urban growth (Garrison, 1962; Morrill, 1965a; Morrill, 1965b), diffusion (Brown, 1963) and central place theory (Morrill, 1962; Morrill, 1963). Computer simulation has been used to a limited degree in the study of the settlement process. Bylund (1960) constructed a deterministic simulation of settlement in northern Sweden, and Norton (1976) a stochastic simulation of settlement in southern Ontario. Simulation has also been utilized in the analysis of hazard damage by insurance companies (Friedman and Roy, 1966; Friedman, 1969; Friedman, 1973; Friedman, 1975).

Computer simulation lends itself to the development of theoretical models because of its ability to duplicate the actual dynamics of the system. As McPhee has explained: "When that computer is programmed to represent one's theory, its processes are then synonymous with those of the theory, and pressing the GO button sets the theory in motion" (McPhee, 1960, p. 61). The use of computer simulation allows us to have a GO button for a theoretical model. Furthermore, the necessity of transforming a verbal model into a simulation requires a greater degree of precision in the model. This precision will often necessitate a more thorough consideration of the system to be modeled and will require a deeper analysis of the relationships to be simulated.

However, computer simulation may play a much larger role in the development of a theoretical model than allowing a dynamic representation of the model or requiring a more precise definition of the system. Indeed, computer simulation may be used as an important tool in the actual process of theory development. Gullahorn and Gullahorn have explained that a

> . . . computer simulation not only plays a passive role of verifying and testing theory; it performs active functions for the development of theory . . . . In a computer run investigating a theory's processes it is not unlikely that unanticipated, anomalous, and strategic data may result and become the occasion for developing a new theory or for extending the existing model (Gullahorn and Gullahorn, 1965, pp. 445-6).

Thus in this endeavor to develop a model of the interaction of the settlement process with a hazard system, not only is the manifestation of the verbal model as a computer simulation viewed as an important step in ascertaining the actual implications of the model's assumptions, but it is also an important step in the development of the theoretical model.

This chapter is an attempt to explain the translation of the model into a computer simulation and give a basic description of how the simulation functions. Each element of the model is treated in turn, and general flow charts of the simulated sub-system are included. Much is made of the distinction between stochastic and deterministic simulations. In spite of a number of deterministic relationships contained within the model, principally in the adjustment process, the fact that the human-use system and natural event system have been developed in the context of probability demands that this simulation be termed a stochastic one. This will become more clear later in the chapter. The simulation is designed to function on even time increments of one year; that is, the system is simulated on a year to year basis.

The Settlement Process

The translation of that part of the model devoted to the settlement process necessitated a number of basic definitions. An idealized settlement plane, similar to a gameboard, on which the simulation might take place, was a necessary construct. Arbitrarily this plane is divided up into 25 settlement "areas," which can be seen as forming a 5*5 "area" matrix. Each of these areas are again divided into 16 "cells" which form a 4*4 cell matrix within each area. The settlement plane, as portrayed in Figure 12, is composed of a 20*20 cell grid. A commonly accepted notion concerning North American settlement, or at least that settlement east of the Great Plains, is that 160 acres was a suitable size for a single family farm. Indeed, the Homestead Act of 1862 originally provided that the head of a family could receive a quarter section (160 acres) simply by paying a nominal fee (Brown, 1948). If we consider each cell to represent 160 acres, then each "area" contains four Congressional Survey Sections. A survey township is comprised of 36 sections. Thus, the inner 3*3 square of settlement "areas" may be seen as representing what we know as a Congressional Survey township. Each settlement "cell" may be settled by one and only one settler.

To begin the simulation, the user is given the opportunity to choose the initial settlement pattern. It is this pattern that the simulation considers as the settlement condition at the start (Time (T) = 0) of a given run. The options that the user may choose from are: (1) the center of each settlement area is settled, (2) the east (right) of the plane is settled, (3) the center of the entire grid is settled, and (4) the settlement plane is left unsettled for the beginning of the simulation. The first option represents a situation where initial colonization of the plane has developed into a uniform pattern.

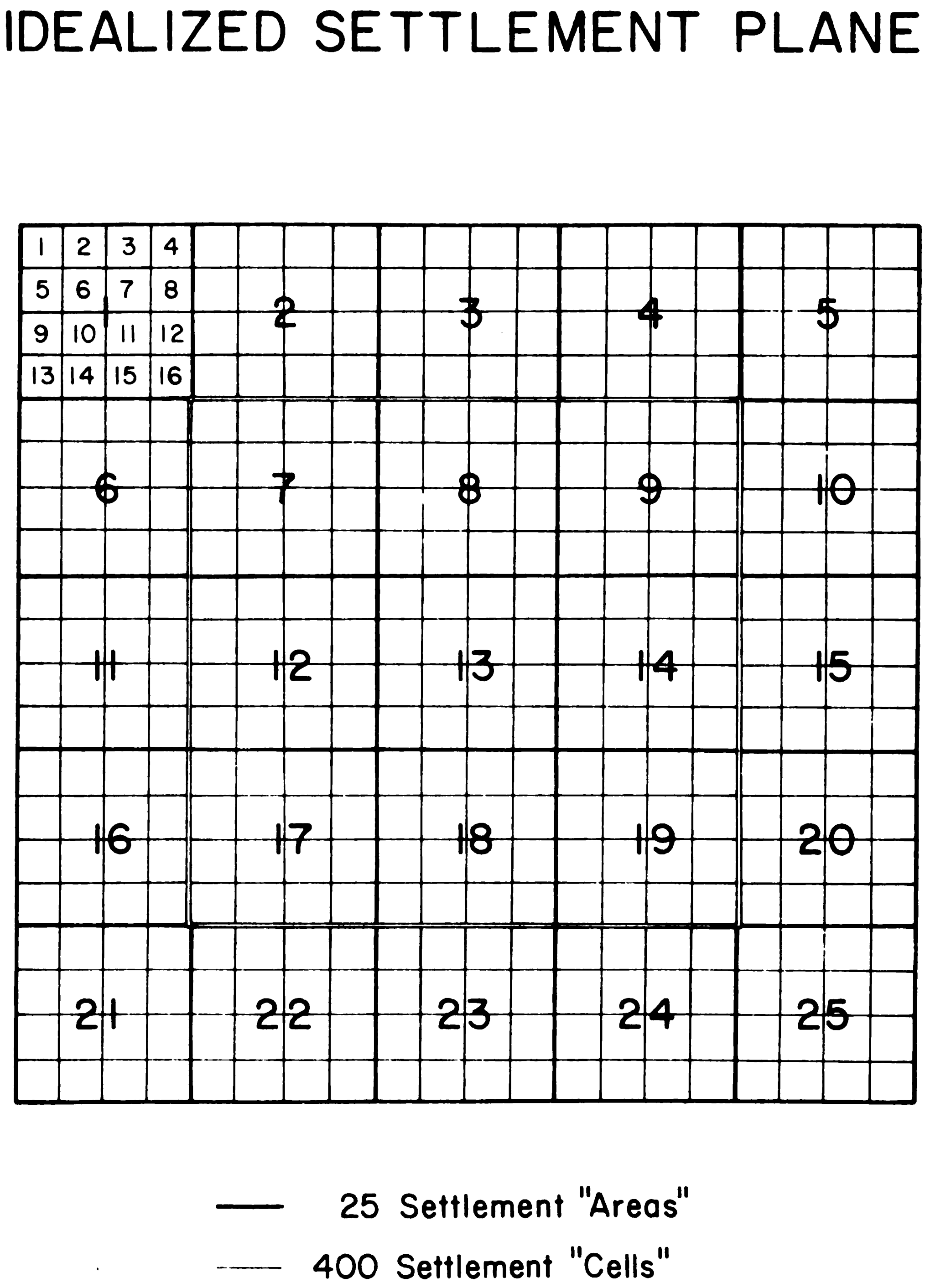

Fig. 12.--The Idealized Settlement Plane.

The second option is designed to replicate a situation where a settlement frontier has begun to move from the east into the settlement plane. The third option is intended to represent a situation where a few settlers have chosen to initially colonize the region by settling near a central point. The fourth option represents a completely unsettled region.

Because the initial pattern is determined by the user, the variable representing that pattern (P) is considered an input or exogenous variable.

An important part of the theoretical model developed in the previous chapter was that early periods of settlement are characterized by clustered settlement patterns. Simply, the concept said that people will tend to settle in areas where other people have chosen to settle, or that given a prospective settler, there is a greater probability that he/she will settle near other settlers. Furthermore, the more settlers in a region, the greater the probability that a new settler will settle in that region. Utilizing the settlement areas and the concept of the Mean Information Field (MIF) (Marble and Nystuen, 1963), a process was devised by which clustered settlement might be effectively simulated. The development of a Mean Information Field requires the calculation of the probability of an event occurring within a particular area. That is, the probability of a settler choosing to settle in any given settlement area needed to be calculated. The probability that a particular area would be chosen for settlement may reflect the number of settlers already located in that area. If there were no settlers located in the settlement plane, as the P = 4 option allows, then the first settler to be located in the settlement field would face equal probabilities of settling in any of the 25 settlement areas. This situation is represented in Figure 13. If there were four settlers located in the middle area, as the P = 3 option would dictate, and if we had determined that the probabilities of settlement were directly proportional to the differences in settlers located in an area, that is, an area with one settler would be twice as likely to receive the next settler as an area with zero settlers, then the MIF might be represented as in Figure 14. The single area probabilities in any MIF by definition sum to 1.0. This allows the translation of the MIF in Figure 14 into the MIF in Figure 15 which displays the cumulative probability of settling any given area, left to right along the rows of the plane. Having constructed a cumulative MIF it is a simple procedure to choose a prospective settler a settlement area. A random number with a uniform distribution between 0.0 and 1.0 may be generated. The area whose cumulative probability range contains the generated variate is the chosen area. A uniform distribution is used because the MIF requires a

.04	.04	.04	.04	.04
.04	.04	.04	.04	.04
.04	.04	.04	.04	.04
.04	.04	.04	.04	.04
.04	.04	.04	.04	.04

Fig. 13.--Mean Information Field of Equal Settlement In All Areas.

.034	.034	.034	.034	.034
.034	.034	.034	.034	.034
.034	.034	.172	.034	.034
.034	.034	.034	.034	.034
.034	.034	.034	.034	.034

Fig. 14.--Mean Information Field of Four Settlers in Center Area.

.034	.068	.103	.137	.172
.206	.241	.275	.310	.344
.379	.413	.586	.620	.655
.689	.724	.758	.793	.827
.862	.896	.931	.965	1.00

Fig. 15.--Cumulative Mean Information Field of Four Settlers in Central Area.

continuous probability distribution. Discrete distributions such as the Poisson and the negative binomial are frequently used in the analysis of real-world settlement patterns. However, the model requires each new settler to be located on the basis of those previously settled and this assumption necessitates the utilization of an MIF and a uniform distribution. A series of discrete variates could be generated, one for each settlement area, yet it would not be possible to have the variate series reflect any previous settlement conditions. A cell within the designated settlement area is chosen randomly by generating a random cell variate with a uniform distribution between the numbers of 1 and 16. A uniform distribution was used to choose a settlement cell simply because there seemed to be no reason to weight the probability of one cell being chosen any more than any other.

The user is given the opportunity at the beginning of each year to specify the number of incoming settlers (N) who will need to be located that year. Each of these settlers is located within the settlement plane given the procedures outlined above. The MIF is revised for each new settler. That is, the settlement process is dynamic as the probability of an area being chosen for settlement is updated for each new individual settler. As a settlement area begins to fill up, that is, as more and more of its cells are settled, it is not uncommon for a settler to choose an already settled cell within the chosen settlement area. If this occurs, the settler randomly chooses another cell. After 15 successive choices of cells that are already settled, the settler is determined to be disheartened with the entire region, being unable to find a location to settle, and is assumed to have moved on to another region. Effectively the settler is dropped from the queue. However, if a settler chooses an area that is settled to capacity, a new area is chosen.

The number of incoming settlers each year (N) is determined by the user, and as such is another input or exogenous variable. The area (S) and cell (C) variables are determined internally and thus are status variables;

because the values of these variables are generated from operational characteristics in the form of probability density functions they are stochastic variables as well. The different values that a stochastic variable may take are called variates. A flow chart of the simulated settlement process appears in Figure 16.

