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NATURAL HAZARD IN HUMAN ECOLOGICAL PERSPECTIVE: HYPOTHESES AND MODELS

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The lives and affairs of men constantly interact with the natural world. Elaborate technical and social mechanisms enable men to seek in nature that which is useful and to buffer that which is harmful to man. To cope with the harmful effects of nature, complex sets of human adjustments are found in all human use systems. By chance, or even by design, these adjustments can prove insufficient to cope with a given set of natural events, and serious and detrimental effects may ensue. Thus a natural hazard is an interaction of man and nature, governed by the coexistent state of adjustment in the human use system and the state of nature in the natural events system. In this context, it is those extreme events of nature that exceed the capabilities of the system to reflect, absorb, or buffer that lead to the harmful effects, ofttimes dramatic, that characterize our image of natural hazards. But it is also the continuous process of adjustment that enables men to survive and indeed benefit from the natural world. Therefore, the burden of hazard is twofold: a continuing effort to make the human use system less vulnerable to the vagaries of nature, and specific impacts on man and his works arising from natural events that exceed the adjustments incorporated into the system.

For the past dozen years, the collaborators in Natural Hazard Research have sought to study this process of adjustment.[1] Beginning with floods, these studies were extended to coastal storm, earthquake, drought, and snow hazard. Subsequently, the list has been enlarged by colleagues and students to include tsunami, frost, coastal erosion, and water pollution hazards. These varied studies employed all or part of a research paradigm which sought to: 1) assess the extent of human occupance in hazard zones; 2) identify the full range of possible human adjustment to the hazard; 3) study how men perceive and estimate the occurrence of the hazard; 4) describe the process of adoption of damage reducing adjustments in their social context; and 5) estimate the optimal set of adjustments in terms of anticipated social consequences.

But 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, 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.[2]

A rudimentary model of the short-run process of adjustment constitutes the major focus of this paper. Our present understanding of this process, particularly in North America, is considerably greater than our comprehension of the long-run adaptive process in the global context. Nevertheless, some hypotheses, having as their core the man-nature interaction and an evolutionary sequence of techno-social stages of adjustment,

[1] See Burton, Kates, and White [2].

[2] Given present, rapid rates of change, the long run increasingly shortens, and it remains to be seen whether that which is seemingly adaptive will not prove maladaptive in the future.

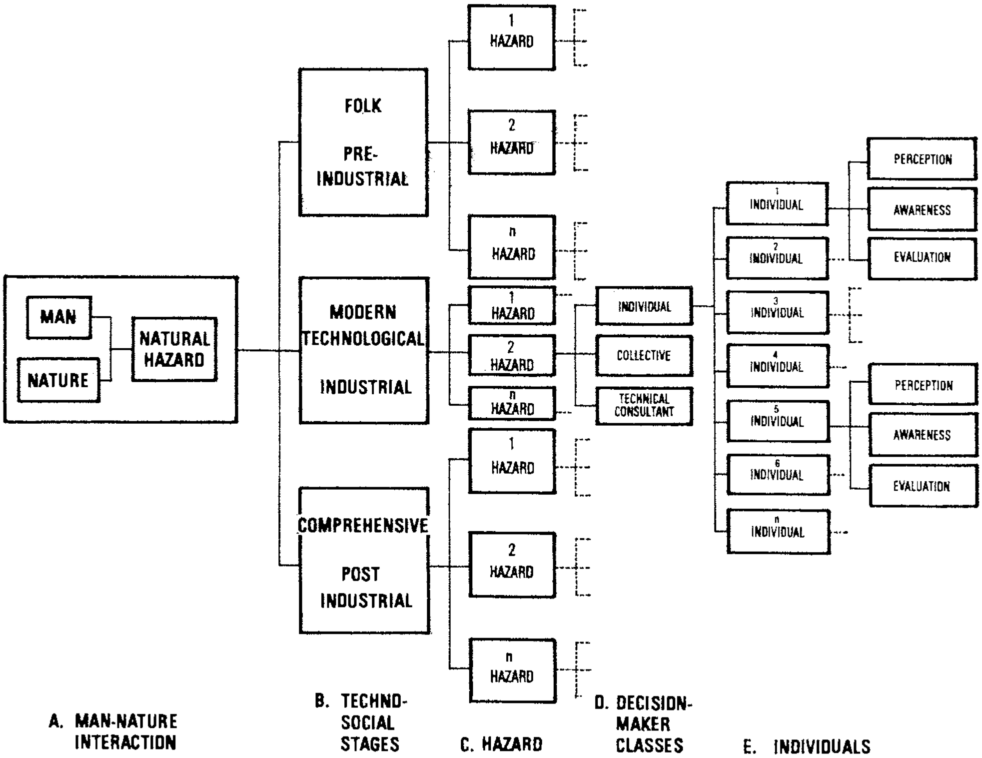

Fig. 1. Links between natural hazard hypotheses.

have been developed from the body of hazard-specific and place-specific research.

