

Decision Processes, Rationality, and Adjustment to Natural Hazards

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I. Introduction

In November 1970, 120 m.p.h. winds and 20-foot waves ravaged the coastline and inland areas off the Bay of Bengal, destroying 90% of the buildings and 90% of the rice crop over a 3000-square-mile area and killing several hundred thousand Pakistanis. Only a few months earlier, an earthquake dislodged 65 million cubic yards of earth from a mountainside and sent it surging over the Peruvian valley town of Yungay, burying more than 25,000 persons. While these are two of the more dramatic incidents, major disasters, involving more than 1 million dollars damage or at least 100 persons dead or injured, occur more than thirty times a year in the world, with floods, hurricanes, and earthquakes the most prevalent (Sheehan & Hewitt, 1969). In addition, innumerable smaller disasters contribute to a massive annual toll of death and destruction.

Although "developing" nations suffer the greatest loss of life due to natural hazards, technologically advanced, post-industrial nations are not immune to vast damage. Indeed, the average annual cost of natural disasters in the U.S. is probably between two and three billion dollars a year (Burton, Kates, & White, 1968); and some expect that the next major earthquake under an urban area could cause as much as \$20 billion in damage (Gillette & Walsh, 1971).

In technologically advanced countries, man is becoming increasingly susceptible to damage from natural hazards. Although the U.S. government spent more than \$7 billion between 1936 and 1962 on dams and other structures intended to curb flood damages, the mean annual toll of flood losses rose

steadily during that period (Cook & White, 1963) and has continued to increase. In this circumstance, attempts at technological solutions seem to have backfired. The partial protection offered by a dam apparently gives residents a false sense of security and thus promotes extensive development of vulnerable lower sections of the flood plain. When a rare flood exceeds the capacity of a levee, damage is extensive. More likely than not, the victims of the disaster will return and rebuild on the same site. Similar phenomena have occurred in India, New Zealand, Ceylon, and other countries. While an increase in losses is not necessarily suboptimal, the increased exposure to hazard in many flood plains has not been balanced by proportionate economic gains, leaving the net effect clearly negative (U.S. Congress, 1966). Thus, one of the striking aspects of technical efforts to come to grips with hazards in nature is that the well-intentioned program too often yields results contrary to those desired.

The social and economic importance of these phenomena has stimulated considerable interest in understanding and improving the decision-making processes that determine a manager's mode of adjustment to natural hazards.¹ Technological solutions to the problem of coping with hazards have typically been justified by a computation of benefits and costs that assume the people involved will behave in what the policy maker considers to be an economically rational way. However, it has slowly become evident that technological

¹Throughout the paper we shall use the terms decision maker and manager synonymously. Managers are defined as individuals who act in the management of an establishment. An establishment is defined as a single residence, agricultural, commercial, or public-service organization that has distinct use of an area. The term "adjustments" refers to the many courses of action available to the manager for coping with natural hazards. For example, in the case of floods, potential adjustments include bearing the loss, insurance, land elevation, structural works (such as dams), and public relief.

solutions, by themselves, are inadequate without knowledge of how they will effect decision making. In reviewing adjustment to floods, it has been observed that attempts to control nature and determine government policy will not succeed without a better understanding of the interplay among psychological, economic, and environmental factors as they determine the adjustment process (White, 1966).

By assuming that managers are rational and that they act according to the same decision criteria that public agencies prescribe, federal programs to reduce hazards have been based upon predictions that often failed to materialize. These failures have been attributed to the ignorance and irrationality of the occupants of a hazard zone; but recent work suggests that adjustments to hazards may be understandable and, in a sense reasonable, within the framework of decision models different from the traditional optimization models. One such model is that of "bounded rationality," which takes into account limitations of the decision maker's perceptual and cognitive capabilities. The need for an improved understanding of the decision-making process is urgent, and is at the heart of systematic

improvement of public policy. Such improvement becomes increasingly significant as man intervenes still further in natural processes and thereby opens himself to further hazard from their variability and uncertainty.

Aims and Organization of the Paper

This paper focuses on cognitive elements of decision making under risk that are important for understanding adjustment to natural hazards in a modern, technological society. Thus we shall discuss such topics as human understanding of probabilistic events, perception of hazards, and the processes involved in balancing risks and benefits when choosing among alternative modes of adjustment to hazard. The phenomena we shall review are, for the most part, likely to generalize across cultures and across individuals and are likely to help us understand adjustments to man-made hazards as well as natural ones. This cognitive emphasis is not meant to deny the obvious importance of personality and cultural factors in determining adjustments to natural hazards. The influence of culturally-ingrained attitudes towards nature and towards fate has been illustrated by Burton and Kates (1964), Bauman and Sims (1972), Parra (1971), and others. Individual personality factors that influence adjustment to hazards are discussed by Schiff (1970), and Burton (1972). The reader interested in a model of the interrelationships among cognitive, personality, and cultural factors in the context of adjustment to natural hazards should see Kates (1970).

The organization of the paper is as follows. In Section II we shall present a brief overview of the leading normative and descriptive theories of decision making. Particular emphasis will be given to a comparison between a theory that espouses maximization of expected utility as a normative guideline

and a conceptualization of bounded rationality which has both normative and descriptive intent. Section III presents evidence from the psychological laboratory and data from field observations of adjustment to natural hazards to document the usefulness of the notion of bounded rationality as a framework for understanding adjustment to hazards. Whenever possible, related data from laboratory and field are juxtaposed to highlight the generality and importance of these phenomena. The picture that emerges from this work illustrates some rather startling limitations in the ability of the decision maker to think in probabilistic terms and to bring relevant information to bear on his judgments in an effective way. However, the knowledge gained about human cognitive limitations has implications for improving the decision-making process. These implications are discussed in Section IV.

II. Theories of Decision Making Under Risk

Maximization of Expected Utility

The objective of decision theory is to provide a rationale for making wise decisions under conditions of risk and uncertainty. It is normative in intent, concerned with prescribing the course of action that will conform most fully to the decision maker's own goals, expectations, and values. Since good expositions of decision theory are available elsewhere (see Coombs, Dawes, & Tversky, 1970; Dillon, 1971; Luce & Raiffa, 1957; or Savage, 1954), our coverage here will be quite brief.

Decisions under uncertainty are typically represented by a payoff matrix, in which the rows correspond to alternative acts that the decision maker can select and the columns correspond to possible states of nature. In the cells of the payoff matrix are one set of consequences contingent upon the joint occurrence of a decision and a state of nature. A simple illustration for a traveler is given in Table 1.

Table 1

		<u>State of Nature</u>	
		sun (E_1)	rain (E_2)
<u>Alternatives</u>	A_1 carry umbrella	(+1) stay dry carrying umbrella	(+1) stay dry carrying umbrella
	A_2 leave umbrella	(+2) dry and unbur- dened	(0) wet and unbur- dened

Since it is impossible to make a decision that will turn out best in any eventuality, decision theorists view choice alternatives as gambles and try to choose according to the "best bet." In 1738, Daniel Bernouilli defined the notion of a best bet as one that maximizes the "expected utility" of the decision. That is, it maximizes the quantity

$$EU(A) = \sum_{i=1}^n P(E_i) U(X_i)$$

where $EU(A)$ represents the expected utility of a course of action which has consequences X_1, X_2, \dots, X_n depending on events E_1, E_2, \dots, E_n ; $P(E_i)$ represents the probability of the i^{th} outcome of that action, and $U(X_i)$ represents the subjective value or utility of that outcome. If we assume that the parenthesized values in the cells of Table 1 represent the traveler's utilities for the various consequences and if the probability of sun and rain are taken to be .6 and .4, respectively, we can compute the expected utility for each action as follows:

$$EU(A_1) = .6(+1) + .4(+1) = 1.0$$

$$EU(A_2) = .6(+2) + .4(0) = 1.2$$

In this situation, leaving the umbrella has greater expected utility than taking it along.

A major advance in decision theory came when von Neumann and Morgenstern (1947) developed a formal justification for the expected utility criterion. They showed that, if an individual's preferences satisfied certain basic axioms of rational behavior, then his decisions could be described as the maximization of expected utility. Savage (1954) later generalized the theory to allow the $P(E_i)$ values to represent subjective or personal probabilities.

Maximization of expected utility commands respect as a guideline for wise behavior because it is deduced from axiomatic principles that presumably would be accepted by any rational man. One such principle, that of transitivity, is usually defined on outcomes but applies equally well to actions or probabilities. It asserts that, if a decision maker prefers Outcome A to Outcome B and Outcome B to Outcome C, it would be irrational for him to prefer Outcome C to Outcome A. Any individual who is deliberately and systematically intransitive can be used as a "money pump." You can say to him: "I'll give you C. Now, for a penny, I'll take back C and give you B." Since he prefers B to C, he accepts. Next you offer to replace B with A for another penny and again he accepts. The cycle is completed by offering to replace A by C for another penny, he accepts and is 3¢ poorer, back where he started, and ready for another round.