Simulating the Natural Event System

The essential task of simulating the natural event system element of the model depends upon the generation of log-normally distributed annual flood levels. There are standard routines for the generation of log-normal variates (see Naylor et al., 1966) which require a predetermined mean (μ) and variance (σ^2) of the population to be generated. That is, the routine must know the basic form of the population before it may generate the variates. Rather than simply seize on mean and variance statistics out of thin air, a specific site and annual series was chosen as a basis for this part of the simulation. The flood experience at Lafayette, Indiana, which sits on the Wabash River, was chosen for this purpose. The annual series and the recurrence interval for each discharge is displayed in Table 1.

An assumption of the model is that the annual series is log-normally distributed. To determine whether Lafayette, Indiana's annual series was so distributed, the annual peak discharges were plotted against the

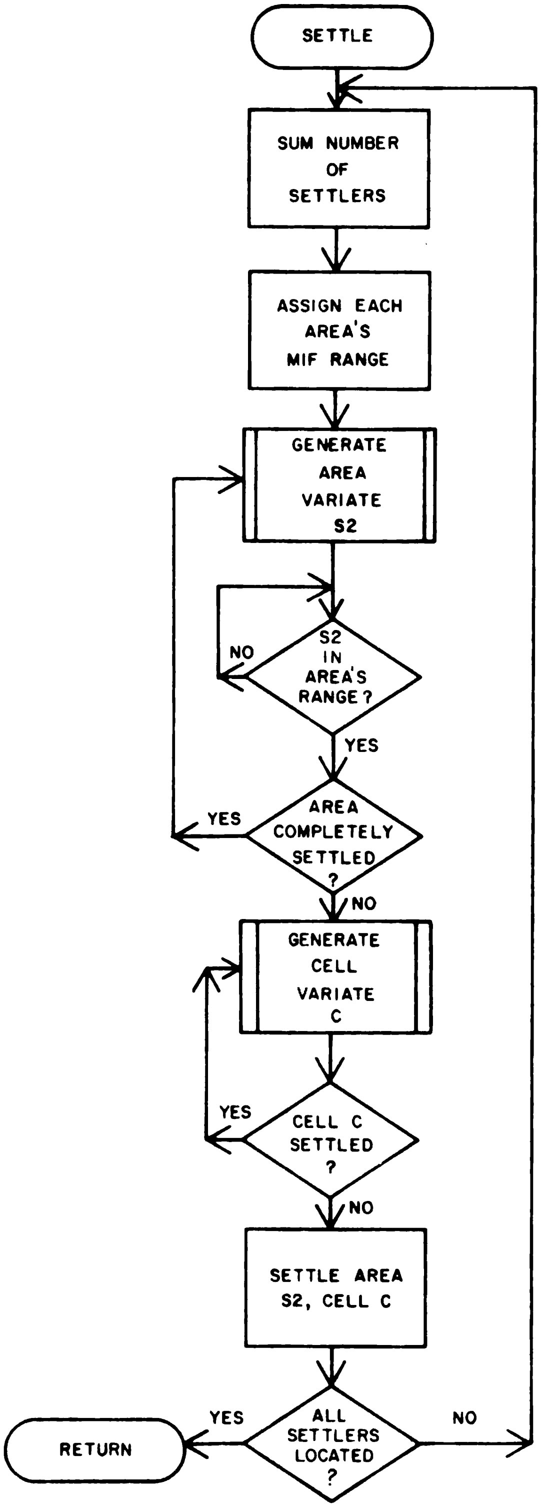

Fig. 16.--Flowchart of SETTLE Routine.

Table 1.--Annual Floods on the Wabash River, at Lafayette, Indiana 1924-57.

Year	Peak Discharge (Cubic Ft/Sec)	Ranking Order	Discharge (Cubic Ft/Sec)	Recurrence Interval (years)
1924	59,800	1	131,000	35
1925	63,300	2	93,500	17.5
1926	57,700	3	90,000	11.7
1927	64,000	4	74,600	8.8
1928	63,500	5	74,400	7.0
1929	38,000	6	73,300	5.8
1930	74,600	7	67,500	5.0
1931	13,100	8	64,000	4.4
1932	37,600	9	63,500	3.9
1933	67,500	10	63,300	3.5
1934	21,700	11	63,300	3.2
1935	37,000	12	62,000	2.9
1936	93,500	13	59,800	2.7
1937	58,500	14	58,500	2.5
1938	63,300	15	57,700	2.3
1939	74,400	16	52,600	2.2
1940	34,200	17	50,600	2.06
1941	14,600	18	46,600	1.95
1942	44,200	19	44,200	1.84
1943	131,000	20	41,900	1.75
1944	73,300	21	41,300	1.67
1945	46,600	22	41,200	1.59
1946	39,400	23	38,400	1.53
1947	41,200	24	38,000	1.46
1948	41,300	25	37,600	1.40
1949	62,000	26	37,000	1.34
1950	90,000	27	35,300	1.29
1951	50,600	28	35,000	1.25
1952	41,900	29	34,700	1.21
1953	35,000	30	30,000	1.17
1954	16,500	31	21,700	1.13
1955	35,300	32	16,500	1.09
1956	30,000	33	14,600	1.06
1957	52,600	34	13,100	1.03

Data: Dury (1971).

recurrence intervals on logarithmic probability paper. By definition, this type of paper will straighten a log-normal distribution into a straight line. Figure 17 displays the result of this plotting.

Having chosen the Lafayette series as a model for the simulation of peak discharges and having shown that the series is approximately log-normally distributed, the mean and variance of the series were used in the development of an event generator. This generator will produce an annual discharge level (X) during each year of a simulation run, by sampling a log-normal probability distribution. A histogram representing 1,000 individual discharge variates generated by this routine is shown in Figure 18.

Each of the floods in an annual series have a specific recurrence interval (RI). The different levels of the discharge variable, because they are determined from a continuous probability function, may be infinite and each of these would have its own RI. How might the RI of each year's discharge level be determined? The plot of Lafayette's annual series on regular graph paper is shown in Figure 19, RI against Discharge. Polynomial regression was used to determine the best fitting curve to approximate the trends of the plotted points. Discharge was used as the independent variable, and recurrence interval was used as the dependent variable. The relevant statistics for the polynomial regression are reproduced in Table 2. The most

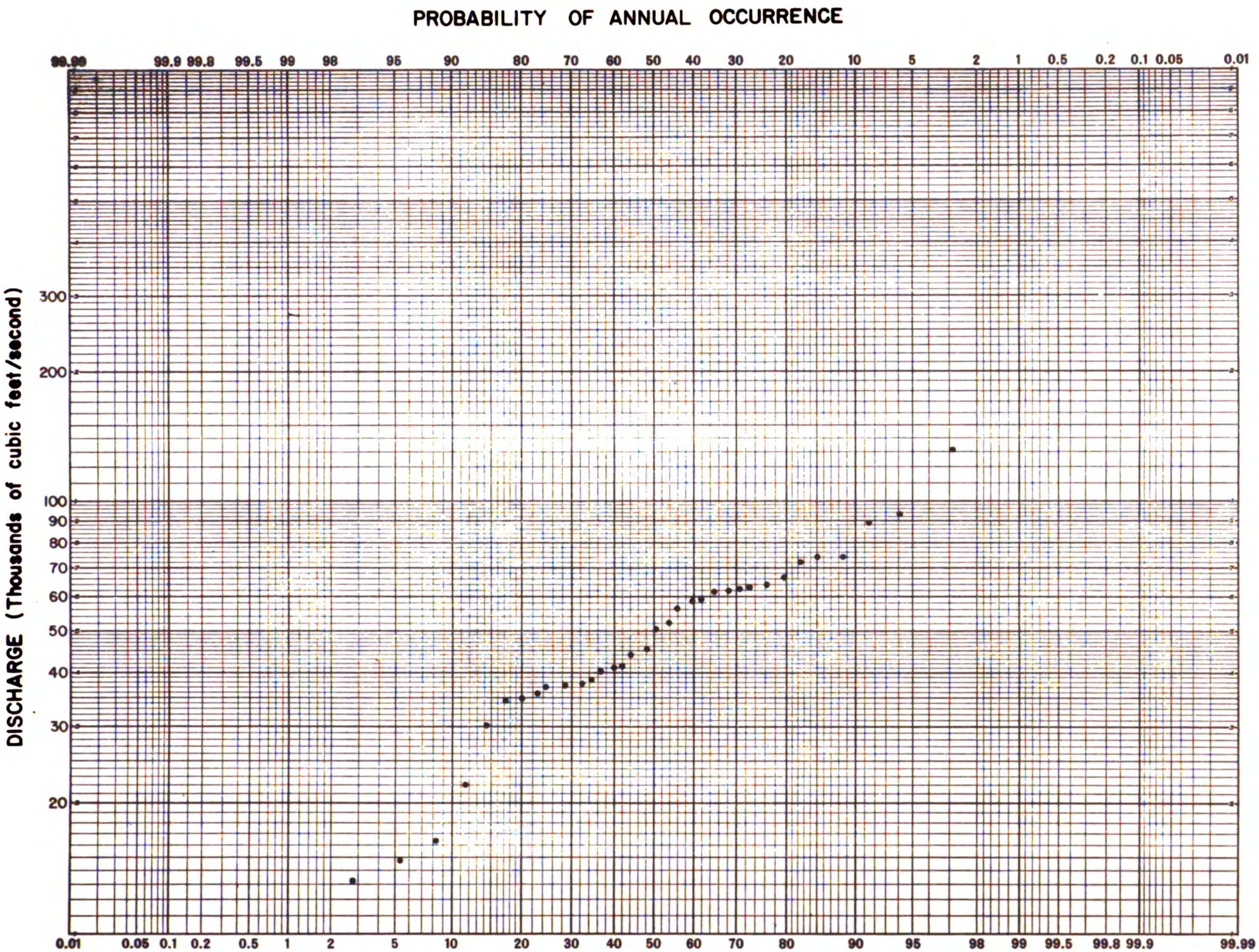

Fig. 17.--Annual Flood Series at Lafayette, Indiana on Logarithmic Probability Paper.

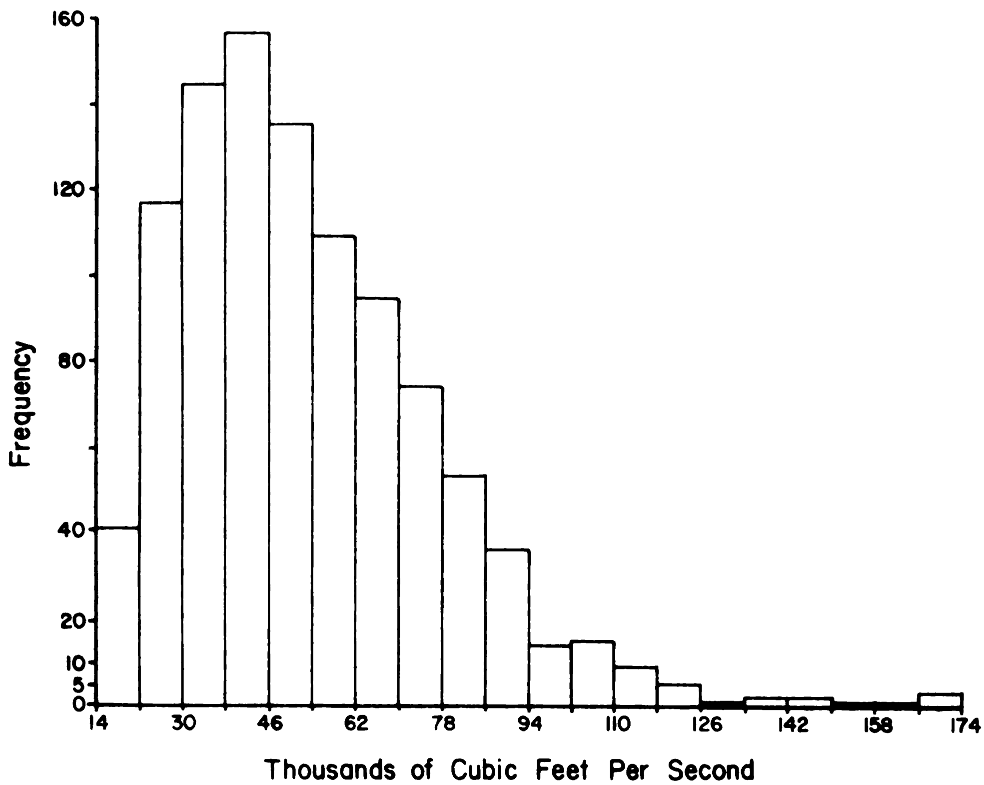

Fig. 18.--Histogram of 1000 Lognormal Variates.