GLOBAL HYPOTHESES OF NATURAL HAZARDS

The present state of global understanding of natural hazard phenomena may be stated as a series of linked, succinct, but complex hypotheses as to the nature of natural hazard, adjustments to it, and the choice thereof made by the human occupants of hazard areas.[3] They purport to explain major sources of variation in human behavior, as between great techno-social stages, specific hazards, specific classes of decisions and decision makers, and between individuals within a specific group of managerial decision makers (these are linked as in Figure 1).

Man-Nature Interaction. Natural hazard is an aspect of the interaction of man and nature arising from the common process in which men seek in nature that which is useful, and attempt to buffer that which is harmful to man. This process, whether employing elaborate technical and social mechanisms or simple ones, makes possible human occupance of areas of even frequent and recurrent natural hazard.

Thus it is rare in such areas to discover individuals in substantial ignorance of the hazard or unaware of alternative locations. Rather, locations either offer opportunities of relative or absolute superiority, or appear less threatening from the unique, terminal perspective of the individual than from the longer-run view of the external observer.

Techno-Social Stages. Human response

[3] Walker Banning and Carlos Alsina helped develop an initial list of hazard hypotheses, subsequently refined in many discussions with project collaborators.

to natural hazard is organized into three distinctive techno-social patterns or stages of adjustment: folk or preindustrial; modern technological or industrial; and comprehensive or postindustrial. Each stage is marked by a preferred cluster of adjustments, a distinctive process of choice, and characteristic patterns of damage occurrence.

Folk or preindustrial adjustments, for example: are often mystical, arational, or imbedded in the broader cultural context of life and livelihood; require more modification of human behavior in harmony with nature than reliance on the control of nature; are flexible and easily abandoned; are low in capital requirements; require action only by individuals or small groups; and can vary drastically over short distances. Damage-causing natural events appear to be frequent; the average loss per event is low; but the ratio of deaths-to-damage is high.

Modern technological, or industrial, adjustments: involve more or less conscious decisions from a limited range of technological actions emphasizing control of nature; are inflexible and difficult to change; are high in capital requirements; require interlocking and interdependent social organization; and tend to be uniform. Damage-causing natural events become less frequent; death rates diminish drastically; but average damage loss per event is extremely high.

Comprehensive, or postindustrial, adjustments combine features of both earlier stages so as to involve a larger range of adjustments, greater flexibility and variety of capital and organizational requirements, and the institutionalization of broadened choice from the array of potential actions. Damage-causing natural events increase slightly, death rates further diminish; and average damage losses per event decrease by up to half the maximum potential damage. Nevertheless, absolute damages and deaths may remain high as a function of increase in population and wealth.

Hazard Differences. Within the context of any of these three patterns of response to natural hazard, considerable variation exists. There are noticeable differences in the choice of adjustments between various hazards, and differences as well between decision makers. These decision makers include both collectivities such as communities, public bodies, and corporations, together with their technical consultants and individuals who occupy or use hazard areas.

Four critical features of natural hazards give rise to different choices of adjustments. Three are features of the natural events: the frequency of occurrence, the magnitude of energy release, and the suddenness of onset. A fourth feature arises from the ecological setting, namely, whether the hazard is intrinsic to the use characteristics or locational advantage of the site (e.g., drought in rain-fed agriculture, coastal storms at scenic locations), or is not intimately related to occupance activity (e.g., earthquake, tornado).

Decision Maker Differences. In the context of a single hazard, the characteristics of the choice process vary with the nature of the decision maker: some choices being collective actions, others, individual actions, and many actions are sequentially constrained by previous collective or individual choices. While differing in detail and setting, our reading of the community, organization, and administration literature does not suggest a fundamental discrepancy between individual and collective behavior. Thus, while the appropriate managerial unit may differ, the ways in which the choice of adjustment is made does not fundamentally differ.

Individual Differences. Thus, all men who choose — user of a hazard area, public guardian, technical consultant, or single individuals or committees — seem to perceive hazard and are aware of a range of adjustments. They evaluate these adjustments with reference to their environmental fit, technical feasibility, economic gainfulness, and social conformity. But again in the context of a single hazard, considerable variation can be found in the perception of hazard, the knowledge of adjustments, and the evaluation criteria applied to these adjustments.

Perception of Hazard. Variation in the perception of a specific natural hazard (expectation of future occurrence and of personal vulnerability) can be accounted for by a combination of: the way in which characteristics of the natural event are perceived, the nature of personal encounters with the hazard, and factors of individual personality. Such perception appears to be independent of common socioeconomic indicators. Of the many possible characteristics of natural events, the perception of magnitude, duration, frequency, and temporal spacing of the natural event appears to be most significant. For personal experience, it is the recency, frequency, and intensity of such an experience that appears most critical with intermediate frequency generating greatest variation in hazard interpretation and expectation. Of the many possible personality factors, fate control, differential views of nature, and tolerance of dissonance-creating information seem most relevant. Risk-taking propensity, which appeared logically relevant, has not been shown to be a consistent trait and has proved operationally difficult to measure.