A second important tenet of rationality, known as the extended sure-thing principle, states that, if an outcome X_i is the same for two risky actions, then the value of X_i should be disregarded in choosing between the two options. Another way to view this principle is that outcomes that are not affected by your choice should not influence your decision.

These two principles, combined with several others of technical importance, imply a rather powerful conclusion--namely that the wise decision maker chooses that act whose expected utility is greatest. To do otherwise would violate one or more of these basic tenets of rationality.

Applied decision theory assumes that the rational decision maker wishes to select an action that is logically consistent with his basic preferences for outcomes and his feelings about the likelihoods of the events upon which those outcomes depend. Given this assumption, the practical problem becomes one of listing the alternatives and scaling the subjective values of outcomes and their likelihoods so that subjective expected utility can be calculated for each alternative. Another problem in application arises from the fact that the range of theoretically possible alternatives is often quite large. In addition to carrying an umbrella, the risk-taking traveler in our earlier example may have the option of carrying a raincoat, getting a ride, waiting for the rain to stop, and numerous other actions. Likewise, the outcomes are considerably more complex than in our simple example. For example, the consequences of building a dam are multiple, involving effects on flood potential, hydroelectric power, recreation, the local ecology, etc. We shall discuss later some specific approaches that have been developed for dealing with the additional complexities of any real decision situation.

Descriptive Decision Theory and Bounded Rationality

Although the maximization theory described above grew primarily out of normative concerns, a good deal of debate and empirical research has centered around the question of whether this theory could also describe both the goals that motivate actual decision makers and the processes they employ when reaching their decisions. The leading critic of utility maximization as a descriptive theory has been Herbert Simon, who observed:

"The classical theory is a theory of a man choosing among fixed and known alternatives, to each of which is attached known consequences. But when perception and cognition intervene between the decision-maker and his objective environment, this model no longer proves adequate. We need a description of the choice process that recognizes that alternatives are not given but must be sought; and a description that takes into account the arduous task of determining what consequences will follow on each alternative [Simon, 1959; p.]."

As an alternative to the maximization hypothesis, Simon introduced the theory of "bounded rationality," which asserts that the cognitive limitations of the decision maker force him to construct a simplified model of the world in order to deal with it. The key principle of bounded rationality is the notion of "satisficing" whereby an organism strives to attain some satisfactory, though not necessarily maximal, level of achievement. Simon conjectured that, ". . . however adaptive the behavior of organisms in learning and choice situations, this adaptiveness falls far short of the ideal of 'maximizing' postulated in economic theory. Evidently organisms adapt well enough to 'satisfice'; they do not, in general, optimize [Simon, 1956; p. 129]."

The "behavioral theory of the firm" proposed by Cyert and March (1963) elaborated the workings of bounded rationality in business organizations. Cyert and March argued that to understand decision making in the firm we must recognize that there are multiple goals and we must understand the development of these goals, the manner in which the firm acts to satisfy them, and the procedures the firm employs to reduce uncertainty. They described how uncertainty is avoided by following fixed decision rules (standard operating procedures) whenever possible and reacting to short-run feedback rather than trying to forecast the future (which is too uncertain). Firms avoid the uncertainties of depending on other persons by negotiating implicit and

explicit arrangements with suppliers, competitors, and customers. A firm's search for new alternatives is triggered by a failure to satisfy one or more goals, thus it often takes a crisis to spur corrective action. Cyert and March claim this short-run behavior is adaptive, given the complexity of the environment and the decision maker's cognitive limitations.

At about the same time as Simon and Cyert and March were developing their ideas, Lindblom (1964) was coming to a similar conclusion on the basis of his analysis of governmental policy making. Lindblom argued that administrators avoid the difficult task of taking all important factors into consideration and weighing their relative merits and drawbacks comprehensively by employing what he calls "the method of successive limited comparisons." This method drastically simplifies decisions by comparing only those policies that differ in relatively small degree from policies already in effect. Thus, it is not necessary to undertake fundamental inquiry into an alternative and its consequences; one need study only those respects in which the proposed alternative and its consequences differ from the status quo. As an example, Lindblom cites the similarity between the major political parties in the United States. They agree on fundamentals and offer only a few small points of difference. Lindblom refers to this conservative method as "muddling through" and defends it as efficient and effective, although he admits that its use may cause good new policies to be overlooked or worse--never even formulated.

Just as Cyert and March's business firms act and react on the basis of short-term feedback, Lindblom's policy maker recognizes his inability to avoid error in predicting the consequences of policy moves and thus attempts to proceed through a succession of small changes, oriented towards remedying a negatively-perceived situation, rather than attaining a preconceived goal:

"His decision is only one step, one that if successful can quickly be followed by another. . . . he is in effect able to test his previous predictions as he moves on to each further step. Lastly, he often can remedy a past error fairly quickly--more quickly than if policy proceeded through distinct steps widely spaced in time [Lindblom, 1964; p. 166]."

Comparison of the Two Theories

Although utility theory is primarily normative in intent and bounded rationality has a descriptive character, this distinction is not completely accurate. There are those who argue that utility theory has some relevance for describing how decisions are actually made and, as we shall see later, the notion of bounded rationality has normative as well as descriptive implications.

From a descriptive standpoint, utility theory is concerned with probabilities, payoffs, and the merger of these factors--expectation. The problem of comparing the worth of one consequence with the worth of another consequence is faced directly by translating both into a common scale of utility. The theory of bounded rationality, on the other hand, postulates that decision makers do not think probabilistically and try to avoid the necessity of facing uncertainty directly. Likewise they avoid the problems of evaluating utilities and comparing incommensurable features. The goal of the decision maker is assumed to be the achievement of a satisfactory, rather than a maximum, outcome. Because he is constrained by limitations of perception and intelligence, the boundedly rational decision maker is forced to proceed by trial and error, modifying plans that don't yield satisfactory outcomes and maintaining those that do until they fail.

Bounded Rationality and Adjustment to Natural Hazards

Several lines of evidence illustrate the workings of bounded rationality in the context of adjustment to natural hazards. This evidence will be discussed

in the remainder of this section and in Section III.

Limited range of alternatives. It is clear that the resource manager never has available the full range of alternatives from which to make a decision (White, 1961, 1964, 1970). Local regulations or cultural traditions eliminate some alternatives from consideration and lack of awareness eliminates the others. Early studies of individual and public decisions regarding flood damage reduction, for example, revealed that the traditional choice for users of flood lands in the United States has been simply to bear the loss or construct engineering works to protect against flooding. Other adjustments such as structural changes in buildings and land-use changes were, until recently, practiced by relatively few managers and were typically ignored in public action.

Misperception of risks and denial of uncertainty. There is extensive data indicating that the risks of natural hazards are misjudged. For example, Burton and Kates (1964) pointed out that the estimates of hazards made by technical experts often fail to agree. As an illustration of this, they noted that three highly regarded methods of flood frequency analysis placed the long-run average return period of the largest flood on record in the Lehigh Valley as either 27, 45, or 75 years.

further

Misperception of hazards by resource users is/illustrated by an extensive study of flood perception by Kates (1962) who interviewed occupants of locations for which detailed records of flood occurrences were available. The major findings related to the difficulties these flood-plain dwellers had in interpreting the hazard within a probabilistic framework. Unlike the technical personnel who never entirely discounted the possibility of a flood recurring in a previously-flooded location, 84 out of 216 flood-plain dwellers indicated they did not expect to be flooded in the future.

Close examination of the residents' views illustrated several systematic mechanisms for dispelling uncertainty. The most common of these was to view floods as repetitive and even cyclical phenomena. In this way, the randomness that characterizes the occurrence of the hazard is replaced by a determinate order in which history is seen as repeating itself at regular intervals (Burton & Kates, 1964). Another common view was the "law of averages" approach, in which the occurrence of a severe flood in one year made it unlikely to recur the following year. Other occupants reduced uncertainty by means of various forms of denial. Some thought that new protective devices made them 100% safe. Others attributed previous floods to a freak combination of circumstances unlikely to ever recur. Still others denied that past events were floods, viewing them instead as "high water." Another mechanism was to deny the determinability of natural phenomena. For these people, all was in the hands of a higher power (God or the government). Thus, they did not need to trouble themselves with the problem of dealing with the uncertainty.

Crisis orientation. Just as Cyert and March's business firms and Lindblom's policy analysts appear to need direct experience with misfortune as a stimulus to action, so do resource managers. White (1945) observed: "National catastrophes have led to insistent demands for national action, and the timing of the legislative process has been set by the tempo of destructive floods [White, 1945; p.]." And Burton and Kates (1964) commented that, despite the self-image of the conservation movement as a conscious and rational attempt at long-range policy and planning, most of the major policy changes have arisen out of crises generated by catastrophic natural hazards. After interviewing flood-plain residents, Kates (1962) concluded that it is only in areas where elaborate adjustments have evolved

by repeated experiences that experience has been a teacher, rather than a prison. He added: "Floods need to be experienced, not only in magnitude, but in frequency as well. Without repeated experiences, the process whereby managers evolve emergency measures of coping with floods does not take place [Kates, 1962; p. 140]."