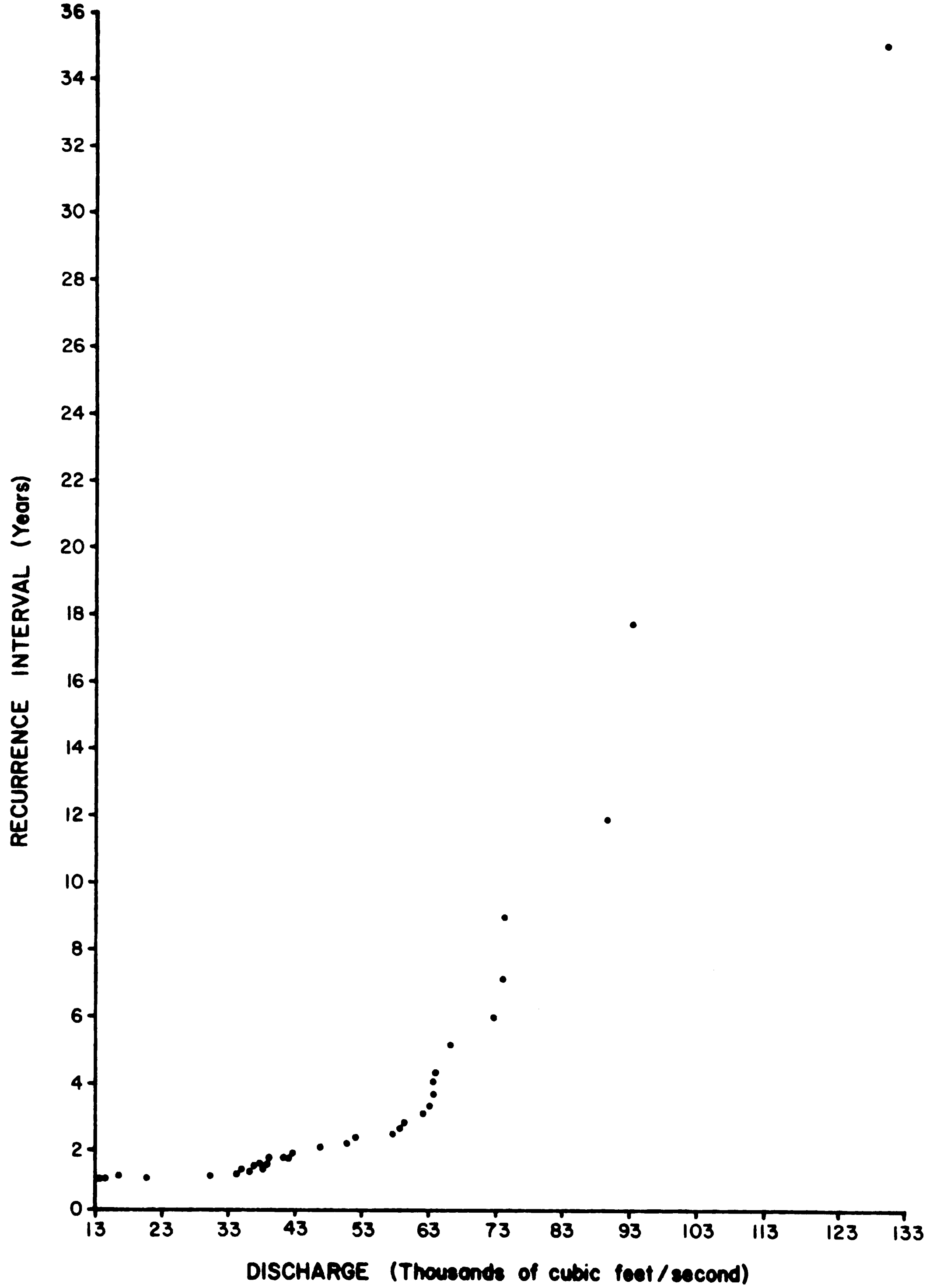

Fig. 19.--Annual Flood Series at Lafayette, Indiana.

Table 2.--Results of Polynomial Regression.

	Degree of Freedom	Sum of Squares	Mean Square	F Value	Improvement in Terms Of Sum of Squares
Polynomial Regression of Degree 1					
Intercept -.7313567E+01					
Regression Coefficients .2223185E-03					
Analysis of Variance for 1 Degree Polynomial					
Source of Variation					
Due to Regression	1	996.39	996.39	76.74	966.39
Deviation About Regression	32	402.97	12.59		
Total	33	1369.36			
Polynomial Regression of Degree 2					
Intercept .4160048E+01					
Regression Coefficients -.2178402E-03		.3480496E-08			
Analysis of Variance for 2 Degree Polynomial					
Source of Variation					
Due to Regression	2	1343.49	671.72	803.59	377.05
Deviation About Regression	31	25.91	.84		
Total	33	1369.36			
Polynomial Regression of Degree 3					
Intercept .3660075E+01					
Regression Coefficients -.1855195E-03		.2920610E-08	.2693383E-14		
Analysis of Variance for 3 Degree Polynomial					
Source of Variation					
Due to Regression	3	1343.68	447.89	523.18	.23
Deviation About Regression	30	25.68	.86		
Total	33	1369.36			

immediately noticeable fact is the considerable improvement in the sum of squares figure between the first degree polynomial, a standard regression line, and the second degree polynomial, a basic curve. As we would expect from a series that we consider lognormally distributed, the improvement in the sum of squares drops considerably with the addition of another term. That is, a curve with two inflexion points was hardly able to improve on the basic one inflexion point curve's ability to approximate the data. Thus the results of the 2nd degree polynominal may be used to construct the equation:

$$RI = 4.16 - .00218X + .0000000034X^2$$

where RI is the recurrence interval and X is the level of discharge for any given year. The quite small regression coefficients are simply due to the large discharge values (X), the small RI values, and using X to predict RI. The basic assumption of any polynomial regression is that random sampling has occurred and that the dependent variable is normally distributed. Because we have considered the annual series in a probabilistic manner as described by the Theory of Extreme Values (Gumbel, 1958) and because chance has no memory, an annual series is considered to be a random sample. The recurrence intervals are not at all normally distributed with $\bar{x}$ of 4.242, skewness index of

3.6, kurtosis of 13.877, and variance of 41.49. The assumption of normality was necessarily relaxed.

With the development of the above polynomial equation a value of RI may be predicted each year upon the generation of a flood level. This allows the simulation to notify the user of not only the level of discharge, but also its recurrence interval and the probability of annual occurrence. These are, of course, much more meaningful to the user than the number of cubic feet per second.

The flood level (X) is a status variable produced from an operating characteristic based on a log-normal probability function. It is a stochastic variable. Recurrence interval (RI) is also a status variable, but its level is determined by an internal tautological identity. A flow chart representing the natural event system is found in Figure 20.

The Adjustment Process

In the development of the simulation model the translation of the adjustment process subsystem was a particularly important task. While the natural event system provided the dynamic element of the model, and the focus of the model as a whole was on the process of settlement, the adjustment process was in many ways the backbone of the model. The treatment of the perception of the hazard event, and the role of accumulated perception were the key elements in the behavioral feedback to the

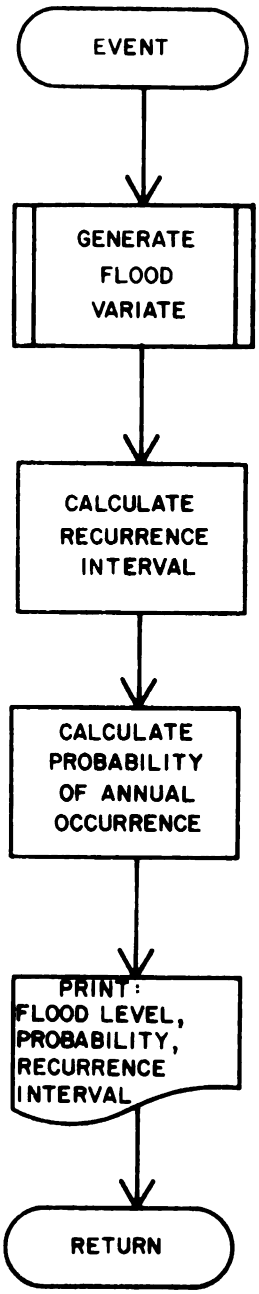

Fig. 20.--Flowchart of EVENT Routine.

settlement process. How was the perception of the annual flood to be simulated? How could the accumulated perception of the hazard system be handled?

A basic assumption of the model was that medium-frequent medium-intense events were perceived as more hazardous events than any others, and that these events commonly contributed more to actual behavioral responses to the hazard system. A convenient way to translate the generated event into a perceived event, was through the use of a normal curve equation. By centering the normal curve at that area of the event scale which has been determined to be perceived as the most hazardous, each event might be put into the normal curve equation. This would consequently weight medium-frequent events more, and weight the very frequent, and the quite infrequent events less.

It was necessary to utilize the computed recurrence intervals in this procedure. The use of the RI value of each generated flood discharge level was more convenient in that rather than weighting discharge in cubic feet per second, the average occurrence in years could be utilized. More importantly however was that the whole concept of the importance of middle range events was based on the idea of a standardized perceived event system. By using the RI values the discharge levels are standardized in relationship to the system's most common event. A graphic representation of the perception procedure may be found in Figure 21. The hazard perception transformation curve represents the value of the perceived hazard (H) at any given recurrence interval (RI).

The accumulated perception of the hazard system was simulated by summing the annual levels of the perceived hazard factor for each settler.

To simulate the effects of man's natural ability to cope with stress, and the importance of the recency of the event, each year a settler's accumulated perception of the hazard system (APHS) is reduced by an arbitrarily chosen 10 percent before that year's perceived hazard index is

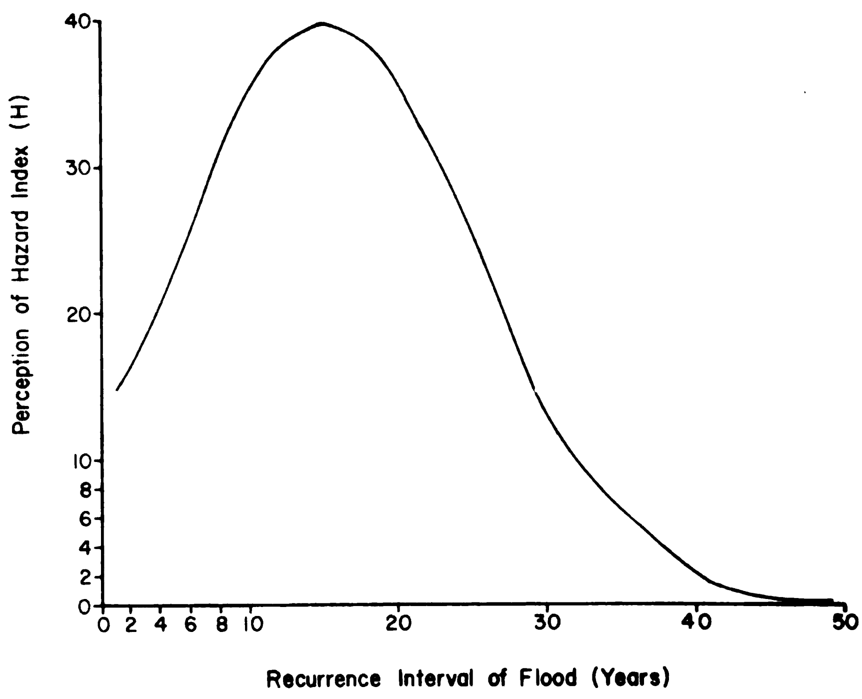

Fig. 21.--Hazard Perception Transformation Curve.

added in. At the end of each year after the accumulated perception of the hazard system has been adjusted for the event of that year, each settler's APHS is compared with the mover/stayer threshold (M). This threshold may be determined by the user at the beginning of each simulated run. The user's choice is limited to low, medium and high perception thresholds. The low threshold is equivalent to experiencing three successive years of floods with a RI of five years, and medium threshold is equivalent to experiencing three years of floods with a RI of ten years. The high threshold is equivalent to three years of floods with a RI of fifteen years. It was felt that typical rural agricultural units would be able to absorb both mentally and agriculturally two years of relatively hazardous events, but that the third successive year would be enough to make them move elsewhere. At the end of every simulated year each settler's APHS is compared with the user determined threshold (M). Should the settler's APHS exceed the threshold, that settler is assumed to pick up and leave the area, and is removed from the settlement plane.