Awareness of Adjustments. Awareness of adjustments, of their number and type, and the quality of knowledge thereof, is a function in the main of the casual access to communication networks and, to a lesser degree, of motivation to search for new modes of adjustment. Variation in awareness might be accounted for by factors controlling access to information. Intensity of personal experience or role-related responsibility might provide motivation for increased knowledge of adjustments when encouraged by positive views of fate control and the efficacy of action.

Evaluation of Adjustments. Evaluation of known adjustments, with reference to environmental fit involves the conformity of the adjustment to an appraisal of site or situation for certain activities. Technical feasibility involves an assessment as to the efficacy of the adjustment, the availability of skills, tools, and materials, and the indivisibility of the activity from related processes. Economic gain involves an estimate of anticipated costs and gains in the light of the perceived time horizon, the ratio of reserves to anticipated loss, and the degree to which the choice is required. Social conformity involves a judgment of the degree of conflict or conformity with law, tradition, or expected mores of behavior.

The foregoing criteria for evaluating adjustments are not of equal importance and vary as between major stages, hazards, and individuals. For preindustrial adjustments, criteria of environmental fit and social conformity seem most important, while those of technological feasibility and economic gainfulness appear more prominent in considering industrial adjustments. The entire set of criteria appear relevant for postindustrial adjustments.

In the context of a single hazard and stage of response, variation in the importance of criteria appears related both to the perception of the hazard and the role training and responsibility of the decision maker. For example, in modern industrial adjustments, for decision makers with high hazard perception, technological feasibility should dominate questions of economic gainfulness. In cases of moderate to low hazard perception, role inclinations towards technological or economic considerations dominate.

The foregoing hypotheses range from those of great culture realms of nations and history to those explaining the diversity of behavior of individual farmers on the shores of Lake Victoria or residents of the flood plain of La Follette, Tennessee. To move from a set of hypotheses to a theory of hazard behavior requires the careful refinement of questions and the extensive research for answers in the series of comparative cross-cultural studies presently underway in over fifteen countries.[4] Models can contribute in a special way to the refinement of good questions.

On Models

A good model of a system is a theory of that system. It purports to identify major elements of the system, describe the strengths and direction of the linkages between those elements, and to simulate dynamically the processes that underlie the elements and linkages. Good models serve also as practical laboratories for social scientists in which the consequences of changes in process elements or linkages can be examined for their practical import.

Most models fail to do either function well. Lacking a theoretical understanding of process, the model builder resorts to black boxes, frequently in the form of some probability distribution. A working model may ensue, even one useful for prediction; but unless one subscribes to the fiction that equates prediction with understanding, the model itself does not necessarily enhance the state of theory. Nor do most models succeed very well in their practical simulations. It is common to find in the literature authors who bemoan the absence of certain critical data, the size of computer memory, or the fact that by the time the elaborate simulation is completed, the real world policies, towards which the model was intended to contribute, have changed several times over.

Nevertheless, we do learn many things from models, even in their failure, and that is why we turn to them again and again in our research strategies.[5] Faced with the need to model processes that we do not understand, we are given pause to determine whether we should seek to understand them before proceeding further. Then if we resort to a black box, it may be because we have found that the process is not intrinsic to understanding the phenomenon directly under study. Or when faced with the absence of critical data, we now might be encouraged to try to obtain it, but with increased confidence, having now established that in truth the data are critical. Thus we can emerge with what is most helpful for science, a statement not of gross ignorance but of highly specific ignorance, a veritable agenda for research needs.

A model may not only humble us in our ignorance but give us courage as well. So complex is the world, so many the events that occur, so simultaneous their occurrence, that the mind boggles at ever hoping to capture any complex process in all its dimensions. When we model a system, we reduce it to a mosaic, with distinguishable elements, boundaries, and single characteristics which combine, nevertheless, to give a representation greater than the sum of its parts. To make it dynamic, we can animate the mosaic and if its representation is still recognizable, we have some reason to be encouraged.

Based on these general observations, let me suggest some specific qualities for a model for hazard research: it should be parsimonious, conservative, flexible, useful, and aesthetically pleasing. The model should strip the adjustment process to its barest bones, it should minimize detail, subject only to the constraint of some verisimilitude toward the real world. It should be conservative with what has been done over the last decade utilizing wherever possible accumulated materials rather than demanding fresh

[4] These studies, involving the collaborative effort of many colleagues, have been organized by the Commission on Man and Environment of the International Geographical Union, and consist of comparative field observations of hazards including drought, earthquake, flood, frost, hurricane, landslide, pollution, and volcanic activity, and national appraisal of drought, flood, hurricane, and air pollution.

[5] That is, quite aside from fads or fun in research, which also contribute to the spate of model building.