Individual vs. collective management. It is tempting to draw generalizations embracing individual managers, firms, and community organizations, but the evidence for doing so is slim. The situational factors are quite different and the methods of handling information may be different for individuals than for groups with corporate memories and organized analysis. Nevertheless, it appears that there are a number of parallels among the bounded rationality of business firms, the behavior of political policy makers, and the behavior of individuals with regard to the hazards in their environment. Specifically, decision makers in all these settings exhibit limited awareness of alternatives; they tend to misperceive probabilistic events and employ numerous mechanisms to reduce uncertainty and avoid dealing with it. Finally, they exhibit a short-run, crisis-oriented approach to adaptation.

III. Psychological Research: Further Evidence for Bounded Rationality

Thus far we have discussed evidence for a theory of bounded rationality within the contexts of business, policy making, and adjustment to natural hazards. In doing so, we have reviewed little that is new or that has not been reviewed by others. However, most of the evidence has been anecdotal in nature, coming from close observation of behavior and interviews in natural settings. Although this type of analysis has the benefit of realism and relevance, it lacks rigor. Moreover, most of

the evidence for bounded rationality in hazard adjustment comes from studies of flood-plain residents, and the generality of the conclusions to other types of hazards remains to be demonstrated. Current efforts are underway to extend the studies of floods in the United States to other cultures and to other hazards (Gilbert--please supply references). As the detailed analysis of that additional evidence about avalanches, droughts, earthquakes, frost, hail, hurricanes, snow, tornados, and volcanos begins, it is helpful to ask how the evidence from the field may be compared with that from the laboratory. This question is vital to understanding the complex processes by which man comes to terms with risk in nature, but it also has wider implications. It bears upon the degree to which experience with natural hazards can be extrapolated to other sectors of behavior. Should comparable evidence be obtained from laboratory and field research, the validity and importance of both endeavors will be enhanced.

In keeping with the above points, we shall now examine the recent psychological literature for evidence bearing upon man's limitations as a processor of information as it might relate to hazard adjustment. This work differs from that previously discussed in that it comes primarily from controlled, laboratory research. Also, its relevance to hazard adjustment has not been reviewed before. Although Burton and Kates (1964) contended that the artificiality of the laboratory seemed to provide only limited insights into decision strategies and the perception of probabilities, it is our belief that the results of many recent laboratory studies merge nicely with the observations of geographers in their field studies of flood-plain dwellers and help provide a more complete understanding of bounded rationality as it impinges upon adjustments to natural hazards.

The format to be followed in this section is as follows. First the psychological principles and data will be presented, followed by speculations about the relevance of this work for understanding adjustment to natural hazards. Wherever possible, evidence from field surveys of human response to natural hazards will be presented to further highlight the relevance and generality of these phenomena.

The research on information processing to be described below is organized around several basic issues of concern to a decision maker. First, he wonders what will happen or how likely it is to happen, and his use of information to answer these questions gets him involved in probabilistic tasks such as inference, prediction, probability estimation, and diagnosis. He must also evaluate the worth of objects or consequences, and this often requires him to combine information from several components into an overall judgment. Finally, he is called upon to integrate his opinions about probabilities and values into the selection of some course of action. What is referred to as "weighing risks against benefits" is an example of the latter combinatorial process.

Studies of Probabilistic Information Processing

As anyone who has ever planned a picnic understands, nature epitomizes uncertainty. Thus, it is no coincidence that the column headings of payoff matrices used to exemplify risk-taking decisions are typically labeled "states of nature." The uncertainties of natural hazards are compounded by the need to plan for periods of time far longer than those considered in other endeavors. The usual damaging flood in urban areas, for example, has a recurrence interval of 50-500 years.

Efficient adjustment to natural hazards demands an understanding of the probabilistic character of natural events and an ability to think in probab-

ilistic terms. Because of the importance of probabilistic reasoning to decision making in general, a great deal of recent experimental effort has been devoted to understanding how people perceive, process, and evaluate the probabilities of uncertain events. Although no systematic theory about the psychology of uncertainty has emerged from this literature, several empirical generalizations have been established. Perhaps the most general conclusion is that people do not follow the principles of probability theory in judging the likelihood of uncertain events. Indeed, the distortions of subjective probabilities are often large, consistent, and difficult to eliminate. Instead of applying the correct rules for estimating probabilities they replace the laws of chance by intuitive heuristics. These sometimes produce good estimates, but all too often yield large systematic biases. Given these findings, Kates' observations that individuals refuse to deal with natural hazards as probabilistic events are not surprising. To do otherwise may be beyond human cognitive abilities.

The law of small numbers. We shall begin our review of psychological research on subjective probability by describing a series of recent studies by Tversky and Kahneman (1971) who analyzed the kinds of decisions psychologists make when planning their scientific experiments. Despite extensive formal training in statistics, psychologists usually rely upon their educated intuitions when they make their decisions about how large a sample of data to collect or whether they should repeat an experiment to make sure their results are reliable.

After questioning a number of psychologists about their research practices and after studying the designs of experiments reported in psychological journals, Tversky and Kahneman concluded that these scientists had seriously incorrect notions about the amount of error and unreliability inherent in

small samples of data. They found that the typical psychologist gambles his research hypotheses on small samples without realizing that the odds against his obtaining accurate results are unreasonably high; second, he has undue confidence in early trends from the first few data points and in the stability of observed patterns of data. In addition, he has unreasonably high expectations about the replicability of statistically significant results. Finally, he rarely attributes a deviation of results from his expectations to sampling variability because he finds a causal explanation for any discrepancy.

Tversky and Kahneman summarized these results by asserting that people's intuitions seemed to satisfy a "law of small numbers," which means that the "law of large numbers" applies to small samples as well as to large ones. The "law of large numbers" says that very large samples will be highly representative of the population from which they are drawn. For the scientists in this study, small samples were also expected to be highly representative of the population. Since his acquaintance with logic or probability theory did not make the scientist any less susceptible to these cognitive biases, Tversky and Kahneman concluded that the only effective precaution is the use of formal statistical procedures; rather than intuition, to design experiments and evaluate data.²

In a related study, this time using Stanford University undergraduates as subjects, Kahneman and Tversky (1972a) found that many of these subjects did not understand the fundamental principle of sampling--namely, the notion that the error in a sample becomes smaller as the sample size gets larger. To illustrate, consider one of the questions used in this study.

²People are not always incautious when drawing inferences from samples of data. Under somewhat different circumstances they become quite conservative, responding as though data are much less diagnostic than they truly are (see Edwards, 1968).

"A certain town is served by two hospitals. In the larger hospital about 45 babies are born each day, and in the smaller hospital about 15 babies are born each day. As you know, about 50% of all babies are boys. The exact percentage of baby boys, however, varies from day to day. Sometimes it may be higher than 50%, sometimes lower.

"For a period of one year, each hospital recorded the days on which more than 60% of the babies born were boys. Which hospital do you think recorded more such days?

"Check one:

- a) The larger hospital _____
- b) The smaller hospital _____
- c) About the same (i.e.,
of days were within
5% of each other) _____."

About 24% of the subjects chose answer a, 20% chose b, and 56% selected c.

The correct answer is, of course, b. A deviation of 10% or more from the 50% proportion in the population is much more likely when the sample size is small.

From these and other results, Kahneman and Tversky concluded that "the notion that sampling variance decreases in proportion to sample size is apparently not part of man's repertoire of intuitions. . . . For anyone who would wish to view man as a reasonable intuitive statistician, such results are discouraging [pp. 444-445]."

What are the implications of this work for adjustment to natural hazards? We hypothesize that those in charge of collecting data for the purposes of making inferences about degree of hazard would fall prey to the same tendency to overgeneralize on the basis of small samples as do the research psychologists, unless they employ formal statistical procedures to hold their intuitions in check. Although it is common for scientists concerned with recurrence intervals of extreme natural events to lament

the short periods of recorded data, we suspect that once the computation is made, be it on the basis of data from 20 years or from 70 years, the results will be treated with equal confidence. One rather dramatic example of over-generalization on the basis of a ridiculously small amount of evidence is given by Burton and Kates (1964, p. 434), who describe how the occurrence of two earthquakes in London in 1750, exactly one lunar month apart (28 days), with the second more severe than the first, led to predictions that a third and more terrible earthquake would occur 28 days after the second. A contagious panic spread through the town and it was almost completely evacuated.