Both the perceived hazard factor (H) and the accumulated perception of the hazard system (APHS) are status variables, internally determined on the basis of tautological identities. The mover/stayer threshold (M) is of course an exogenous variable, determined by the user. A flow chart of the adjust process appears as Figure 22.

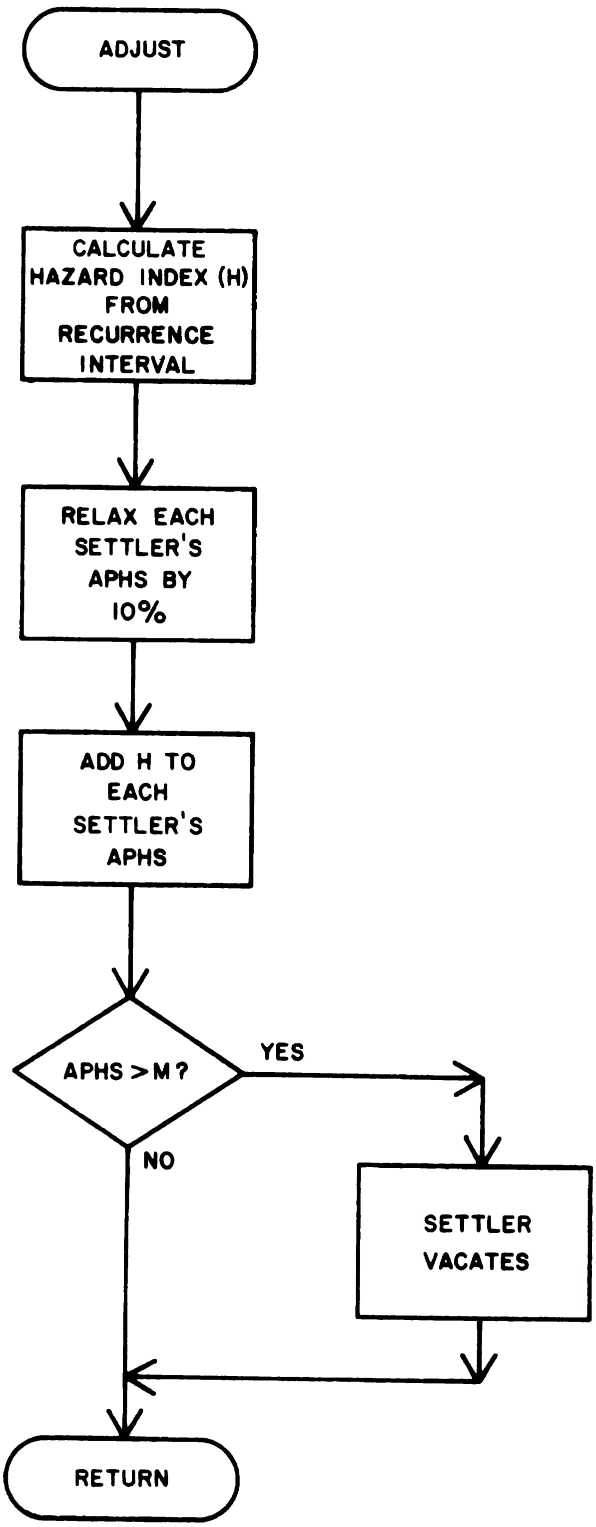

Fig. 22.--Flowchart of ADJUST Routine.

The Simulation: Setsim

The individual elements of the simulation as identified above fit together to compose a user-oriented interactive stochastic simulation called SETSIM. The simulation has been written in BASIC, a FORTRAN-like language designed for interactive use, and is operable on the Computer Institute for Social Science Research's Hewlett-Packard 2000 mini-computer located in the Behavioral Science Instructional Laboratory, at Michigan State University. The interactive user-oriented aspect of SETSIM suggests its use as a Computer-Assisted Instructional device (CAI).

A flow chart of the simulation as a whole is presented in Figure 23. A user, having begun running the simulation, is first asked if he/she needs an introduction to the simulation and an explanation of how it runs. This function is fulfilled by a routine called EXPLAN which orients the user to the simulation. It is felt that EXPLAN need only be called during a user's initial experience with the simulation. The next step involves the user determining the values of the input variables: number of years for the simulation to run (Y1); initial settlement pattern (P) and the mover/stayer threshold (M). Then the user is asked to specify the number of settlers that will arrive that year (N). In succession the following routines are called: SETTLE which locates the settlers (N) on the

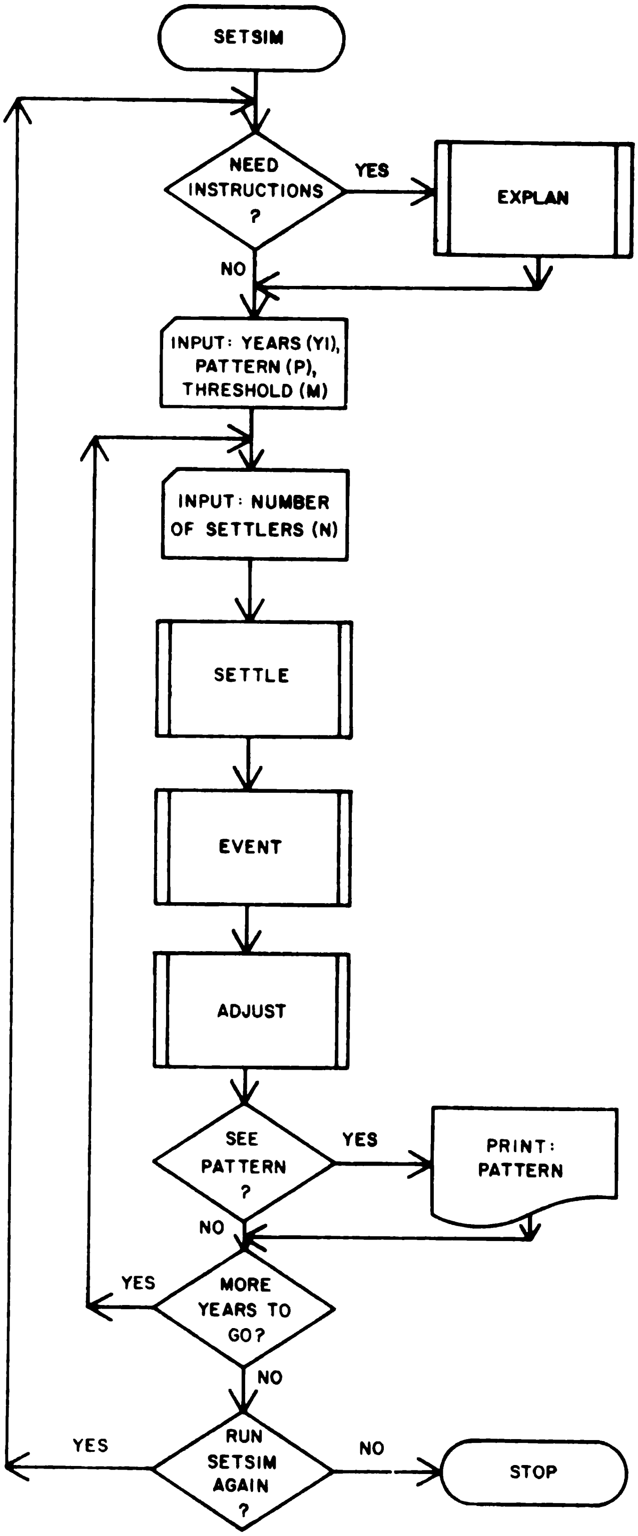

Fig. 23.--Flowchart of SETSIM Program.

plane, EVENT which produces the annual discharge level (X), and ADJUST which translates the event into a perceived event and updates the accumulated hazard perception and finds if any settler has exceeded the APHS threshold.
At the end of the year the user has the option to see the resultant pattern. The clock (T) is updated, and if the simulation is to continue for another year, the flow of the simulation is transferred back to the point where the user may determine the number of incoming settlers expected during the year about to commence. At the end of the simulation the user is given the option to begin a complete new simulation. A user's guide to the simulation, a sample SETSIM session, and a listing of the simulation program appear as Appendices.

CHAPTER VI

CONCLUSION

In this study a conceptual model and computer simulation of the interaction between a natural hazard system and the process of settlement is developed. The model is put forth as an addition to the small but growing literature of settlement theory. It is designed as an explanatory model of the actual process of man settling the land and his interaction with a local hazard system. The model is also an attempt to portray the role of a hazard system in an historical process.

Three questions were initially posed in the development of the model. These questions are: (1) In what manner is an area initially settled? (2) How often and with what intensity do natural hazards occur? and (3) What is the relationship between the settlement process and natural hazards? It was hypothesized that early settlements are usually clustered, that the frequency and intensity of hazard events have a linear inverse relationship, and that the behavioral relationship between settlement and hazards is dependent upon the settlers' hazard perception which tends to perceive events of moderate intensity and medium frequency as requiring more serious adjustment than other events.

It was shown that the process of rural settlement in its early stages does usually develop a clustered pattern. The frequency and intensity of natural hazard events, rather than exhibiting a true linearly inverse pattern, were shown to frequently approximate a log-normal distribution. Thus the inverse relationship holds, but logarithmic-probability paper is needed to straighten out the curve to approximate the hypothesized relationship. The behavioral relationship between settlement and hazard events is dependent upon the settlers' perception of the hazard system. The role of perception was to rationalize extreme events of infrequent occurrence, and accept events of common occurrence, yet interpret medium intense events of relatively frequent occurrence as creating a hazardous situation which required the most significant behavioral adjustment. The adjustment in this model was assumed to be the act of vacating the settlement location. Each of the answers to these questions is established as being grounded in sound empirical as well as theoretical research, and thus, become the basic theoretical assumptions of the model.

This study, as an exercise in theoretical model-building, illustrates the key importance of clearly establishing each assumption in existing theory. The utility of any model is limited by the legitimacy of each of its assumptions and each assumption of the model presented in this study is shown to stand on sound theoretical underpinnings.

In the last analysis, the utility of the model presented depends upon its validation through comparison with actual real-world situations. Validation of any model or simulation is a difficult and time-consuming task, and is often impossible, or at least inconclusive. The validation of this model is outside the scope of this study, and will be the focus of another project. However, the sound theoretical basis of the model allows it to be considered as a small but significant addition to the literature of settlement and hazard theory. Also the embodiment of the model as a simulation suggests its use as a computer-assisted instructional device.

APPENDICES

APPENDIX A

A USER'S GUIDE TO SETSIM

APPENDIX A

A USER'S GUIDE TO SETSIM

SETSIM is a stochastic simulation designed to model the response of rural agricultural settlement to a local hazard system. It is an interactive simulation, and has been designed as a Computer Assisted Instructional device (CAI). SETSIM is written in BASIC, and is operable on the Computer Institute for Social Science Research's Hewlett-Packard 2000 mini-computer located in the Behavioral Science Instructional Laboratory (BSIL), at Michigan State University. SETSIM is designed to illustrate three specific relationships: (1) Dispersed rural agricultural settlement commonly exhibits clustered settlement patterns in its early stages of development (Hudson, 1969), (2) The frequency and magnitude of hazard events often approximate a log-normal distribution (Wolman and Miller, 1960; Hewitt, 1970), and (3) Behavioral adjustment to a hazard system is dependent upon a person's hazard perception which tends to interpret moderately intense events of medium frequency as those which require the most significant response (White and Haas, 1977; Mitchell, 1974).

The simulation takes place on an idealized settlement plane similar to a game board. The plane is made up of 25 settlement "areas" which form a 5 * 5 matrix. Each area contains 16 settlement "cells" in a 4 * 4 matrix. One and only one settler may locate in any given cell. Each prospective settler is chosen a settlement area randomly. However, the probability of an area being chosen for settlement is greater the more settlers there are already settled in that area. A cell within the area is then chosen randomly. The simulation guards against the overloading of specific areas or the entire plane.

After all the settlers have been located, a natural hazard event is generated. The hazard system was arbitrarily determined to be that of annual flooding and the hazard generator produces random flood variates based on the flood experience of Lafayette, Indiana on the Wabash River (see Dury, 1971).

The flood discharge level is transformed into a perceived hazard event utilizing a normal curve equation. The equation weights medium frequent hazard events more, and weights the very frequent and quite infrequent events less. The simulation assumes that each settler is limited to two responses to the hazard system. A settler may absorb the hazard's damage or he/she may decide to move. This decision is based upon the settler's accumulated perception of the hazard system. When a settler's accumulated perception reaches a threshold level, then the settler vacates his settlement location.