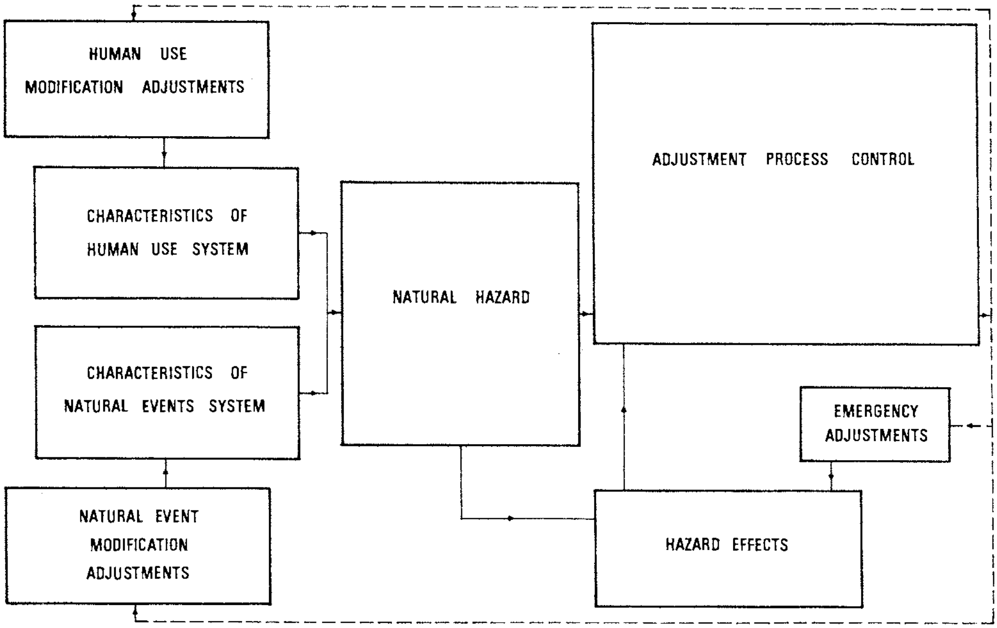

Fig. 2. Human adjustment to natural hazards: outlines of a general systems model.

constructs or data. It should be flexible in its ability to accept new findings and insight, such as may be derived from the extensive cross-cultural studies now underway. It should be capable of providing practical answers by duplicating desired patterns of adjustment and evaluating unambiguously the advantages and disadvantages of each. To do so it must be programmable, suitable to the simplistic linear thinking (loops notwithstanding) of the modern computer. Finally, and perhaps most importantly, it should prove aesthetic. None of those involved in hazards research finds model building a pleasant avocation for its own sake. If it is to be justified it must have aesthetic scientific appeal, namely that the final product has genuinely enhanced our understanding in such a way as to provide some sense of pleasure.

These qualities, desirable in themselves, seriously compromise reality. Human society or natural process are simplified in ways that seldom meet the approval of specialists in a specific area of study. Subtle but cumulatively important processes are ignored. A complex, subtle, variegated, almost infinite process of adjustment is reduced to a sequence of crude, iterative steps. But even in its crude form a model of human adjustment involves a formidable understanding of systems, collection of data, and knowledge of functional relationships.

MODELING THE ECOLOGICAL PERSPECTIVE WITHIN A GENERAL SYSTEMS FRAMEWORK

The model shown in outline in Figure 2 is only a small slice of the global system for which the above hypotheses represent the first step towards a theoretical formulation. The system modeled is a single cross-section of space and time: an area with a relatively homogeneous expectation of a single hazard and a duration in time appropriate to the temporal character of the natural events and the related human activity.

For some bit of the earth's surface, for some small moment in time, man and nature, in the form of a *human use sys-*

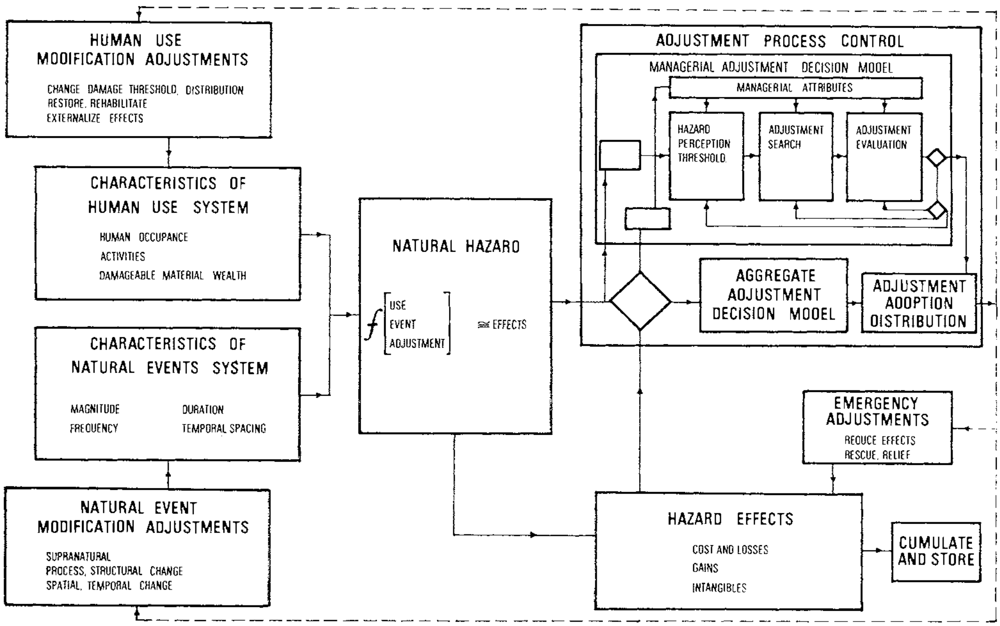

Fig. 3. Human adjustment to natural hazards: a general systems model.

tem and a *natural events system*, interact to pose a *natural hazard*. The existence of such hazard generates a specific set of *hazard effects* and its own homeostatic control in the guise of various adjustments.[6] The *adjustment process control* governs the adoption of adjustments that modify the human use system, modify the natural events system, and modify the hazard effects through *emergency adjustments*. The characteristics of each of the elements are specific and the linkages are functional between elements. These are shown in greater detail in Figure 3.