Perception of randomness. A number of experiments bear ample testimony to the fact that people have a very poor conception of randomness; they don't recognize it when they see it and they cannot produce it when they try (see, for example, Cohen & Hansel, 1966; Jarvik, 1951; and Chapanis, 1953). The latter conclusion is illustrated in a study by Bakan (1960) where subjects were asked to generate a series of outcomes representing the tosses of a coin. Subjects' sequences showed more alternation than would be expected in a truly random sequence. Thus, for triples of responses, HHH and TTT occurred less often than expected and alternating sequences such as HHT, TTH, HTH, and THT were produced too often. Ross and Levy (1958) found that subjects could not behave randomly even when warned of the types of biases to expect in their responses. The tendency to expect a tail to be more likely after a head or series of heads and vice versa is a common finding and is known as the negative recency effect. Others call it the gambler's fallacy. This basic result is found also in the views of some of the flood-plain residents interviewed by Kates (1962). These individuals believed that a flood was less likely to occur in year $x+1$ if one had occurred in year x .

Judgments of Correlation and Causality

Next, we wish to consider another important facet of intuitive thinking-- the perception of correlational relationships between pairs of variables that are related probabilistically. Correlation between two such variables implies that knowledge of one will help you to predict the value of the other, although perfect prediction may not be possible.

Chapman and Chapman (1969), studying a phenomenon they have labeled illusory correlation, have shown how one's prior expectations of probabilistic relationships can lead him to perceive these relationships in data where they do not really exist. They presented naive subjects with human figure drawings, each of which was paired with a statement about the personality of the patients who allegedly drew the figures. These statements were randomly paired with the figure drawings so that the figure cues were unrelated to the personality of the drawer. They found that most subjects learned to see what they expected to see. In fact, naive subjects discovered the same relationships between drawings and personality that expert clinicians report observing in clinical practice, although these relationships were absent in the experimental materials. The illusory correlates corresponded to commonly-held expectations, such as figures with big eyes being drawn by suspicious people, muscular figures being drawn by individuals who worried about their manliness, etc.

The Chapmans noted that in clinical practice the observer is reinforced in his observation of illusory correlates by the reports of his fellow clinicians, who themselves are subject to the same illusions. Such agreement among experts is, unfortunately, often mistaken as evidence for the truth of the observation. The Chapmans concluded that the clinician's cognitive task may exceed the capacity of the human intellect. They suggested that

subjective intuition may need to be replaced, at least partially, by statistical methods of prediction.

Will illusory correlation influence perceptions of natural hazards?

Remarks by Kates (1962; p. 141) suggest it may:

"For some managers, a belief that floods come in cycles reduces an uncertain world into a more predictable one. They might be expected to develop interpretive mechanisms that would enable them to transform any hazard information by selective abstraction into a buttress for their existing belief. Managers in LaFollette appear to do this with their observed experience and might find it even easier to do so with information conveyed by maps or printed word."

Several studies have investigated people's perceptions of correlation or causality in simple probabilistic situations involving two binary variables. Consider a 2×2 table of frequencies in which variable X is the antecedent or input variable and Y is the consequent or output variable (as shown in Table 2). The small letters are the frequencies with which the levels of these variables occur together, thus X_1 is followed by Y_1 on a occasions and it is followed by Y_2 on b occasions, etc.

Table 2

Frequency with Which Various Levels of Y Occur Jointly with Levels of X

		<u>output</u>	
		Y_1	Y_2
<u>input</u>	X_1	a	b
	X_2	c	d

A correlation exists between X and Y to the extent that the probability of Y_1 given X_1 differs from the probability of Y_1 given X_2 ; that is, to the extent that $a/a+b$ differs from $c/c+d$. In other words, if Y_1 is as likely to occur given X_2 as it is given X_1 , there is no correlation between X and Y . Causal

relationships can sometimes be inferred from tables such as these. If X_1 causes Y_1 , we would expect the occurrence of Y_1 to be more probable after X_1 had occurred than after X_2 had occurred, other considerations being equal.

Research indicates that subjects' judgments of correlation and causality are not based on a comparison of $a/(a + b)$ versus $c/(c + d)$. For example, Smedslund (1963) had students of nursing judge the relation between a symptom and the occurrence of a particular disease across a series of trials where the symptom was either present or absent and the disease was either present or absent. He found that the judgments were based mainly on the frequency of joint occurrence of symptom and disease (cell a in the matrix), without taking the frequency of the other three event combinations into account. As a result, the judgments were unrelated to statistical correlation. Similar results were obtained by Jenkins and Ward (1965) and by Ward and Jenkins (1965).

The tendency for people to misperceive the degree to which causation is present in a probabilistic environment has important implications for decisions regarding natural hazards. For example, Boyd, Howard, Matheson, and North (1971), in discussing the decision to modify a hurricane by cloud seeding, pointed out that observed changes in seeded hurricanes can result from both the effect of seeding and from the natural variability of the storm. Suppose that a seeded hurricane intensifies, changes course, and causes damage to a point not on the apparent trajectory before seeding. Would the public react to the joint occurrence of seeding and this unfortunate outcome by assuming that the seeding caused the unfortunate result? Would they conclude that meteorologists are irresponsible? The research described above strongly implies that the initiators of a cloud-seeding enterprise would be blamed for any unfavorable change in a hurricane, even though such changes would occur as frequently or even more frequently in the absence of human intervention.

As Boyd et al. indicated, the government must be prepared to be held liable for damages occurring from a seeded hurricane and this possibility must be weighed carefully in their decisions concerning the general feasibility of hurricane modification programs. This clearly is a situation in which it will be imperative to educate the public on the uncertainty involved in such circumstances, lest a bad outcome be equated with a bad decision.

Judgment of probability by availability. Tversky and Kahneman (1973a) have proposed that people estimate probability and frequency by a number of heuristics or mental strategies which allow them to reduce these difficult tasks to simpler judgments. One such heuristic is that of availability, according to which one judges the probability of an event (e.g., snow in November) by the ease with which relevant instances are imagined or by the number of such instances that are readily retrieved from memory. Our everyday experience has taught us that instances of frequent events are easier to recall than instances of less frequent events and that likely occurrences are easier to imagine than unlikely ones, thus mental availability will often be a valid cue for the assessment of frequency and probability. However, availability is also affected by recency, emotional saliency and other subtle factors, which may be unrelated to actual frequency. If the availability heuristic is applied, then factors that increase the availability of instances should correspondingly increase the perceived frequency and subjective probability of the events under consideration. Thus, use of the availability heuristic results in predictable systematic biases in judgment.

Consider, for example, sampling a word (containing three or more letters) from an English text. Is it more likely that the word starts with a "k," or that it has a "k" in the third position? To answer such a question, people often try to think of words beginning with a "k" (e.g., key) and

words that have a "k" in third position (e.g., like), and then compare the frequency or the ease with which the two types of words come to mind. It is easier to think of words that start with a "k" than of words with a "k" in the third position. As a result, the majority of people judge the former event more likely despite the fact that English text contains about twice as many words with a "k" in the third position. This example and many other experiments are presented by Tversky and Kahneman to document the pervasive effects of availability.

The notion of availability is potentially one of the most important ideas for helping us understand the distortions likely to occur in our perceptions of natural hazards. For example, Kates (1962) writes:

"A major limitation to human ability to use improved flood hazard information is a basic reliance on experience. Men on flood plains appear to be very much prisoners of their experience. . . . Recently experienced floods appear to set an upward bound to the size of loss with which managers believe they ought to be concerned [p. 140]."

Kates further attributes much of the difficulty in achieving better flood control to the "inability of individuals to conceptualize floods that have never occurred [p. 92]." He observed that, in making forecasts of future flood potential, individuals "are strongly conditioned by their immediate past and limit their extrapolation to simplified constructs, seeing the future as a mirror of that past [p. 88]." In this regard, it is interesting to observe how the purchase of earthquake insurance increases sharply after a quake but decreases steadily thereafter, as the memories become less vivid (Steinbrugge, McClure, & Snow, 1969).

Some hazards may be inherently more memorable than others. For example, one would expect drought, with its gradual onset and offset, to be much less memorable, and thus less accurately perceived, than flooding. Kirkby (1972) provides some evidence for this hypothesis in her study of Oaxacan farmers.

Kirkby also found that memory of salient natural events seems to begin with an extreme event, which effectively blots out recall of earlier events and acts as a fixed point against which to calibrate later points. A similar result was obtained by Parra (1971), studying farmers in the Yucatan. Parra found that perception of a lesser drought was obscured if it had been followed by a more severe drought. He also observed that droughts were perceived as greater in severity if they were recent and thus easier to remember.

Natural catastrophes are typically rare events. For example, Holmes (1961) found that 50% of the damage due to major floods was caused by floods whose probability of occurrence at that place in any year was less than .01. The city of Skopje was leveled by earthquake in 518 AD, 1555, and 1963. The mudflow that took 25,000 lives in Yungay, Peru, had similarly swept across the valley between 1,000 and 10,000 years previously. Adequate decision making regarding natural hazards obviously requires a realistic appreciation of the likelihood of these rare events yet such appreciation is likely to be especially sensitive to the effects of availability. For example, ease of imagination almost certainly plays an important role in the public's perception of the risks of injury and death from attack by a grizzly bear in the national parks of North America. In view of the widespread public concern over the dangerousness of these bears, it is indeed surprising that the rate of injury is only 1 per 2 million visitors and the rate of death is even smaller (Herrero, 1970). Imaginability of death at the claws of an enraged grizzly is heightened by newspaper stories and movies which portray only attacks, while the multitude of favorable public experiences go unpublicized.