The simulation functions on even time increments of one year. The user is asked to input the number of years the simulation is to run, the mover/stayer threshold, and the number of settlers that will locate on the plane each year. The user is also required to choose the initial settlement pattern to begin the simulation. The settlement pattern is displayed at the end of the simulation run. The user may choose to display the pattern at the end of each year, and has the option to see it more often. SETSIM, has two special facilities which may be initiated when the routine asks the user for his/her name at the beginning of each SETSIM session. By responding with the word FAST, SETSIM eliminates a great deal of output and allows the simulation to run faster. This facility is designed for the user who is interested in comparing final patterns and who is not interested in the evolution of the pattern from year to year. By responding with the word DEBUG, a switch system is initialized which causes a great deal of extra output to be generated at each step of the simulation. This is designed to aid in any revision or debugging procedures. A sample SETSIM session appears in another Appendix, as does a listing of the program.

APPENDIX B

A SAMPLE SETSIM SESSION

APPENDIX B

A SAMPLE SETSIM SESSION

```
SETSIM

WELCOME TO SETSIM



TO PERSONALIZE THIS EXPERIENCE A BIT MORE PLEASE TYPE YOUR NAME=
?MARY


THANKS, MARY, DO YOU NEED AN INTRODUCTORY EXPLANATION ON HOW
SETSIM OPERATES? (Y OR N)?Y


SETSIM IS AN INTERACTIVE ROUTINE DESIGNED TO SIMULATE THE
SETTLEMENT OF AN IDEALIZED SETTLEMENT PLANE.


THE PRINCIPAL DYNAMIC FEATURE OF SETSIM IS ITS INCORPORATION
OF A PROCESS WHICH IS DESIGNED TO GENERATE THE FREQUENCY AND
INTENSITY OF A NATURAL HAZARD (e.g.  A DROUGHT OR A FLOOD) AND
SIMULATE THE RESPONSE OF THE SETTLERS TO THIS HAZARD.


THE DEVELOPMENT OF THIS ROUTINE HAS BEEN PRIMARILY A CONCEPTUAL
EXERCISE AND IS NOT BASED ON ANY EMPIRICAL STUDY.
```

(WHEN YOU ARE DONE READING A SET OF INSTRUCTIONS PRESS THE RETURN KEY TO CONTINUE.)

THE CELL FRAME WORK LOOKS LIKE THIS=

```
X X X X . . . . X X X X . . . . X X X X
X X X X . . . . X X X X . . . . X X X X
X X X X . . . . X X X X . . . . X X X X
X X X X . . . . X X X X . . . . X X X X
. . . . X X X X . . . . X X X X . . . .
. . . . X X X X . . . . X X X X . . . .
. . . . X X X X . . . . X X X X . . . .
. . . . X X X X . . . . X X X X . . . .
X X X X . . . . X X X X . . . . X X X X
X X X X . . . . X X X X . . . . X X X X
X X X X . . . . X X X X . . . . X X X X
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X X X X . . . . X X X X . . . . X X X X
X X X X . . . . X X X X . . . . X X X X
```

A SETTLEMENT AREA IS DEFINED AS A BLOCK OF 16 CELLS WHICH MAKE UP A FOUR BY FOUR SQUARE. THE PLANE IS MADE UP OF 25 SETTLEMENT AREAS, OR A 5 AREA BY 5 AREA MATRIX. THESE 'AREAS' ARE EMPHASIZED ABOVE.

THE SIMULATION FUNCTIONS ROUGHLY LIKE THIS:

1) EACH PROSPECTIVE SETTLER IS CHOSEN A SETTLEMENT AREA. THE PROBABILITY OF AN AREA BEING CHOSEN IS INCREASED THE MORE THE AREA IS ALREADY SETTLED. A CELL WITHIN THE CHOSEN AREA IS PICKED RANDOMLY. EACH CELL REPRESENTS A POSSIBLE LOCATION FOR ONE (1) SINGLE-FAMILY FARM.

2) AFTER ALL THE SETTLERS HAVE FOUND A HOME, A NATURAL HAZARD IS GENERATED, THE LEVEL OF WHICH IS GOVERNED BY CHANCE.

3) EACH NATURAL HAZARD IS PERCEIVED BY EACH SETTLER WHO ADDS IT TO HIS/HER ACCUMULATING SENSE OF HAZARD AWARENESS. THE LEVEL OF HAZARD PERCEPTION FROM EACH GENERATED NATURAL HAZARD IS WEIGHTED IN A MANNER WHICH TENDS TO GIVE MODERATELY INTENSE EVENTS MORE INFLUENCE UPON THE PERCEPTION OF THE SETTLER, THAN THE VERY FREQUENT OR EXTREMELY INFREQUENT HAZARDOUS EVENTS.