Characteristics of the Human Use System. What constitutes a minimal but sufficient description of the human use characteristics of a relatively small, homogeneously hazardous area? To evade a classic question in regional description (and in all behavioral and social science), we define sufficiency in terms of adjustment capability and hazard effects. Thus we describe the human use in terms of managerial units; the smallest units of occupance capable of independent and indivisible decision making relative to adjustment adoption. For each managerial unit we describe those characteristics which capture the most significant of hazard effects.

With these general but imprecise guides, smaller managerial units would consist of households in most societies, but include as well all sorts of commercial, industrial, and governmental units, and on the highest level constitute an aggregate based on the nation-state. Unfortunately, one cannot simply aggregate the smaller units to arrive at the higher levels of hierarchy, where very different managerial responsibilities are found.

For each unit, a minimal set of descriptive data would include: 1) the specific human occupance in such terms as the number, age, sex, and diurnal or seasonal occupance of the hazard area; 2) activities, with material or service-productive activities described simply in

[6] The notion of natural hazard as a joint probability of states of natural events and human adjustments to them was developed with Russell and Arey in a study of humid area drought in Massachusetts [7]. A fuller appreciation of the ecological perspective comes from the work of Hewitt and Burton [5].

terms of their outputs and factor or process inputs, and non material-productive but important social and personal activities, described in terms of their age-sex participation rates; and 3) an inventory of damageable material wealth.

Characteristics of the Natural Event System. The study of the natural processes that govern the generation of hazard-causing events is the subject of entire disciplines: seismology, hydrology, meteorology, vulcanology, parasitology, just to name a few. Each discipline develops key indexes to describe its events and these are not necessarily transferable. Nevertheless, in a current attempt to describe all types of environmental hazards twelve critical indexes are being used, seven of which are primarily characteristics of the natural event system: spatial distribution, magnitude, frequency, duration, areal extent, forecast capability, and warning time.[7]

In the model further reduction is suggested. Events can be described in terms of *magnitude* expressed as a dimension, volume, or energy expression; *frequency* expressed as a probability of occurrence in a unit of time or an average return or recurrence period of time; *duration* expressed as temporal periods ranging from seconds to years; and *temporal spacing* describing the patterned occurrence of the event in time – random, even (seasonal or regular periodic), or clustered (serially correlated).

It should be noted that the measurement of these characteristics are indeed perceptions, those of the scientist and engineer. Other perceptions exist, those of the manager, and these may employ different characteristics and measurements. These enter the model in terms of managerial decision making; for the description of events we seek the best technical, albeit subjective, appraisal.

Natural Hazard. A natural hazard is a threatening state 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.

Such functional statements are available for certain characteristics of flood plain occupance (productive and residential activities and damageable material wealth) under differential adjustments.[8] Thus we have generalized functions that relate stage of flood (a dimensional measure of magnitude) to the structure, contents, and productive activities of manufacturing, commerce, and residence to yield monetary damage effects. But for most other hazards, relationships with predictive potential are rare.

Hazard Effects. The occurrence of a specific natural event may or may not have any impact on the human use system, this being a function of the size of the event and the character of adjustment. The cost of adjustment, which can vary drastically, may be a continuing levy on the wealth and energies of the managerial units. These effects are registered in their direct impacts on the health and well-being of the human occupance, in the loss of wealth from curtailment of productive activities and damage to material wealth, and in losses in the opportunity to participate in important social and personal activities. There are gains as well, the work or location well-placed to profit from a hazard: the farmer who benefits in higher prices because of another's loss, the well-digger in time of drought. Finally, there are intangible impacts, some unidentifi-

[7] The remaining five indexes being used for a study designed for UNESCO are: damage potential, adjustments, adoption of adjustments, perception of hazard, and perception of adjustment.

[8] See White [11] and Kates [6].

able, and others, though identifiable, for which the consequences are not easily assessed. The model needs to identify these contrasting impacts, to cumulate and store them, and to follow the resulting change in the human system and its level of adjustment.

Adjustment Process Control: Managerial Adjustment Decision Model. The presence of a natural hazard encourages human action to minimize its threat and mitigate its effects. For any individual managerial unit the decision process is a complex but interesting one, and it has been a focus of hazard research for many years.

A model of decision making applicable both to the choice of resource and natural hazard adjustment has been developed. This model by White [*10*] is heavily influenced by the work of Simon particularly in the notions of "bounded rationality" and "satisficing" [*9*]. The work also parallels the complex model of resource use developed by Firey [*4*].