The availability hypothesis implies that any factor which makes a hazard highly memorable or imaginable--such as a recent disaster or a vivid film

or lecture--could considerably increase the perceived risk of that hazard. The Tennessee Valley Authority (TVA) apparently recognizes this, at least at an intuitive level. Kates (1962) noted that the TVA goes to considerable lengths to try to bring home the graphic reality of potential floods. It plots potential floods on easily read maps, and shows flood heights on photographs of familiar buildings. In a similar vein, a recent film entitled "The City that Waits to Die" depicts the vast death and destruction that would occur in San Francisco's next major earthquake. The film was promoted by a group attempting to prohibit the building of new skyscrapers in the city but was initially banned from public showings. As Kates noted, there is a great need for well-designed studies investigating the effects of such graphic presentations on hazard perception. A decade after Kates' remarks, the need remains unmet.

One additional comment on availability seems warranted. Subtle changes in an individual's mental set are likely to alter the images and memories he brings to bear on the evaluation of hazard, with profound influence on his judgments. For example, an analyst who attempts to evaluate the likelihood of a flood of given magnitude may do so by recalling hydrologic conditions similar to those of the present or by recalling previous floods. The latter are easier to remember because they are more sharply defined, whereas hydrologic states are more difficult to characterize and, therefore, harder to recall. The resulting probability estimate is likely to be greatly dependent upon which of these two sets the analyst adopts. Even the form of the question may be important. Consider the following questions:

- a) "How likely is it that there will be flood this season?"
- b) "How likely is it that, given the present hydrologic state, there will be a flood this season?"

The first question may focus attention on past instances of flood, whereas the latter may cause the analyst to think about previous hydrologic conditions. In many instances, the answers to these two questions might be quite different.

Dominance of individuating information in intuitive prediction. A second general heuristic for making judgments about uncertain events is a rather complex device which Kahneman and Tversky (1972a, 1972b) have called representativeness. Although representativeness manifests itself in many judgmental settings, we shall consider here its expression in problems of intuitive prediction as studied by Kahneman and Tversky (1972b). One problem was to judge the likelihood that an individual, Tom W., is a graduate student in a particular field of specialization. The judges in this study were all graduate students in psychology. The only information they had available to them was the following brief description written several years earlier by a psychologist on the basis of some projective tests:

"Tom W. is of high intelligence, although lacking in true creativity. He has a need for order and clarity, and for neat and tidy systems in which every detail finds its appropriate place. His writing is rather dull and mechanical, occasionally enlivened by somewhat corny puns and by flashes of imagination of the sci-fi type. He has a strong drive for competence. He seems to have little feel and little sympathy for other people, and does not enjoy interacting with others. Self-centered, he nonetheless has a deep moral sense.

"Tom W. is currently a graduate student. Please rank the following nine fields of graduate specialization in order of the likelihood that Tom W. is now a student in that field. Let rank 1 be the most probable choice."

- _____ Business Administration
- _____ Computer Sciences
- _____ Engineering
- _____ Humanities and Education
- _____ Law
- _____ Library Sciences
- _____ Medicine
- _____ Physical and Life Sciences
- _____ Social Science and Social Work

In this particular study, the representativeness hypothesis predicted that people should rank the graduate programs on the basis of the similarity between the brief description and a typical student in each program. This is exactly what happened. Ratings of similarity and ratings of likelihood coincided almost exactly. What was remarkable here was that the a priori probabilities, as determined by the base rates of enrollment for these graduate programs, had no influence whatsoever upon the judgments. Computer Sciences and Engineering were judged to be the most probable fields for Tom W., even though these fields have relatively few students in them. This is especially surprising considering the fact that the judges recognized the thumbnail personality sketch as having little or no validity. In addition, all of these judges had statistical training and they made their predictions according to the a priori probabilities (base rates) in a condition where no other information was provided. The important result here is the apparent inability of subjects to integrate the similarity ordering with the a priori probabilities in a situation where the latter should have been predominant. In other words, the judges knew the description was of low validity and they knew that the a priori probabilities of the graduate specialties differed, yet they were unable to put this knowledge into practice. As a result, their judgments did not properly reflect their underlying beliefs.

Additional experiments by Kahneman and Tversky have shown that, even when statistical base rates are made explicit, they have considerably less influence on intuitive predictions than does individuating information. The importance of this work merits another example. Consider the following "jury" question given by Kahneman and Tversky to a group of college students.

"Two cab companies, the Blue and the Green, operate in a given city. 85% of the cabs in the city are Blue and the remaining 15% are green.

"A cab was involved in a hit-and-run accident at night. A witness identified the cab as a Green cab. The court tested his ability to distinguish a Blue cab from a Green cab at night and found that he was able to make a correct identification in 4 out of 5 tries.

"What is your opinion about the probability that a Green cab was involved in the accident?"

Any valid approach to answering this question should merge the statistical base rates (85% Blue, 15% Green) with the evidence concerning the reliability of the witness. The former implies odds of 5.67 to 1 that the cab was Blue; the latter implies odds of 4:1 that it was Green. If these two sources of information are independent, they jointly imply odds of about 5.67 to 4 that the cab was Blue. This translates to a .63 probability of Blue and a .37 probability of Green. The median response given by the subjects was .80 probability of Green; thus they were not moved by the statistical base rate. The reader who finds himself compelled to agree that the reliability of the witness is the salient factor and the base rate is irrelevant should consider what his response to this question would be were all cabs in the city Blue.

This research implies that people may readily ignore or discount historical data regarding the frequencies of natural disasters in their area, relying instead on information specific to an individual setting, no matter how tenuous this information is. Thus we would expect that the casual reassurance of a neighbor to the effect that "sure this town has floods but, as I recall, they haven't been very severe" may have a stronger effect on the judgment of a prospective home builder than a detailed flood frequency map. The neighbor's comment is "representative" of a safe situation. The statistical data, on the other hand, applies to nothing in particular. What relevance could it have?

Anchoring and adjustment in quantifying uncertainty. Another heuristic that seems useful in describing how humans ease the strain of integrating information is a process called anchoring and adjustment. In this process, a natural starting point is used as a first approximation to the judgment, an anchor, so to speak. This anchor is then adjusted to accommodate the implications of the additional information. Typically, the adjustment is a crude and imprecise one which fails to do justice to the importance of additional information.

Application of the anchoring and adjustment heuristic is hypothesized to produce an interesting bias that occurs when people attempt to calibrate the degree to which they are uncertain about an estimate or prediction. Specifically, in studies by Alpert and Raiffa (1968) and Tversky and Kahneman (1973b), subjects were given almanac questions such as the following:

"How many foreign cars were imported into the U.S. in 1968?

- (a) Make a high estimate such that you feel there is only a 1% probability the true answer would exceed your estimate.
- (b) Make a low estimate such that you feel there is only a 1% probability the true answer would be below this estimate."

In essence, the subject is being asked to estimate an interval such that he believes there is a 98% chance that the true answer will fall within that interval. The spacing between his high and low estimates is his expression of his uncertainty about the quantity in question. We cannot say that this single pair of estimates is right or wrong. However, if he were to make many such estimates or if a large number of persons were to answer this question, we should expect the range between upper and lower estimates to include the truth about 98% of the time--if the subjective probabilities

were unbiased. What is typically found, however, by Alpert and Raiffa and by Tversky and Kahneman, is that the 98% confidence range fails to include the true value from 40% to 50% of the time, across many subjects answering many kinds of almanac questions. In other words, subjects' confidence bands are much too narrow, given their state of knowledge. Alpert and Raiffa observed that this bias persisted even when subjects were given feedback about their overly-narrow confidence bands and urged to widen the bands on a new set of estimation problems.

These studies indicate that people believe they have a much better picture of the truth than they really do. Why this happens is not entirely clear. Tversky and Kahneman tentatively hypothesize that people approach these problems by searching for a calculational scheme or algorithm by which to estimate a best guess which they then adjust up and down to get a 98% confidence range. For example, in answering the above question, one might proceed as follows:

"I think there were about 180 million people in the U.S. in 1968; there is about one car for every three people thus there would have been about 60 million cars; the lifetime of a car is about 10 years, this suggests that there should be about 6 million new cars in a year but since the population and the number of cars is increasing let's make that 9 million for 1968; foreign cars make up about 10% of the U.S. market, thus there were probably about 900,000 foreign imports; to set my 98% confidence band, I'll add and subtract a few hundred thousand cars from my estimate of 900,000."

Tversky and Kahneman argue that people's estimates assume that their computational algorithms are 100% correct. However, there are two sources of uncertainty that plague these algorithms. First, there is uncertainty associated with every step in the algorithm and there is uncertainty about the algorithm itself. That is, the whole calculational scheme may be incorrect.