4) AT THE END OF EVERY 'YEAR' EACH SETTLER IS EVALUATED TO SEE IF HIS/HER ACCUMULATED SENSE OF HAZARD HAS REACHED A THRESHOLD, WHICH YOU WILL SPECIFY. IF THE THRESHOLD IS REACHED THE SETTLER IS ASSUMED TO VACATE, AS THE AREA OF HIS SETTLEMENT IS TOO HAZARDOUS FOR THAT PARTICULAR SETTLER'S LIKING.

```
FOR AN INITIAL SETTLEMENT PATTERN YOU HAVE FOUR CHOICES=
                1). THE CENTER OF EACH AREA IS SETTLED.
                2). THE EAST OF THE STUDY PLANE IS SETTLED.
                3). THE CENTER OF THE ENTIRE GRID IS SETTLED.
                4). THE PLANE IS LEFT UNSETTLED.
WITH WHICH PATTERN WOULD YOU LIKE TO BEGIN THE SIMULATION?
?3


CHOSEN INITIAL SETTLEMENT PATTERN =
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HOW MANY YEARS WOULD YOU LIKE THIS RUN TO PROGRESS?6


YOU HAVE THREE CHOICES FOR AN ACCUMULATED PERCEPTION THRESHOLD:
1). LOW, 2). MEDIUM, OR 3). HIGH.


THE LOW THRESHOLD REPRESENTS THE EQUIVALENT OF EXPERIENCING
THREE SUCCESIVE ANNUAL FLOODS WITH AN  AVERAGE OCCURRENCE
OF 5 YEARS, THAT IS THREE '5-YEAR FLOODS'.


THE MEDIUM THRESHOLD REPRESENTS THE EQUIVALENT OF EXPERIENCING
THREE SUCCESIVE YEARS OF A '10-YEAR FLOOD'.


THE HIGH THRESHOLD REPRESENTS THE EQUIVALENT OF THREE SUCCESSIVE
YEARS OF A '15-YEAR FLOOD'.
```

```
WHAT THRESHOLD DO YOU WISH TO USE DURING THIS RUN?
(MARY--PLEASE TYPE 1,2,OR 3)
?1



HOW MANY SETTLERS WILL BE MOVING INTO THE SETTLEMENT REGION THIS
YEAR?40
STANDBY--SETTLERS BEING LOCATED


 ALL SETTLERS HAVE BEEN LOCATED. TO SEE THE RESULTING
PATTERN TYPE 'Y', TO CONTINUE TYPE 'N'.
?Y
RESULTS OF SETTLING ALL SETTLERS =
 X . . X . . . . . . . . . . . . . . . .
 . X . . . . . . . . . . . . . . . . . .
 . . . . . . . . . . . . . . . . . . . .
 . . . . X . X . . . . . . . . . . . . .
 . . . . . . . . . . . . . . . . . . . .
 . . . . . . . . . . X . . . . . . . . .
 . . . . . . . . . . . . . . . . . . . .
 . . . . . X . . . X . . . . . . . . . .
 . . . . . . . . X X X X . . . . . . . .
 . . . . . . . . X X X X . . . . . . . .
 . . . . . . . . X X X X . . . . . . . .
 . . . . . X . . X X X X X . . . . . . .
 . X . . . . . X . X X . . . . . . . . .
 . X X . . . . . X . X X . . . . . . . .
 . . . X . X X X . . X . . . . . . . . .
 . . . . . . X . . . . . . . . . . . . .
 . X . . . . . . . . . . . . . . . . . .
 . . . . . . . . . . . . . . . . . . . .
 . . . . . . . X . . . . . . . . . . . .
 . . . . . . . . . . X . . . . . . . . .
TO CONTINUE HIT RETURN


FLOOD THIS YEAR PEAKED AT   49497 CUBIC FEET PER SECOND
EVENT HAS AN AVERAGE OCCURRENCE OF   1.90YEARS
WITH A PROBABILITY OF OCCURRING IN ANY GIVEN YEAR OF 0.52
```

```
PERCEIVED HAZARD INDEX =  16.9
TO CONTINUE HIT RETURN




YEAR  1      HAS CONCLUDED
DO YOU WISH TO SEE THE SETTLEMENT PATTERN?
?N


A NEW YEAR IS ABOUT TO BEGIN
HOW MANY SETTLER'S DO YOU EXPECT TO ARRIVE THIS YEAR?30
STANDBY--SETTLERS BEING LOCATED


 ALL SETTLERS HAVE BEEN LOCATED. TO SEE THE RESULTING
PATTERN TYPE 'Y', TO CONTINUE TYPE 'N'.
?Y
RESULTS OF SETTLING ALL SETTLERS =
 X . . X . . . . . . . . . . . . . . . .
 . X . . X . . . . . . . . . . . . . . .
 . . X X . . X . . . . . . . . . . . . .
 X . . . X X X . . . . . . . . . . . . .
 . . . . . . X . . . . . . . . . . . . .
 . . . . . . . . . . X . . . . . . . . .
 . . . . . . . . . . . . . . . . . . . .
 . . . . . X . . . X . . . . . . . . . .
 . . . . . . X . X X X X . X . . . . . .
 . . . . . X . . X X X X . . . . . . . .
 . . . . X . . . X X X X . . . . . . . .
 . . . . . X X X X X X X X . . . . . . .
 . X X . . X . X . X X . . . . . . . . .
 . X X . . . X . X X X X . . . . . . . .
 . . X X . X X X X X X X . . . . . . . .
 X . . . X . X . X . . . . . . . . . . .
 . X . . . . . . . . . . . . . . . . . .
 . X . X . . . . . . . . . . . . . . . .
 . . . . . . . X . . . . . . X . . . . X
 . . . . . . . . . . X . X X . . . . . .
TO CONTINUE HIT RETURN


FLOOD THIS YEAR PEAKED AT   39622 CUBIC FEET PER SECOND
EVENT HAS AN AVERAGE OCCURRENCE OF   1.00YEARS
WITH A PROBABILITY OF OCCURRING IN ANY GIVEN YEAR OF 1.00
```

```
PERCEIVED HAZARD INDEX =  15.0
TO CONTINUE HIT RETURN



YEAR  2     HAS CONCLUDED
DO YOU WISH TO SEE THE SETTLEMENT PATTERN?
?N


A NEW YEAR IS ABOUT TO BEGIN
HOW MANY SETTLER'S DO YOU EXPECT TO ARRIVE THIS YEAR?25
STANDBY--SETTLERS BEING LOCATED


 ALL SETTLERS HAVE BEEN LOCATED. TO SEE THE RESULTING
PATTERN TYPE 'Y', TO CONTINUE TYPE 'N'.
?Y
RESULTS OF SETTLING ALL SETTLERS =
 X . . X X . . X . . . . . . . . . . . .
 . X . . X X X X . . . . . . . . . . . .
 . X X X . X X X . . . . . . . . . . . .
 X . X . X X X . . . . . . . . . . . . .
 . . . . . . X . . . . . . . . . . . . .
 . . . . . . . . . . X . . . . . . . . .
 . . . . . . X . . . . . . . . . . . . .
 . . . . . X . . . X . . . . . . . . . .
 . . . . . . X . X X X X . X . . . . . .
 . . . . X X . X X X X X . . . . . . . .
 . . . . X . . . X X X X . . . . . X . .
 . . . . X X X X X X X X X . . . . . . .
 . X X . . X . X X X X . . . . . . . . .
 X X X X . X X . X X X X . . . . . . . .
 . . X X . X X X X X X X . . . . . . . .
 X . X . X X X . X X . . . . . . . . . .
 . X . . . . . . . . . . . X . . . X . .
 . X . X . . . . . . . . . X . . . . . .
 . . . . . . . X . . . . . . X . . . . X
 . . . . . . . X . . X . X X . . . . . .
TO CONTINUE HIT RETURN


FLOOD THIS YEAR PEAKED AT   40382 CUBIC FEET PER SECOND
EVENT HAS AN AVERAGE OCCURRENCE OF   1.03YEARS
WITH A PROBABILITY OF OCCURRING IN ANY GIVEN YEAR OF 0.97
```

```
PERCEIVED HAZARD INDEX =  15.0
TO CONTINUE HIT RETURN




YEAR  3     HAS CONCLUDED
DO YOU WISH TO SEE THE SETTLEMENT PATTERN?
?N


A NEW YEAR IS ABOUT TO BEGIN
HOW MANY SETTLER'S DO YOU EXPECT TO ARRIVE THIS YEAR?30
STANDBY--SETTLERS BEING LOCATED


SETTLER UNABLE TO FIND A SUITABLE LOCATION TO SETTLE IN AREA 17
THIS YEAR AND MOVED AWAY FROM THE SETTLEMENT PLANE.


 ALL SETTLERS HAVE BEEN LOCATED. TO SEE THE RESULTING
PATTERN TYPE 'Y', TO CONTINUE TYPE 'N'.
?Y
RESULTS OF SETTLING ALL SETTLERS =
 X X X X X X X X . . . . . . . . . . . .
 X X . . X X X X . . . . . . . . . . . .
 X X X X X X X X . . . . . . . . . . . .
 X . X . X X X X . . . . . . . . . . . .
 . . . . . . X . . . . . . . . . . . . .
 . . . . . . . . . . X . . . . . . . . .
 . . . . . . X X . . . . . . . . . . . .
 . . . . . X . . . X . . . . . . . . . .
 . . . . . . X . X X X X . X . . . . . .
 . . . . X X . X X X X X . . . . . . . .
 . . . . X X X X X X X X . . . . X X X .
 . . . . X X X X X X X X X . . . . . . .
 X X X X X X X X X X X . . . . . . . . .
 X X X X X X X X X X X X . . . . . . . .
 X X X X X X X X X X X X . . . . . . . .
 X X X X X X X X X X . X . . . . . . . .
 . X . . . . . . . . . . . X . . . X . .
 . X . X . . . . . . . . . X . . . . . .
 . . . . . . . X . . . . . . X . . . . X
 . . . . . . . X . . X . X X X X . . . .
TO CONTINUE HIT RETURN
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FLOOD THIS YEAR PEAKED AT   16635 CUBIC FEET PER SECOND
EVENT HAS AN AVERAGE OCCURRENCE OF   1.49YEARS
WITH A PROBABILITY OF OCCURRING IN ANY GIVEN YEAR OF 0.67



PERCEIVED HAZARD INDEX =  16.0
TO CONTINUE HIT RETURN




YEAR  4     HAS CONCLUDED
DO YOU WISH TO SEE THE SETTLEMENT PATTERN?
?N


A NEW YEAR IS ABOUT TO BEGIN
HOW MANY SETTLER'S DO YOU EXPECT TO ARRIVE THIS YEAR?10
STANDBY--SETTLERS BEING LOCATED


 ALL SETTLERS HAVE BEEN LOCATED. TO SEE THE RESULTING
PATTERN TYPE 'Y', TO CONTINUE TYPE 'N'.
?Y
RESULTS OF SETTLING ALL SETTLERS =
 X X X X X X X X . . . . . . . . . . . .
 X X . X X X X X . . . . . . . . . . . .
 X X X X X X X X . . . . . . . . . . . .
 X . X . X X X X . . . . . . . . . . . .
 . . . . . . X . . . . . . . . . . . . .
 . . . . . . . . . . X . . . . . . . . .
 . . . . . . X X . . . . . . . . . . . .
 . . . . . X . . . X . . . . . . . . . .
 . . . . . . X . X X X X . X . X . X X .
 . . . . X X X X X X X X . . . . . . . .
 . . . . X X X X X X X X . . . . X X X .
 . . . . X X X X X X X X X . . . . . . .
 X X X X X X X X X X X X . . . . . . . .
 X X X X X X X X X X X X . . . . . . . .
 X X X X X X X X X X X X . . . . . . . .
 X X X X X X X X X X X X . . . . . . . .
 . X . . . . . X . . . . . X . X . X . .
 . X . X . . . . . . . . . X . . . . . .
 . . . . . . . X . . . . . . X . . . . X
 . . . . . X . X . . X . X X X X . . . .
TO CONTINUE HIT RETURN
```

```
FLOOD THIS YEAR PEAKED AT   44223 CUBIC FEET PER SECOND
EVENT HAS AN AVERAGE OCCURRENCE OF   1.33YEARS
WITH A PROBABILITY OF OCCURRING IN ANY GIVEN YEAR OF 0.75



PERCEIVED HAZARD INDEX =  15.7
TO CONTINUE HIT RETURN



YEAR  5     HAS CONCLUDED
DO YOU WISH TO SEE THE SETTLEMENT PATTERN?
?N


A NEW YEAR IS ABOUT TO BEGIN
HOW MANY SETTLER'S DO YOU EXPECT TO ARRIVE THIS YEAR?5
STANDBY--SETTLERS BEING LOCATED


 ALL SETTLERS HAVE BEEN LOCATED. TO SEE THE RESULTING
PATTERN TYPE 'Y', TO CONTINUE TYPE 'N'.
?N


FLOOD THIS YEAR PEAKED AT   57055 CUBIC FEET PER SECOND
EVENT HAS AN AVERAGE OCCURRENCE OF   3.06YEARS
WITH A PROBABILITY OF OCCURRING IN ANY GIVEN YEAR OF 0.32



PERCEIVED HAZARD INDEX =  19.5
TO CONTINUE HIT RETURN

SETTLER 'HAZARDED OUT' FROM AREA 1    CELL 1
SETTLER 'HAZARDED OUT' FROM AREA 1    CELL 4
SETTLER 'HAZARDED OUT' FROM AREA 1    CELL 6
SETTLER 'HAZARDED OUT' FROM AREA 1    CELL 11
SETTLER 'HAZARDED OUT' FROM AREA 1    CELL 12
SETTLER 'HAZARDED OUT' FROM AREA 1    CELL 13
SETTLER 'HAZARDED OUT' FROM AREA 2    CELL 5
SETTLER 'HAZARDED OUT' FROM AREA 2    CELL 11
SETTLER 'HAZARDED OUT' FROM AREA 2    CELL 13
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SETTLER 'HAZARDED OUT' FROM AREA 2    CELL 14
SETTLER 'HAZARDED OUT' FROM AREA 2    CELL 15
SETTLER 'HAZARDED OUT' FROM AREA 7    CELL 3
SETTLER 'HAZARDED OUT' FROM AREA 7    CELL 14
SETTLER 'HAZARDED OUT' FROM AREA 8    CELL 7
SETTLER 'HAZARDED OUT' FROM AREA 8    CELL 14
SETTLER 'HAZARDED OUT' FROM AREA 12   CELL 3
SETTLER 'HAZARDED OUT' FROM AREA 12   CELL 6
SETTLER 'HAZARDED OUT' FROM AREA 12   CELL 9
SETTLER 'HAZARDED OUT' FROM AREA 12   CELL 14
SETTLER 'HAZARDED OUT' FROM AREA 12   CELL 15
SETTLER 'HAZARDED OUT' FROM AREA 12   CELL 16
SETTLER 'HAZARDED OUT' FROM AREA 13   CELL 1
SETTLER 'HAZARDED OUT' FROM AREA 13   CELL 2
SETTLER 'HAZARDED OUT' FROM AREA 13   CELL 3
SETTLER 'HAZARDED OUT' FROM AREA 13   CELL 4
SETTLER 'HAZARDED OUT' FROM AREA 13   CELL 5
SETTLER 'HAZARDED OUT' FROM AREA 13   CELL 6
SETTLER 'HAZARDED OUT' FROM AREA 13   CELL 7
SETTLER 'HAZARDED OUT' FROM AREA 13   CELL 8
SETTLER 'HAZARDED OUT' FROM AREA 13   CELL 9
SETTLER 'HAZARDED OUT' FROM AREA 13   CELL 10
SETTLER 'HAZARDED OUT' FROM AREA 13   CELL 11
SETTLER 'HAZARDED OUT' FROM AREA 13   CELL 12
SETTLER 'HAZARDED OUT' FROM AREA 13   CELL 13
SETTLER 'HAZARDED OUT' FROM AREA 13   CELL 14
SETTLER 'HAZARDED OUT' FROM AREA 13   CELL 15
SETTLER 'HAZARDED OUT' FROM AREA 13   CELL 16
SETTLER 'HAZARDED OUT' FROM AREA 14   CELL 2
SETTLER 'HAZARDED OUT' FROM AREA 14   CELL 13
SETTLER 'HAZARDED OUT' FROM AREA 16   CELL 2
SETTLER 'HAZARDED OUT' FROM AREA 16   CELL 3
SETTLER 'HAZARDED OUT' FROM AREA 16   CELL 6
SETTLER 'HAZARDED OUT' FROM AREA 16   CELL 7
SETTLER 'HAZARDED OUT' FROM AREA 16   CELL 11
SETTLER 'HAZARDED OUT' FROM AREA 16   CELL 12
SETTLER 'HAZARDED OUT' FROM AREA 16   CELL 13
SETTLER 'HAZARDED OUT' FROM AREA 17   CELL 2
SETTLER 'HAZARDED OUT' FROM AREA 17   CELL 4
SETTLER 'HAZARDED OUT' FROM AREA 17   CELL 7
SETTLER 'HAZARDED OUT' FROM AREA 17   CELL 10
SETTLER 'HAZARDED OUT' FROM AREA 17   CELL 11
SETTLER 'HAZARDED OUT' FROM AREA 17   CELL 12
SETTLER 'HAZARDED OUT' FROM AREA 17   CELL 13
SETTLER 'HAZARDED OUT' FROM AREA 17   CELL 15
SETTLER 'HAZARDED OUT' FROM AREA 18   CELL 2
SETTLER 'HAZARDED OUT' FROM AREA 18   CELL 3
SETTLER 'HAZARDED OUT' FROM AREA 18   CELL 5
SETTLER 'HAZARDED OUT' FROM AREA 18   CELL 6
SETTLER 'HAZARDED OUT' FROM AREA 18   CELL 7
SETTLER 'HAZARDED OUT' FROM AREA 18   CELL 8
SETTLER 'HAZARDED OUT' FROM AREA 18   CELL 9
SETTLER 'HAZARDED OUT' FROM AREA 18   CELL 10
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SETTLER 'HAZARDED OUT' FROM AREA 18   CELL 11
SETTLER 'HAZARDED OUT' FROM AREA 18   CELL 12
SETTLER 'HAZARDED OUT' FROM AREA 18   CELL 13
SETTLER 'HAZARDED OUT' FROM AREA 21   CELL 2
SETTLER 'HAZARDED OUT' FROM AREA 21   CELL 6
SETTLER 'HAZARDED OUT' FROM AREA 21   CELL 8
SETTLER 'HAZARDED OUT' FROM AREA 22   CELL 12
SETTLER 'HAZARDED OUT' FROM AREA 23   CELL 15
SETTLER 'HAZARDED OUT' FROM AREA 24   CELL 11
SETTLER 'HAZARDED OUT' FROM AREA 24   CELL 13
SETTLER 'HAZARDED OUT' FROM AREA 24   CELL 14
SETTLER 'HAZARDED OUT' FROM AREA 25   CELL 12


WELL, MARY, THAT'S IT FOR THIS RUN


AFTER 6    YEARS THE FINAL SETTLEMENT PATTERN LOOKS LIKE THIS=
 . X X . X X X X . . . . . . . . . . . .
 X . X X . X X X . . . . . . . . . . . .
 X X . . X X . X . . . . . . . . . . . .
 . . X . . . . X . . . . . . . . . . . .
 . . . . . . . . . . . . . . . . . . . .
 . . . . . . . . . . . . . . . . . . . .
 . . . . . . X X . . X . . . . . . . . .
 . . . . . . . . . . . . . . . . . . . .
 . . . . . . . . . . . . . . X X . X X .
 . . . . X . X X . . . . . . . . . . . X
 . . . . . X X X . . . . . . . . X X X .
 . . . . X . . . . . . . . . . . . . . .
 X . . X X . X . X . . X . . . . . . . .
 X . . X X X . X . . . . . . . . . . . .
 X X . . X . . . . . . . . . . . . . . .
 . X X X . X . X . X X X . . . . . . . .
 . . . . . . . X . . . . . X . X . X . .
 . . . . . . . . . . . . . X . . . . . .
 . . . . . . . . . . . . . X . . . . . .
 . . . . . X . X . . . . . . X X . . . .


WOULD YOU LIKE TO RUN THE SIMULATION AGAIN?(TYPE Y OR N)?N


TYPE BYE TO LOGOUT

DONE
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APPENDIX C

A LISTING OF THE PROGRAM SETSIM

APPENDIX C

A LISTING OF THE PROGRAM SETSIM

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File: OUT      Program Name: SETSIM      Aug-04-77 Thursday    Page:  1

100  REM*********************************SETSIM***********************************
110  REM
120  REM                 A SIMULATION OF THE RESPONSE OF RURAL SETTLEMENT
130  REM                            TO A LOCAL HAZARD SYSTEM
140  REM
150  REM
160  REM                               MAIN PROGRAM
170  REM                                  Y1= NUMBER OF YEARS SIMULATION IS TO RUN
180  REM                                   M= MOVER/STAYER THRESHOLD
190  REM                                   N= NUMBER OF SETTLERS TO BE LOCATED IN
200  REM                                             A GIVEN YEAR
210  REM                                   T= CLOCK, YEARS SIMULATION HAS RUN
220  REM                                  T1= TOTAL SETTLERS ON PLANE
230  REM                           A(25,16)= MASTER ARRAY- 25 AREAS WITH 16 CELLS
240  REM
250  REM
260  COM Z$[80],N$[80],D$[80],B$[80],M$[80]
270  DIM A[25,18]
280  T=0
290  PRINT "WELCOME TO SETSIM"
300  PRINT LIN(3)
310  PRINT "TO PERSONALIZE THIS EXPERIENCE A BIT MORE PLEASE TYPE YOUR NAME="
320  INPUT Z$
330  REM                                   SWITCH INITIALIZATION
340  REM                                        J1 = DEBUG SWITCH
350  REM                                        J2 = FAST SWITCH
360  IF Z$="FAST" THEN 390
370  J2=0
380  GOTO 420
390  J2=1
400  J1=1
410  GOTO 460
420  IF Z$="DEBUG" THEN 450
430  J1=1
440  GOTO 460
450  J1=0
460  IF J2 THEN 610
470  PRINT LIN(2)
480  PRINT "THANKS, ";Z$;", DO YOU NEED AN INTRODUCTORY EXPLANATION ON HOW "
490  PRINT "SETSIM OPERATES? (Y OR N)";
500  INPUT N$
510  IF N$="y" THEN 570
520  IF N$="n" THEN 610
530  IF N$="Y" THEN 570
540  IF N$="N" THEN 610
```

```
550  PRINT "PLEASE TYPE Y OR N"
560  GOTO 500
570  REM(((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((()(
580  REM                                                     CALL EXPLAN SUB
590  GOSUB 4440
600  REM))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))
610  T1=0
620  MAT A=ZER
630  REM((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((
640  REM                                                         CALL INITAL SUB
650  GOSUB 2800
660  REM))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))
670  PRINT LIN(1)
680  REM                      USER DEFINES EXOGENOUS VARIABLES
690  REM
700  PRINT "HOW MANY YEARS WOULD YOU LIKE THIS RUN TO PROGRESS";
710  INPUT Y1
720  IF Y1 >= 1 AND Y1 <= 30 THEN 750
730  PRINT "PLEASE CHOOSE A NUMBER BETWEEN 1 AND 30"
740  GOTO 710
750  PRINT LIN(2)
760  PRINT "YOU HAVE THREE CHOICES FOR AN ACCUMULATED PERCEPTION THRESHOLD:"
770  PRINT "1). LOW, 2). MEDIUM, OR 3). HIGH."
780  PRINT LIN(1)
790  PRINT "THE LOW THRESHOLD REPRESENTS THE EQUIVALENT OF EXPERIENCING"
800  PRINT "THREE SUCCESIVE ANNUAL FLOODS WITH AN  AVERAGE OCCURRENCE"
810  PRINT "OF 5 YEARS, THAT IS THREE '5-YEAR FLOODS'."
820  PRINT LIN(1)
830  PRINT "THE MEDIUM THRESHOLD REPRESENTS THE EQUIVALENT OF EXPERIENCING"
840  PRINT "THREE SUCCESIVE YEARS OF A '10-YEAR FLOOD'."
850  PRINT LIN(1)
860  PRINT "THE HIGH THRESHOLD REPRESENTS THE EQUIVALENT OF THREE SUCCESSIVE"
870  PRINT "YEARS OF A '15-YEAR FLOOD'."
880  PRINT LIN(1)
890  PRINT "WHAT THRESHOLD DO YOU WISH TO USE DURING THIS RUN?"
900  PRINT "(";Z$;"--PLEASE TYPE 1,2,OR 3)"
910  INPUT M
920  IF M=1 THEN 970
930  IF M=2 THEN 990
940  IF M=3 THEN 1010
950  PRINT "TYPE 1, 2, OR 3, PLEASE"
960  GOTO 910
970  M=65.57
980  GOTO 1030
990  M=95.41
```