Over the years, variants of this approach have been tested in different hazard and resource use situations. Two emphases can be found in this work: to develop a sharper, more predictive decision making model and to incorporate individual personality characteristics into it. This is a continuing task, providing new challenges in the cross-cultural context.

The sub-model presented in Figure 4, then, is really the current state of our decision making theory, strung together in an operative sequence. The sequence is as follows: for the manager of each unit there is a threshold of hazard perception below which he does not seek nor evaluate adjustments. This threshold is in turn a function of the way in which the manager perceives natural events, his personal hazard experience, and specific personality characteristics that include attitudes towards fate and the efficacy of action, differential views of nature, tolerance of dissonance, and risk-taking propensity. The perception of events and personal hazard experience can change at each iteration; personality traits are fixed for the duration of a model run.

The initial set of known adjustments is also a function of an individual manager's attributes, specifically his casual and specialized access to communication networks. General access can be approximated by socioeconomic indications of age, education, income, and travel, specialized access by unique role responsibilities and training.

When the hazard perception threshold reaches a certain value, a search of known alternatives begins, and each is evaluated in turn by reference to four basic questions.

1. Is it suitable for the environmental setting?
2. Is it technically efficacious and feasible given the available tools, skills, materials and the indivisibility of activity?
3. Is it economically gainful in the context of the managerial unit's time horizon, reserve-loss ratio, and constraints on choice?
4. Does it conform to social guides of law, tradition, or expected norms of behavior?

The questions are not of equal priority however, and the model would allow sequencing them or giving the evaluation criteria different worth. It is clear for example that in much of the world engineers faced with a problem of adjustment use technical feasibility — Will it work? — as their prime criterion and employ considerations of cost, social conformity, and the like as constraints. Similarly, social conformity — to do as my father did — is a basic guide in many areas. In the context of a specific area, the order of criteria is probably a function of hazard perception and role responsibility and training.

The actual application of the evaluation criteria is a function primarily of the human use characteristics for the

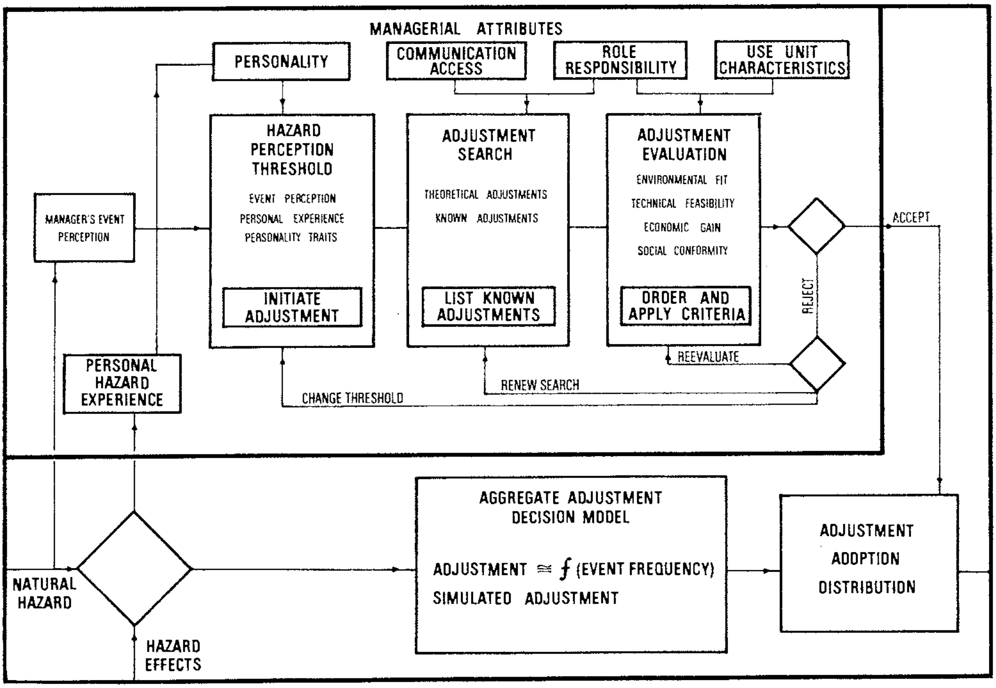

Fig. 4. Adjustment process control.

managerial unit. Based on the evaluation, a decision to adopt or not is made. If rejected, provision is made to feed this back into the process. We know from the concept of satisficing and from cognitive consistency theories, that in the face of either ease or difficulty in developing problem solutions, men will often change their evaluation of the problem, seek new alternatives or modify their standards of acceptance of a solution. Provision is made for each or all of these modes of cognition.

This is truly a complex sub-model reflecting the complexity of real-world processes. But the overall model does not require successful simulation of each individual decision; an alternative path of adjustment control is provided.

Adjustment Process Control: Aggregate Adjustment Decision Model. In any hazard area, the frequency of adoption of adjustments appears to be a function of the hazard frequency. The variation in adoption between individual managerial units is also related to frequency, but variation is highest in areas of intermediate frequency.