It is apparently quite difficult to carry along these several sources of uncertainty and translate them intuitively into a confidence band. Once the "best guess" is arrived at as an anchor (e.g., the 900,000 figure above), the adjustments are insufficient in magnitude, failing to do justice to the many ways in which this estimate could be in error.

The research just described implies that our estimates may be grossly in error--even when we attempt to acknowledge our uncertainty. This may have profound implications for many kinds of judgments about the risks associated with natural hazards or the benefits of plans for coping with those hazards. It is likely, for example, that an individual's intuitive estimates of the size of a flood that would be exceeded only one time in one hundred will be conservative (i.e., too close to his estimate of the "most likely" flood magnitude) and he thus would allow too small a margin of safety in his protective adjustments.

Problems in Integrating Information from Multiple Sources

Thus far, our review of laboratory research has been concerned with the assessment of risks and estimation of uncertain quantities. At this point, we would like to turn to a somewhat different problem. Suppose that we have good information about both risks and benefits. How capable is the decision maker of balancing these several factors and coming up with an optimal decision? By optimal, we don't mean a decision that will, necessarily, turn out well. Some good decisions work out poorly and vice versa. We're thinking of optimal decisions in the sense that such decisions faithfully reflect the decision maker's personal values and opinions.

Information processing biases in risk-taking judgments. As if we didn't have enough problems with our tendencies to bias probability judgments, there

is some evidence to the effect that difficulties in integrating information may often lead people to make judgments that are inconsistent with their underlying values. An example of this within a risk-benefit context comes from two experiments (Lichtenstein & Slovic, 1971, 1972), one of which was conducted on the floor of the Four Queens Casino in Las Vegas. Consider the following pair of gambles used in the Las Vegas experiment:

Bet A

11/12 chance to win 12 chips

1/12 chance to win 24 chips

Bet B

2/12 chance to win 79 chips

10/12 chance to lose 5 chips

where each chip could represent either 10¢, 25¢, \$1, or \$5.

Notice that Bet A has a much better chance of winning but Bet B offers a higher winning payoff. Subjects were shown many such pairs of bets. They were asked to indicate, in two ways, how much they would like to play each bet in a pair. First they made a simple choice, A or B. Later they were asked to assume they owned a ticket to play each bet, and they were to state the lowest price for which they would sell this ticket.

Presumably these selling prices and choices are both governed by the same underlying quality, the subjective attractiveness of each gamble. Therefore, the subject should state a higher selling price for the gamble that he prefers in the choice situation. However, the results indicated that subjects often chose one gamble, yet stated a higher selling price for the other gamble. For the particular pair of gambles shown above, Bets A and B were chosen about equally often. However, Bet B received a higher selling price about 88% of the time. Of the subjects who chose Bet A, 87% gave a higher selling price to Bet B, thus exhibiting an inconsistent preference pattern.

What accounts for the inconsistent pattern of preferences among almost half the subjects? Lichtenstein and Slovic have traced it to the fact that

subjects use different cognitive strategies for setting prices than for making choices. Subjects choose Bet A because of its good odds, but they set a higher price for B because of its large winning payoff. Specifically, it was found that, when making pricing judgments, people who find a gamble basically attractive use the amount to win as a natural starting point. They then adjust the amount to win downward to take into account the less-than-perfect chance of winning and the fact that there is some amount to lose as well. Typically, this adjustment is insufficient and that is why large winning payoffs lead people to set prices that are inconsistent with their choices. Because the pricing and choice responses are inconsistent, it is obvious that at least one of these responses does not accurately reflect what the decision maker believes to be the most important attribute in a gamble.

A "compatibility" effect seems to be operating here. Since a selling price is expressed in terms of monetary units, subjects apparently found it easier to use the monetary aspects of the gamble to produce this type of response. Such a bias did not exist with the choices, since each attribute of one gamble could be directly compared with the same attribute of the other gamble. With no reason to use payoffs as a starting point, subjects were free to use any number of strategies to determine their choices.

Compatibility bias. The overdependence on payoff cues when pricing a gamble suggests a general hypothesis to the effect that the compatibility or commensurability between a dimension of information and the required response affects the importance of that information in determining the response. This hypothesis was tested further in an experiment by Slovic and MacPhillamy (1971), who predicted that dimensions common to each alternative in a choice situation would have greater influence upon decisions than would dimensions that were

unique to a particular alternative. They asked subjects to compare pairs of students and predict which would get the higher college Grade Point Average. The subjects were given each student's scores on two cue dimensions (tests) on which to base their judgments. One dimension was common to both students and the other was unique. For example, Student A might be described in terms of his scores on Need for Achievement and Quantitative Ability, while Student B might be described by his scores on Need for Achievement and English Skill.

In this example, since Need for Achievement is a dimension common to both students, it should be weighted particularly heavily. The rationale for this prediction is as follows: The main source of cognitive effort here arises from the fact that the cues may vary in importance or relevance and must be weighted differentially. If Student A has a higher score on English than does Student B, this has a clear-cut implication for the relative standing of A and B on the GPA criterion--namely, that A will exceed B. But what about the other cues? How does the implication of Student A's standing on Need for Achievement compare with the implication of B's standing on Quantitative Ability and with the implication of the information about English? These are the sorts of questions the judge must resolve in order to integrate all of the cues; the judge must consider not just the standing of each student on the various cue dimensions, but the relative importance of each dimension. A comparison between two students along the same dimension should be easier, cognitively, than a comparison between different dimensions, and this ease of use should lead to greater reliance on the common dimension. The data strongly confirmed this hypothesis. Dimensions were weighted more heavily when common than when they were unique. Interrogation of the subjects after the experiment indicated that most did not wish to give more weight to the common dimension and were unaware that they had done so.

The message in these experiments is that the amalgamation of different types of information and different types of values into an overall judgment or decision is a difficult cognitive process and, in our attempts to ease the strain of processing information, we often resort to judgmental strategies that may do an injustice to our underlying values. In other words, even when the risks and benefits are known and made explicit, as in the gambling situation, subtle aspects of the decision we have to make, acting in combination with our intellectual limitations, may bias the balance we strike between these considerations.

Relevance to decisions regarding natural hazards. The research described above suggests that simplified strategies for easing the strain of making decisions about natural hazards may be used by experts and laymen alike. Although this hypothesis has not been studied systematically, a few relevant examples exist. Perhaps the simplest way to minimize the strain of integrating information is to avoid making decisions. Kates (1962) found that many flood-plain managers wanted to abdicate their responsibilities and leave the decision making to the experts. White (1966) noted that, when attention turned to the possibility of setting aside flood plains for open space, some municipalities adopted the blanket policy of buying up valley bottoms for recreational use without even attempting to weigh the alternatives in any given instance. And Kates (1962) observed that three structures in different sites in a town were each elevated by one foot, despite a wide variation in hazard among the sites. One foot is a convenient number and these decisions suggest that a crude approximation rule was used to determine the elevation changes, much as such approximations were used in the risk-taking studies described above. One wonders also about the depth of analysis that led to the selection of the "100-year flood" as a standard criterion in the design of

flood-protection structures.³

Even technical persons, whose job is to aid the decision-making process, can be accused of grossly oversimplified use of information. Their chief tool, cost-benefit analysis, has focused primarily on the dollar values of various adjustments, presumably because these are readily measured and commensurable. The tendency is to ignore non-economic considerations such as aesthetic and recreational values, or the emotional costs of leaving friends and familiar surroundings when moving to a less hazardous location.

One mechanism that is useful for bringing disparate considerations to bear upon a decision without actually attempting to make them commensurable is to employ a lexicographic decision rule in which one dimension of information is considered at a time. The most important dimension is considered first. Only if this first dimension does not lead to a clearly preferred alternative is the next most important dimension considered. An example of lexicographic behavior in the laboratory that led people to be systematically intransitive in their preferences is presented by Tversky (1969). A natural hazards example is provided in a study of how people, drawing water for household use in a rural area, choose among alternative sources (White, Bradley, & White, 1972). It was found that the users classified the sources

³It is interesting to compare these observations with another example of how simplistic thinking can influence even the most important decisions. With regard to the decision to place a 1.0 megaton nuclear warhead atop the first Atlas missile, physicist Herbert York commented:

". . .why 1.0 megaton? The answer is because and only because one million is a particularly round number in our culture. We picked a one-megaton yield for the Atlas warhead for the same reason that everyone speaks of rich men as being millionaires and never as being tenmillionaires or one-hundred-thousandaires. It really was that mystical, and I was one of the mystics. Thus, the actual physical size of the first Atlas warhead and the number of people it would kill were determined by the fact that human beings have two hands with five fingers each and therefore count by tens [York, 1970; pp. 89-90]."

as good or bad solely on the basis of health effects. If more than one source was satisfactory on this primary dimension, the remaining "good" sources were then discriminated on the basis of the economic costs of transporting the water. There was little indication that they were willing to "trade off" lower-quality water with accompanying health hazard for lower economic costs. The two dimensions were simply not compensatory.