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File: OUT      Program Name: SETSIM       Aug-04-77 Thursday    Page:  3

1000  GOTO 1030
1010  M=108.11
1020  GOTO 1030
1030  PRINT LIN(2)
1040  IF J1 THEN 1060
1050  PRINT TAB(40);"CHOSEN THRESHOLD=";M
1060  REM
1070  PRINT LIN(2)
1080  PRINT "HOW MANY SETTLERS WILL BE MOVING INTO THE SETTLEMENT REGION THIS"
1090  PRINT "YEAR";
1100  INPUT N
1110  IF N >= 0 AND N <= 100 THEN 1140
1120  PRINT "PLEASE CHOOSE A NUMBER BETWEEN 0 AND 100"
1130  GOTO 1100
1140  IF N=0 THEN 1300
1150  T2=T1+N
1160  IF T2 <= 400 THEN 1250
1170  PRINT LIN(1)
1180  PRINT Z$;", THERE ARE ALREADY ";T1;" LOCATED SETTLERS."
1190  PRINT "AN ADDITIONAL ";N;" SETTLERS WOULD OVERLOAD THE SETTLEMENT PLANE."
1200  PRINT " THERE ARE ONLY 400 POSSIBLE SETTLEMENT LOCATIONS."
1210  T2=400-T1
1220  PRINT LIN(1)
1230  PRINT "PLEASE CHOOSE A NEW NUMBER BETWEEN 0 AND ";T2
1240  GOTO 1100
1250  REM
1260  REM((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((
1270  REM                                                 CALL SETTLE SUB
1280  GOSUB 1880
1290  REM)))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))
1300  REM
1310  REM(((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((
1320  REM                                                   CALL EVENT SUB
1330  GOSUB 3660
1340  REM)))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))
1350  REM
1360  REM(((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((
1370  REM                                                     CALL ADJUST SUB
1380  GOSUB 3970
1390  REM)))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))
1400  T=T+1
1410  IF T=Y1 THEN 1630
1420  IF J2 THEN 1570
1430  PRINT LIN(1)
1440  PRINT "YEAR ";T;" HAS CONCLUDED"
```

```
1450  PRINT "DO YOU WISH TO SEE THE SETTLEMENT PATTERN?"
1460  INPUT B$
1470  IF B$="Y" THEN 1530
1480  IF B$="y" THEN 1530
1490  IF B$="N" THEN 1570
1500  IF B$="n" THEN 1570
1510  PRINT "PLEASE TYPE Y OR N"
1520  GOTO 1460
1530  PRINT "SETTLEMENT PATTERN AT THE END OF YEAR NUMBER";T;"="
1540  REM(((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((
1550  REM                                                          CALL PRINT SUB
1560  GOSUB 3310
1570  REM)))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))
1580  PRINT LIN(2)
1590  PRINT "A NEW YEAR IS ABOUT TO BEGIN"
1600  PRINT "HOW MANY SETTLER'S DO YOU EXPECT TO ARRIVE THIS YEAR";
1610  GOTO 1100
1620  REM
1630  PRINT "WELL, ";Z$;", THAT'S IT FOR THIS RUN"
1640  PRINT LIN(2)
1650  PRINT "AFTER";Y1;"YEARS THE FINAL SETTLEMENT PATTERN LOOKS LIKE THIS="
1660  REM(((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((
1670  REM                                                          CALL PRINT SUB
1680  GOSUB 3310
1690  REM))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))
1700  PRINT LIN(2)
1710  PRINT "WOULD YOU LIKE TO RUN THE SIMULATION AGAIN?(TYPE Y OR N)";
1720  INPUT B$
1730  IF B$="y" THEN 1790
1740  IF B$="Y" THEN 1790
1750  IF B$="N" THEN 1810
1760  IF B$="n" THEN 1810
1770  PRINT "PLEASE TYPE Y OR N"
1780  GOTO 1720
1790  REM
1800  GOTO 470
1810  REM                PROGRAMMING HISTORY: DEVELOPED BY MARK NEITHERCUT
1820  REM                                     DEPT OF GEOGRAPHY
1830  REM                                     MICHIGAN STATE UNIVERSITY
1840  REM                                     JUNE, 1977
1850  PRINT LIN(2)
1860  PRINT "TYPE BYE TO LOGOUT"
1870  STOP
1880  REM******************************************************************
1890  REM******************************************************************
```

```
1900  REM                                        SETTLE SUBROUTINE
1910  REM**************************************************************
1920  REM                                          S1=TOTALS NUMBER OF SETTLERS ON PLAN14
1930  REM                                  Z5 & Z6= ARGUMENTS FOR PROBABILITY DENSITY
1940  REM                                                                   FUNCTIONS
1950  REM                                   A(I,18)= MIF UPPER BOUNDARY FOR AREA I
1960  PRINT "STANDBY--SETTLERS BEING LOCATED"
1970  REM
1980  REM                         CHOOSES WHICH SETTLEMENT AREA TO BE SETTED
1990  DEF FNA(Z5)=1+(1000-1)*RND(1)
2000  DEF FNB(Z6)=1+(16-1)*RND(1)
2010  S1=0
2020  FOR I=1 TO 25
2030  S1=(A[I,17]*2)+S1+1
2040  IF J1 THEN 2060
2050  PRINT TAB(40);A[I,17];" SETTLERS IN AREA # ";I
2060  NEXT I
2070  REM
2080  REM                         ALLOCATE MIF PROBABILITIES ON BASIS OF # SETTLED
2090  REM                                                            IN EACH AREA
2100  REM
2110  T8=0
2120  FOR I=1 TO 25
2130  A[I,18]=(((A[I,17]*2)+1)/S1)*1000+T8
2140  T8=A[I,18]
2150  IF J1 THEN 2170
2160  PRINT TAB(35);"TOP MIF LIMIT FOR AREA # ";I;"IS";A[I,18]
2170  NEXT I
2180  REM
2190  REM                            CHOOSE SETTLEMENT AREA
2200  REM
2210  S2=FNA(Z5)
2220  IF J1 THEN 2240
2230  PRINT TAB(40);"AREA VARIATE = ";S2
2240  FOR I=1 TO 25
2250  IF S2>A[I,18] THEN 2280
2260  IF A[I,17] >= 16 THEN 2210
2270  GOTO 2310
2280  NEXT I
2290  PRINT "ERROR IN SETTLE SUB.  FAULTY MIF ALLOCATION"
2300  STOP
2310  IF J1 THEN 2330
2320  PRINT TAB(40);"AREA CHOSEN = ";I
2330  S=I
2340  REM
```