In areas of low frequency, most people adopt few, if any, adjustments. In areas of high frequency, widespread adoption is found. These relationships are modeled by simple functional relationships in the aggregate adjustment decision model, which is also capable of accepting simulated adjustment distributions.

Adjustments to natural hazard. Three distinct sets of adjustments are postulated in the model: those that seek to *modify the natural events system,* those that attempt to *modify the human use system,* and a set of post-event *emergency* adjustments.

The most common adjustment of the set designed to modify the natural events system is an appeal to, or activity for, some supranatural power. In the face of calamity or to prevent it, men everywhere appeal to "whatever Gods may be." Nor are such practices limited to non-literate peoples; witness the widespread practice of water well dowsing in North America.

For some hazards, an attempt can be made to affect the natural process as in fog or hail dispersal by seeding or other forms of weather modification. More common is to seek to shift the spatial or temporal distribution of the natural events to a more favorable one. Barriers of all sorts seek to limit the spread of a hazardous event, and water storage and retardation structures are familiar means of dealing with floods and droughts. Finally, some adjustments affect the internal or chemical structure of the event as in the case of snow melting adjustments.

An even wider array of adjustments affect the human use system. Some seek to raise the damage threshold, the point at which damage begins, while others tend to change the entire damage potential distribution. Examples of the former would be the floodproofing of basement areas, and of the latter, the use of a drought-resistant crop variety. Evacuation and related adjustments may lead to eliminating entirely some damage potential, while conversely the process of restoration and rehabilitation of previous hazard effects may add to or diminish the damage potential. The most common of all adjustments is the bearing of losses when they occur. But this burden can be shared. Indeed all hazards effects can be externalized, spreading them over a wider space, greater time, or broader society by insurance, relief, extended family relations, and the like.

Finally, after a specific event ensues, emergency adjustments can diminish its effects. Rescue and relief operations can save lives and reduce the burden of the hazard; flood-fighting, fire-fighting, evacuation, and emergency repairs prevent greater losses from occurring.

THE GENERAL MODEL APPLIED TO EAST AFRICAN AGRICULTURAL DROUGHT

By way of illustration, let me briefly note the progress being made in modeling drought in a specific context—East African smallholder agriculture.[9] This agriculture is characterized by markedly seasonal rainfall, a hoe-based cultivation system with little or no capital inputs, which mixes crops and cattle, family food and commercial crops, and perennial and annual crops, depending on locale. For all but the most well watered mountain areas, drought and adjustments to drought are essential features of the agricultural system. As the rains come late, are sparse, or fail altogether, varied and widespread suffering is reported. If we would seek to model this system, based on our present knowledge, what would its components look like?

The Human Use System. The managerial unit of the human use system is the household in almost all cases (Figure 5). The productive activities of such a household are very complex. Up to 25 different crops or trees will be grown, many occupying the same plot of land. Nevertheless, much progress has been made in describing the nature of the agricultural system; a dozen or more detailed studies exist today, where there were but one or two five years ago.[10] In these recent studies in Tanzania, it has been found possible to describe crudely the major factors of production, land, and labor, with some precision; but accurate description of crop yields still seems to escape us. In terms of nonproductive activities we know little of their relationship, if any, to drought; and of material wealth, only animal wealth seems particularly sensitive to the phenomenon.

The Natural Events System. It now appears possible to provide a rather sophisticated description of the natural

[9] Work undertaken in conjunction with Len Berry, Director of the Bureau of Resource Assessment and Land Use Planning, University College, Dar es Salaam, Tanzania and Philip Porter of the University of Minnesota.

[10] For a review of many of these studies, see Ruthenberg [8].

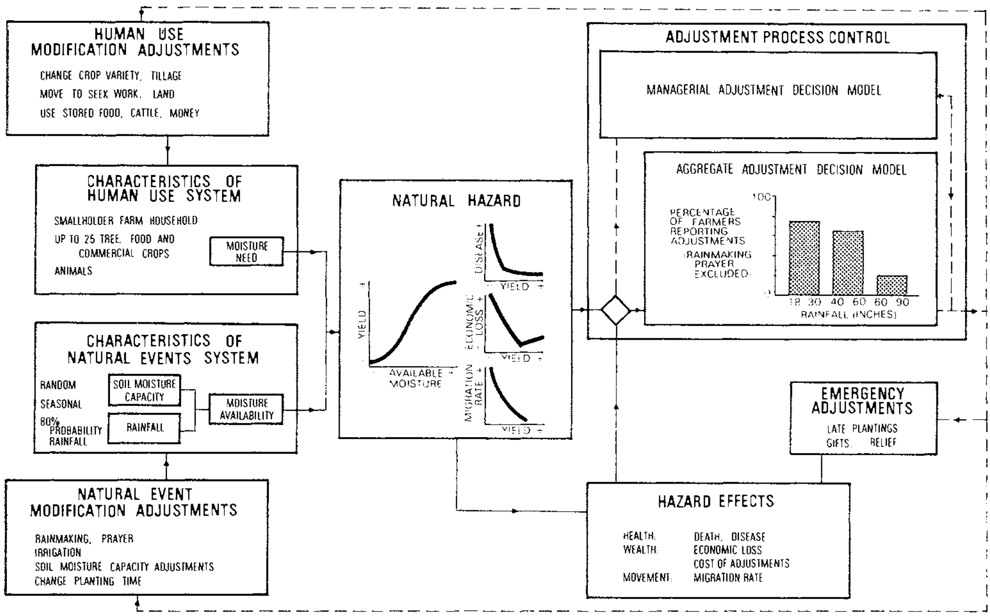

Fig. 5. Human adjustment to natural hazards: an application to East African agricultural drought.