Another non-compensatory mode of processing diverse dimensions of information is to set a criterion level on one or more of these dimensions. Alternatives that do not promise to meet that criterion are rejected. For those alternatives that remain, another dimension can then be employed as a basis for discrimination. This sort of mechanism has been observed in a laboratory study of risk taking by Lichtenstein, Slovic, and Zink (1969). A natural-hazards example is given by Kunreuther (1972), who hypothesized that peasant farmers seek reasonable assurance of survival when deciding how to allocate their resources among crops varying in risk and expected yield. Only for those allocation plans in which survival needs are likely to be met is it likely that maximizing expected yield becomes a consideration. What happens when none of the alternatives meet all of the decision maker's requirements? Something must be sacrificed, and Kunreuther (1973) hypothesizes that this occurs by means of a lexicographic process whereby the decision maker proceeds sequentially, trying always to satisfy his more important goals while relaxing those of lesser importance. Kunreuther again uses a crop-allocation decision in the face of natural disasters to illustrate the process.

Investigating Bounded Rationality in Field Settings

On the preceding pages we have described a number of aspects of bounded rationality that have been demonstrated in laboratory experiments. Some of

the results have close parallel with findings from field studies of flood-plain residents. However, most field work has not been oriented towards cognitive processes, and, therefore, has not provided data relevant to the phenomena described above. We believe it would be profitable to look for illustrations of bounded rationality in future field surveys, much as one would examine personality, cultural, or institutional influences upon behavior in the face of natural disaster. The following serves as an overview of the preceding section and a brief guide to the kinds of phenomena one might wish to examine in the field.

a. The law of small numbers. Do individuals overgeneralize on the basis of small samples of evidence? Do they fail to discriminate between short and long periods of record when evaluating evidence or making decisions? Do they take conclusions on faith without questioning the amount of data upon which those conclusions were based?

b. Judgments of causality and correlation. Do people attribute a bad outcome to a bad decision and a good outcome to a good decision? Do they interpret evidence as supporting a preconceived hypothesis when it does not (illusory correlation)? That is, do they perceive relationships that they expected to see in the data, even when these relationships are not present?

c. Availability. Do factors of imaginability or memorability influence perception of hazards or actions regarding the hazard? Does rephrasing a question about hazard likelihood to influence memorability also influence the answer? Do vivid films, lectures, or newspaper articles influence perception of rare events? Hazards differ in characteristics that may affect their memorability or imaginability. Some have more sudden onset and offset than others. Duration varies. Contrast a flash flood, for example, with a drought. Do these characteristics systematically affect perception of the

hazard? Are people prisoners of their experience, seeing the future as a mirror of the past? Do they predict the future by describing the past?

d. Dominance of individuating information. Does information particular to an individual's personal situation, no matter how tenuous or unproven its relevance, take precedence over historical or statistical records that apply to groups of such individuals, in determining one's perceptions of hazard? Do individuals believe that statistical data does not apply to their particular circumstances?

e. Anchoring and insufficient adjustment. Do individuals use simple starting-point and adjustment mechanisms when making estimates about quantities? When they attempt to calibrate their uncertainty by placing confidence bounds on their estimates, are those bounds too narrow, thus resulting in rare events occurring more often than they were expected to occur?

f. Information-processing shortcuts. Is there evidence for simple decision strategies that avoid weighing of multiple considerations? Do people avoid decision making by relying on experts, authority, fate, custom, etc.? Is there evidence for lexicographic processes or other non-compensatory decision modes in the evaluation of adjustments?

g. Additional needs for research. Finally, there are a number of important situational factors about which we have neither laboratory nor field data. For example, we need to better understand the effects of savings and reserves, time horizon, and amount of diversification upon perception of alternatives and efficiency of adjustment. Will larger amounts of reserves make it more likely that an individual will consider alternatives that have greater risk but also greater expected payoffs? Similarly, will diversification of farming activity reduce the risk of failing to meet one's goals of subsistence and thus permit the farmer to consider risky but profitable alternatives?

We need to know more about the condition of decision as it affects behavior. Will individuals become aware of a wider range of perceived alternatives if they are required to make a decision with respect to a given risk as opposed to conditions where the decision is voluntary?

Finally, we need theoretical models of boundedly rational behavior which, from reasonable assumptions about the constraints pertinent to a given natural-hazards decision, yield testable hypotheses about the effects of income reserves, insurance, time horizon, etc., upon factors such as range of perceived alternatives, criteria for choice, and level of aspiration.

Comment

The experimental work described in this section documents man's difficulties in weighing information and judging uncertainty. Yet this work is quite recent in origin and still very much in the exploratory stage. In addition, its implications do not fit with the high level of confidence that we typically accord our higher mental processes. Consider, for example, the statement by a famed economist to the effect that "We are so built that what seems reasonable to us is likely to be confirmed by experience or we could not live in the world at all [Knight, 1965, p. 227]." Since the laboratory results greatly contradict our self-image, it is reasonable to question whether the observed information-processing difficulties will persist outside the confines of the laboratory in situations where the decision maker uses familiar sources of information to make decisions that are personally important to him. In light of this natural skepticism and since our coverage of the psychological experiments was necessarily rather brief, we should like to point out that evidence for cognitive limitations pervades a wide variety of tasks, where intelligent individuals served as decision makers, often under conditions

designed to maximize motivation and involvement. For example, the subjects studied by Tversky and Kahneman (1971) were scientists, highly trained in statistics, evaluating problems similar to those they faced in their work. Likewise, Alpert and Raiffa (1968) found it extremely difficult to reduce the biased confidence judgments in their subjects, who were students in the advanced management program at a leading graduate school. In many of the experiments reported above, extreme measures were taken to maximize the subjects' motivation to be unbiased. When Lichtenstein and Slovic (1971) observed inconsistent patterns of choices and prices among college student subjects gambling for relatively small stakes, they repeated the study, with identical results, on the floor of a Las Vegas casino. It should also be noted that their experiments involving selling-price responses employed a rather elaborate procedure devised by Becker, De Groot, and Marschak (1964) to persuade the subject to report his true subjective value of the bet as his lowest selling price; any deviations from this strategy, any efforts to "beat the game," necessarily resulted in a game of lesser value to the subject than the game resulting when he honestly reported his subjective valuations. Tversky and Kahneman have also resorted to extreme measures to motivate their subjects to behave in an unbiased manner. Finally, the laboratory conclusions are congruent with many observations of non-optimal decision making outside the laboratory--in business, governmental policy setting, and in adjustment to natural hazards. The belief that man can behave optimally when it is worthwhile for him to do so gains little support from these studies. The sources of judgmental bias appear to be cognitive, not motivational. They have a persistent quality not unlike that of perceptual illusions.

It is interesting to speculate about why we have such great confidence in our intuitive judgments, in the light of the deficiencies that emerge when

they are exposed to scientific scrutiny. For one thing, our basic perceptual motor skills are remarkably good, the product of a long period of evolution, and thus we can process sensory information with remarkable ease. This may fool us into thinking that we can process conceptual information with similar facility. Anyone who tries to predict where a baseball will land by calculating its impact against the bat, trajectory of flight, etc., will quickly realize that his analytic skills are inferior to his perceptual-motor abilities. Another reason for our confidence is that the world is structured in such a complex, multiply-determined way that we can usually find some reason for our failures, other than our inherent inadequacies--bad luck is a particularly good excuse in a probabilistic world. In many situations, we get little or no feedback about the results of our decisions and, in other instances, the criterion for judging our decisions is sufficiently vague that we can't tell how poorly we are actually doing. Finally, when we do make a mistake and recognize it as such, we often have the opportunity to take corrective action--thus we may move from crisis to crisis but, in between crises, we have periods of fairly effective functioning. When we have the opportunity to learn from our mistakes, and can afford to do so, this may be a satisfactory method of proceeding. When we cannot, we must look towards whatever decision aids are available to help us minimize errors of judgment.

IV. Implications for Future Policy: How Can We Improve Adjustment to Natural Hazards?

Research, in both natural and laboratory settings, strongly supports the view of decision processes as boundedly rational. Given this awareness of our cognitive limitations, how are we to maximize our capability for making intelligent decisions about natural hazards?

We shall discuss briefly two approaches to answering this question. The first is primarily non-analytic in character and works within the framework of bounded rationality. The second is an analytic approach that accepts the notion that human beings are fallible in processing information, but strives to help them come as close as possible to an ideal conception of rational decision making.

Implications of Bounded Rationality

Knowledge of the workings of bounded rationality forms a basis for understanding constraints on decision making and suggests methods for helping the decision maker improve as an adapting system. For example, Cyert and March (1963) describe how policy inputs can trigger a search for new alternatives by introducing constraints which make old habits of adjustment unacceptable. Within the context of business decision making, Cyert and March point to three ways in which the firm's decision-making behavior can be altered via policy changes. The first changes the inputs to standard decision rules as exemplified by changes in the product specifications or work regulations. The second use of policy is to force a failure in meeting some valued goal by setting explicit constraints on costs, prices, profits, or the like. The third use of policy is to modify the consequences of potential solutions to problems to enhance the attractiveness of solutions that would otherwise be unacceptable.