```
2350  REM
2360  REM    NOW CHOOSE CELL RANDOMLY WITHIN PICKED AREA
2370  N5=0
2380  C=FNB(Z6)
2390  IF J1 THEN 2410
2400  PRINT TAB(40);"CELL VARIATE IS ";C
2410  IF A[S,C]=0 THEN 2490
2420  IF N5=15 THEN 2450
2430  N5=N5+1
2440  GOTO 2380
2450  PRINT LIN(2)
2460  PRINT "SETTLER UNABLE TO FIND A SUITABLE LOCATION TO SETTLE IN AREA";S
2470  PRINT "THIS YEAR AND MOVED AWAY FROM THE SETTLEMENT PLANE."
2480  GOTO 2540
2490  A[S,C]=1
2500  A[S,17]=A[S,17]+1
2510  T1=T1+1
2520  IF J1 THEN 2540
2530  PRINT TAB(40);"CELL # ";C;"AREA # ";S;"SETTLED "
2540  REM
2550  REM      CONTINUE TO SETTLE THE REST OF THE SETTLERS IN THE QUEUE
2560  N=N-1
2570  IF N>0 THEN 2010
2580  IF J2 THEN 2760
2590  PRINT LIN(2)
2600  PRINT " ALL SETTLERS HAVE BEEN LOCATED. TO SEE THE RESULTING"
2610  PRINT "PATTERN TYPE 'Y', TO CONTINUE TYPE 'N'."
2620  INPUT D$
2630  IF D$="y" THEN 2690
2640  IF D$="Y" THEN 2690
2650  IF D$="n" THEN 2760
2660  IF D$="N" THEN 2760
2670  PRINT "TYPE 'Y' OR 'N' PLEASE "
2680  GOTO 2620
2690  PRINT "RESULTS OF SETTLING ALL SETTLERS ="
2700  REM=================================================================
2710  REM                                         CALL PRINT SUBROUTINE
2720  GOSUB 3310
2730  REM============================================================
2740  PRINT "TO CONTINUE HIT RETURN "
2750  LINPUT M$
2760  REM
2770  REM
2780  RETURN
2790  STOP
```

```
2800  REM*********************************************************************
2810  REM*********************************************************************
2820  REM                                          INITIALIZATION SUBROUTINE
2830  REM**********************************************************************
2840  REM
2850  PRINT LIN(2)
2860  PRINT "FOR AN INITIAL SETTLEMENT PATTERN YOU HAVE FOUR CHOICES="
2870  PRINT "                    1). THE CENTER OF EACH AREA IS SETTLED."
2880  PRINT "                    2). THE EAST OF THE STUDY PLANE IS SETTLED."
2890  PRINT "                    3). THE CENTER OF THE ENTIRE GRID IS SETTLED."
2900  PRINT "                    4). THE PLANE IS LEFT UNSETTLED."
2910  PRINT "WITH WHICH PATTERN WOULD YOU LIKE TO BEGIN THE SIMULATION?"
2920  INPUT P
2930  IF P=1 THEN 3010
2940  IF P=2 THEN 3080
2950  IF P=3 THEN 3150
2960  IF P=4 THEN 3260
2970  PRINT "ILLEGAL PATTERN CHOICE, PLEASE RETYPE"
2980  GOTO 2920
2990  REM
3000  REM              1'S ARE USED TO DESIGNATE CELLS THAT ARE SETTLED
3010  FOR I=1 TO 25
3020  A[I,7]=1
3030  A[I,10]=1
3040  A[I,17]=2
3050  NEXT I
3060  T1=50
3070  GOTO 3220
3080  FOR I=5 TO 25 STEP 5
3090  A[I,4]=1
3100  A[I,12]=1
3110  A[I,17]=2
3120  NEXT I
3130  T1=10
3140  GOTO 3220
3150  A[13,6]=1
3160  A[13,7]=1
3170  A[13,10]=1
3180  A[13,11]=1
3190  A[13,17]=4
3200  T1=4
3210  GOTO 3220
3220  PRINT LIN(2)
3230  IF J2 THEN 3270
3240  PRINT "CHOSEN INITIAL SETTLEMENT PATTERN ="
```

```
3250  GOSUB 3310
3260  REM
3270  RETURN
3280  STOP
3290  REM
3300  REM
3310  REM*****************************************************************
3320  REM*****************************************************************
3330  REM                                        print subroutine
3340  REM*****************************************************************
3350  REM           PRINT SUBROUTINE TO OUTPUT CURRENT PATTERN
3360  REM
3370  IF J1 THEN 3390
3380  PRINT TAB(40);"ENTER PRINT SUB"
3390  Y=0
3400  FOR L=1 TO 5
3410  X=0
3420  IF J1 THEN 3440
3430  PRINT TAB(40);"NEW BLOCK"
3440  FOR I=1 TO 4
3450  IF J1 THEN 3470
3460  PRINT TAB(40);"NEW LINE"
3470  FOR J=1 TO 5
3480  S=J+Y
3490  FOR K=1 TO 4
3500  C=K+X
3510  IF A[S,C]>0 THEN 3550
3520  PRINT  USING 3530
3530  IMAGE #," ."
3540  GOTO 3570
3550  PRINT  USING 3560
3560  IMAGE #," X"
3570  NEXT K
3580  NEXT J
3590  X=X+4
3600  PRINT
3610  NEXT I
3620  Y=Y+5
3630  NEXT L
3640  RETURN
3650  STOP
3660  REM*****************************************************************
3670  REM*****************************************************************
3680  REM                                          EVENT GENERATOR
3690  REM*****************************************************************
```

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```
3700  REM
3710  REM                          GENERATES LOG-NORMAL VARIATES
3720  E2=10.7594
3730  S9=0
3740  S2=.4453
3750  FOR I=1 TO 12
3760  R=RND(1)
3770  S9=S9+R
3780  NEXT I
3790  REM
3800  X=EXP(E2+(S2*(S9-6)))
3810  X=INT(X)
3820  R1=4.16005+(-2.1784E-04*X)+(3.4805E-09*(X ** 2))
3830  IF R1 >= 1 THEN 3850
3840  R1=1
3850  PRINT LIN(2)
3860  PRINT  USING 3870;X
3870  IMAGE "FLOOD THIS YEAR PEAKED AT ",DDDDDDD," CUBIC FEET PER SECOND"
3880  R1=INT(R1*100)/100
3890  PRINT  USING 3900;R1
3900  IMAGE "EVENT HAS AN AVERAGE OCCURRENCE OF ",DDD.DD,"YEARS"
3910  Y9=1/R1
3920  Y9=INT(Y9*100)/100
3930  PRINT  USING 3940;Y9
3940  IMAGE "WITH A PROBABILITY OF OCCURRING IN ANY GIVEN YEAR OF ",D.DD
3950  RETURN
3960  STOP
3970  REM*****************************************************************
3980  REM*****************************************************************
3990  REM                                  ADJUSTMENT PROCESS SUBROUTINE
4000  REM*******************************************************************
4010  REM
4020  REM            TRANSLATES FLOOD EVENT INTO A PERCEIVED EVENT UTILIZING
4030  REM                         A NORMAL EQUATION
4040  X1=15
4050  S=10
4060  P1=3.14159
4070  E=2.71828
4080  A=(R1-X1) ** 2
4090  B=2*(S ** 2)
4100  C=A/B
4110  D=1/(E ** C)
4120  G=2*P1
4130  IF G >= 0 THEN 4160
4140  PRINT "NEGATIVE ARGUMENT IN SQUARE ROOT FUNCTION IN ADJUSTMENT PROCESS"
```

```
4150  STOP
4160  F=1/(S*SQR(G))
4170  H=D*F
4180  H=H*1000
4190  H=INT(H*100)/100
4200  PRINT LIN(1)
4210  PRINT LIN(1)
4220  PRINT  USING 4230;H
4230  IMAGE "PERCEIVED HAZARD INDEX = ",DDD.D
4240  PRINT "TO CONTINUE HIT RETURN"
4250  LINPUT M$
4260  REM                          UPDATES ACCUMULATED PERCEPTION OF HAZARD
4270  REM                       SYSTEM AND CHECKS TO SEE IF MOVER/STAYER
4280  REM                         THRESHOLD HAS BEEN REACHED
4290  FOR I=1 TO 25
4300  FOR J=1 TO 16
4310  IF A[I,J]=0 THEN 4390
4320  A[I,J]=((A[I,J]-1)*.9)+1
4330  A[I,J]=A[I,J]+H
4340  IF (A[I,J]-1)<M THEN 4390
4350  A[I,J]=0
4360  A[I,17]=A[I,17]-1
4370  T1=T1-1
4380  PRINT "SETTLER 'HAZARDED OUT' FROM AREA";I;"CELL";J
4390  NEXT J
4400  NEXT I
4410  PRINT LIN(2)
4420  RETURN
4430  STOP
4440  REM*********************************************************************
4450  REM*********************************************************************
4460  REM                                                INTRO AND EXPLANATORY
4470  REM                                                        SUBROUTINE
4480  REM*********************************************************************
4490  PRINT LIN(2)
4500  MAT A=ZER
4510  FOR I=1 TO 25 STEP 2
4520  FOR J=1 TO 16
4530  A[I,J]=1
4540  NEXT J
4550  NEXT I
4560  PRINT "SETSIM IS AN INTERACTIVE ROUTINE DESIGNED TO SIMULATE THE"
4570  PRINT "SETTLEMENT OF AN IDEALIZED SETTLEMENT PLANE."
4580  PRINT LIN(3)
4590  PRINT "THE PRINCIPAL DYNAMIC FEATURE OF SETSIM IS ITS INCORPORATION"
```

```
4600  PRINT "OF A PROCESS WHICH IS DESIGNED TO GENERATE THE FREQUENCY AND"
4610  PRINT "INTENSITY OF A NATURAL HAZARD (e.g.  A DROUGHT OR A FLOOD) AND"
4620  PRINT "SIMULATE THE RESPONSE OF THE SETTLERS TO THIS HAZARD."
4630  PRINT LIN(3)
4640  PRINT "THE DEVELOPMENT OF THIS ROUTINE HAS BEEN PRIMARILY A CONCEPTUAL"
4650  PRINT "EXERCISE AND IS NOT BASED ON ANY EMPIRICAL STUDY."
4660  PRINT LIN(3)
4670  PRINT "(WHEN YOU ARE DONE READING A SET OF INSTRUCTIONS PRESS THE RETURN"
4680  PRINT " KEY TO CONTINUE.)"
4690  LINPUT M$
4700  PRINT " THE CELL FRAME WORK LOOKS LIKE THIS="
4710  GOSUB 3310
4720  PRINT "A SETTLEMENT AREA IS DEFINED AS A BLOCK OF 16 CELLS WHICH MAKE UP"
4730  PRINT "A FOUR BY FOUR SQUARE. THE PLANE IS MADE UP OF 25 SETTLEMENT AREAS,"
4740  PRINT "OR A 5 AREA BY 5 AREA MATRIX. THESE 'AREAS' ARE EMPHASIZED ABOVE.";
4750  LINPUT M$
4760  PRINT LIN(3)
4770  PRINT "THE SIMULATION FUNCTIONS ROUGHLY LIKE THIS:"
4780  PRINT "        1) EACH PROSPECTIVE SETTLER IS CHOSEN A SETTLEMENT "
4790  PRINT "AREA.  THE PROBABILITY OF AN AREA BEING CHOSEN IS INCREASED "
4800  PRINT "THE MORE THE AREA IS ALREADY SETTLED.  A CELL WITHIN THE "
4810  PRINT "CHOSEN AREA IS PICKED RANDOMLY. EACH CELL REPRESENTS A POSSIBLE"
4820  PRINT "LOCATION FOR ONE (1) SINGLE-FAMILY FARM."
4830  PRINT "        2) AFTER ALL THE SETTLERS HAVE FOUND A HOME, A NATURAL"
4840  PRINT "HAZARD IS GENERATED, THE LEVEL OF WHICH IS GOVERNED BY CHANCE."
4850  PRINT "        3) EACH NATURAL HAZARD IS PERCEIVED BY EACH SETTLER"
4860  PRINT "WHO ADDS IT TO HIS/HER ACCUMULATING SENSE OF HAZARD AWARENESS."
4870  PRINT "THE LEVEL OF HAZARD PERCEPTION FROM EACH GENERATED NATURAL HAZARD"
4880  PRINT "IS WEIGHTED IN A MANNER WHICH TENDS TO GIVE MODERATELY INTENSE"
4890  PRINT "EVENTS MORE INFLUENCE UPON THE PERCEPTION OF THE SETTLER,"
4900  PRINT "THAN THE VERY FREQUENT OR EXTREMELY INFREQUENT HAZARDOUS EVENTS."
4910  PRINT "         4) AT THE END OF EVERY 'YEAR' EACH SETTLER IS EVALUATED"
4920  PRINT "TO SEE IF HIS/HER ACCUMULATED SENSE OF HAZARD HAS REACHED A"
4930  PRINT "THRESHOLD, WHICH YOU WILL SPECIFY. IF THE THRESHOLD IS REACHED"
4940  PRINT "THE SETTLER IS ASSUMED TO VACATE, AS THE AREA OF HIS SETTLEMENT"
4950  PRINT " IS TOO HAZARDOUS FOR THAT PARTICULAR SETTLER'S LIKING."
4960  LINPUT M$
4970  RETURN
4980  STOP
4990  END
```

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