events system in terms of the water balance. Rainfall data, estimates of potential evapotranspiration, and computer programs exist capable of providing probability estimates of soil moisture surplus or deficit by ten-day or monthly periods for selected areas of East Africa [*1*, *3*]. A monthly period appears to be adequate for capturing major variations in weather, the growth cycle, and the human use system during the growing season, but for certain growth processes a daily or weekly period would be desirable. With little carryover for soil moisture, random temporal spacing or the independence of growing season rainfall can be assumed (intra-seasonal rainfall, however, is serially correlated).

Natural Hazard. The essential features of the natural and human use system can be captured in the water-yield relationship, and this can be used to describe the natural hazard. In practice, the most significant range of hazard lies between the wilting point and potential evapotranspiration. We know little about this range of the relationship although we do know something about the optimal and minimal water needs at each point of the plant growth cycle. A distinctive water-yield relationship is needed for each variation in crop, location, cultivation, and tillage practice, essentially for each variation in adjustment. It would be perhaps possible to obtain such relationships for a single place, the East Africa Agricultural and Forest Research Organization station at Muguga, Kenya, but extremely difficult to obtain such data elsewhere. An additional problem with these experimental data is the excellence of the agriculture; the level of practice employed at the station far exceeds that of the general level of agricultural practice.

Hazard Effects. Three kinds of drought effects are considered: effects on health, wealth, and movement. We know very little about the relationship between variation in crop yield and death and disease, economic gains and losses, or movements of population; estimating the impacts of these effects is a major research task.

Adjustments. Pilot studies of adjustment involving interviews with 460 Tanzanian farmers have indicated the range of adjustment and have provided a rudimentary conceptualization of the process.[11] There is widespread resort to supranatural appeal, to bearing losses or externalizing them in time by using stored food or money in the form of cattle, or by moving to seek work or land. More rarely employed are on-farm adjustments that manipulate the human use system by changing crop varieties, cultivation practices, planting dates, and the like.

Adjustment Process Control. The adoption of adjustments appears, as elsewhere, to be a function of the hazard frequency, but not a simple one, and much more needs to be learned in this respect. We think that we now know how to better ask farmers for the data required to simulate managerial decisions and with our collaborators are collecting such data in Australia, Brazil, Mexico, and Tanzania.

In operation of such a model, different adjustments affect either the available moisture, the water-yield relationship, or the hazard effects. With a simulated or historical trace of precipitation employed as an independent variable, it is possible to evaluate the longer term effects of changes in adjustment or the decision process itself. For at least one or two places, where the complex data assembly needs can be met, the model can provide an agenda of research needs, serve as a test of our decision theory when compared with observed behavior, or provide a simulation for the potential outcome of our policy suggestions.

AFTERTHOUGHTS

The general and specific models herein have focused on the interaction of man and nature, as a continuous process where certain extreme concurrences are identifiable as hazards of natural origin and harmful to man. In addition to modeling this process from a human ecological perspective, the models seek to fashion major hypotheses of hazard behavior into structures capable of computer simulation. At this point in their development, their heuristic value seems established but the capability for relatively efficient and meaningful simulation is still in doubt.

But more important and still debatable is the desirability of the general perspective. A case can be made that many of the real determinants of human behavior related to natural hazard lie outside the interface of the natural and human systems modeled here. For example, the simultaneous occurrence of the droughts and floods with economic depression in the 1930s surely led to development of policies different from those that might have prevailed in the absence of the depression. And the encouragement of cash cropping and the prohibitions on migration by the colonial administration in East Africa probably intensified the effects of the disastrous droughts occurring there in the thirties. Critical events such as these, seen as important with hindsight, are not easily handled by the model.

An alternative would be to model in much greater detail the specific human use system related to a particular hazard: smallholder agriculture, urban residential development, municipal water supply, and the like. In this context natural hazard would be but one of a series of concerns facing the manager, and the ways in which he dealt with other forms of uncertainty would surely affect the ways in which he deals with the natural hazard. A greater fidelity of the system to reality would be obtained at the cost of comparative generalization.

This is, of course, an old dilemma and one familiar to many. How quickly have models of systematic systems become regional systems? One begins to model the transportation and ends up modeling the city, the region, its activities and growth. In my earliest introduction to modeling, in working with the Harvard

[11] Reported on in detail in Berry [*1*].

Water Program, I learned that decision comes from the Latin verb "to cut." The decision as to where to make the cut that severs the decision-model from the matrix of reality comes no more easily than do the decisions of even the most knowledgeable in the face of an uncertain natural world.

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