How might we apply knowledge of bounded rationality to improving adjustment to natural hazards? Consider two key aspects of the problem--the need to make the decision maker's perceptions of the hazard more accurate and the need to make him aware of a more complete set of alternative courses of action.

In order to improve probabilistic perception of hazards, it is essential that complete historical records be kept, analyzed, and made available in understandable form to all resource managers. Technical experts should be taught how to express hazards probabilistically and their opinions should be made available in a format which attempts to be comprehensible to individuals not particularly skilled in probabilistic thinking. Records should be continually updated and, when a new development occurs that might render the historical data invalid, the technical expert should estimate the effect of this change on the hazard.

There has been a small amount of experimentation with physical formats for expressing probabilities of natural extremes: the US Geological Survey and the Corps of Engineers have tried several ways of presenting flood frequencies, including historical summaries, graphs of recurrent intervals, eye-witness accounts, photographs, and maps. However, there has been no serious effort to find out what effect, if any, the different formats have upon understanding of the probability. Perhaps the only relatively searching attempt has been in connection with public interpretation of weather forecasts which use probability estimates (Murphy & Winkler, 1971).

Of course, given our limited ability to comprehend probabilistic information, imaginative presentations of records may not be enough. Creative new devices will be necessary to facilitate imaginability and to break through the "prison of experience" that shackles probabilistic thinking. One procedure worth exploration is that of informing decision makers of the biases that are likely to distort their interpretation and use of information. Another device is simulation, which might be particularly effective in conveying an appreciation of sampling variability and probabilities. Consider the important practical situation where a farmer in a frequently

drought-stricken area must decide whether or not to plant drought-resistant corn. Such corn will provide greater yield than regular corn if a drought occurs, but will do worse in the event of normal rainfall. The farmer can be shown an historical record of rainfall for the past 50 years, but from what we know of the Tversky and Kahneman experiments and geographical surveys by Kates, it is unlikely that he will be able to use this information properly. The farmer's problem is increased by the difficulty of taking into account the utilities of various yields as well as their probabilities. It is here that simulation might be particularly valuable. A farming game could give the decision maker realistic and appropriate experience with this type of decision and its consequences. The farmer would begin with a specific amount of cash. In year 1 he would make the decision of what percent of his corn crop to plant with drought-resistant seed. Nature would run its course and the farmer would receive an appropriate bounty. Our subject would be playing against nature and quickly gaining experience that would ordinarily accrue only over many years. Simulations such as this have already been introduced as teaching aids in high school and college geography courses (Patton, 1970; High & Richards, 1972). Kates (1962; p. 140) observed that "Without frequent experience, learned adjustments wither and atrophy with time." Simulation might be a quick and painless way to provide the concrete experiences needed to produce adjustments that are maximally adaptive.

With regard to widening the range of perceived alternatives, several possibilities exist. For example, since we know that perception is typically incomplete, we can take special measures to inform resource managers of the range of available options. Although there have been frequent pleas for encouraging people to consider a wider range of alternatives in coping with hazards (NAS-NRC, 1966; WRC, 1972) the means of doing so have been explored only casually.

Thus, the National Environmental Protection Act of 1969 specifies that environmental impact statements shall indicate alternative measures for resource allocation, without indicating how this will be done. The principal measures now being tried are survey reports, public hearings, public discussions, and informational brochures. With the exception of the studies of Corps of Engineers' public consultations (Borton et al., 1971), these have not been evaluated.

Another way to widen the range of perceived choice is to employ policy to modify the potential consequences of an alternative, thus making a previously unattractive alternative worthy of consideration. Compulsory insurance is a good example of a policy that can play a role in improving hazard perception and widening the range of alternatives. By guaranteeing individuals a minimum level of income if they adopt an innovative adjustment, insurance can decrease the risk entailed by the innovation, thereby enhancing its attractiveness. Probably the most significant role played by insurance is in requiring explicit, conscious attention to risk by the individual concerned. He is faced with an estimate of risk expressed by an annual premium charge, and in some cases may also be provided with a schedule of reduced premiums contingent upon his taking certain actions, such as flood proofing his home. For a more detailed discussion of the role of insurance in the context of natural hazards, see Kunreuther (1968), Dacy and Kunreuther (1969), and Lave (1968).

How safe is safe enough? There are some who believe that, given a static environment, man learns by trial, error, and subsequent corrective actions, to arrive at a reasonably optimal balance between the benefit from an activity and its risk. One such individual, Chauncey Starr, has developed a quantitative measure of the acceptable risk-benefit ratio for an activity based on this assumption (Starr, 1969). Starr assumes that historical national-

accident records are adequate for revealing consistent patterns in risk-benefit ratios and that these historically revealed social preferences are sufficiently enduring to permit their use for predicting what risk levels will be acceptable to society when setting policies or introducing new technologies. Implicit in this approach is yet another assumption, that what is best for society is approximately equivalent to what is traditionally acceptable.

Starr distinguishes between voluntary activities, which the individual can evaluate via his own value system, and involuntary activities, where the options and criteria of evaluation are determined for the individual by some controlling body. His measure of risk is the statistical expectation of fatalities per hour of exposure to the activity under consideration. For voluntary activities, his measure of benefit is assumed to be approximately equal to the amount of money spent on an activity by the average individual. For involuntary activities, benefit is assumed proportional to the contribution that activity makes to an individual's annual income.

Analysis of a number of natural and man-made risks according to these considerations points to several important conclusions: (a) the public seems willing to accept voluntary risks roughly 1000 times greater than involuntary risks at a given level of benefit; (b) the acceptability of a risk is roughly proportional to the real and perceived benefits; and (c) the acceptable level of risk is inversely related to the number of persons participating in an activity.

Starr's assessment technique falls within the purview of bounded-rationality approaches because, rather than assuming that individuals can indicate directly an optimal risk-benefit tradeoff, it merely assumes that across a large group of individuals, given an opportunity to learn from their mistakes, a satisfactory level will emerge.

The importance of knowing the acceptable risk level for an activity cannot be overestimated. The Starr technique thus promises to be a valuable aid for decisions regarding natural hazards, and, in fact, a similar approach has already been used to guide the development of a new earthquake building code for the city of Long Beach, California (Wiggins, 1972). However, several reservations bear mentioning. First, the psychological research described above points to the prevalence of systematic biases in risk-taking decisions. It is unlikely that all such biases will be eliminated as a result of experience. Therefore, just as an individual's decisions may not accurately reflect his "true preferences," historical data may not necessarily reflect the underlying preferences of a group of people. Second, the validity of historical data as an indicant of preference assumes that the public has available a wide selection of alternatives and, furthermore, that these alternatives are perceived as being available. Can we really assume, for example, that the public will demand automobiles that are as safe as they would wish, given the available benefits? Unless the public really knows what is possible from a design standpoint and unless the automobile industry cooperates in making available information that may not necessarily serve its own profit maximization interests, the answer is likely to be no. (For a more detailed discussion of the limitations of the public's "market" behavior as an indicant of their risk values see Schelling, 1968).

With these qualifications in mind, the Starr approach would seem to merit serious consideration as a method for designing and evaluating adjustments to natural hazards.

The Analytic Approach to Improving Adjustments

Bounded rationality, with its emphasis on short-run feedback and adaptation triggered by crises, may work satisfactorily in some settings, particularly

in static environments where the same decision is made repeatedly and the consequences of a poor decision are not too disastrous. However, where natural hazards are concerned, we may prefer not to rely upon learning from experience. First, relevant experiences may be few and far between and, second, mistakes are likely to be too costly. With so much at stake, it is important to search for methods other than the clever ways of "muddling through" and "satisficing" advanced by the advocates of bounded rationality.

The alternative to muddling through is the application of scientific methods and formal analysis to problems of decision making. The analytic approach originated during World War II from the need to solve strategic and tactical problems in situations where experience was either costly or impossible to acquire. It was first labeled "operations analysis," and later became known as "operations research." Operations research is an interdisciplinary effort, bringing together the talents of mathematicians, statisticians, economists, engineers, and others. Since the war, its sphere of application has been extended primarily to business, but its potential is equally great for all areas of decision making.

Simon (1960) outlined the stages of an operations-research analysis as follows: The first step is to construct a mathematical model that mirrors the important factors in the situation of interest. Among the mathematical tools that have been particularly useful in this regard are linear programming, dynamic programming, and probability theory. The second step is to define a criterion function which is to be used to compare the relative merits of the possible alternative actions. Next empirical estimates are obtained for the numerical parameters in the model for the specific situation under study. Finally, mathematical analysis is applied to determine the course of action that maximizes the criterion function.

During recent years, a number of closely-related offshoots of operations research have been applied to decision problems. These include systems analysis and cost-benefit analysis. Systems analysis is a branch of engineering, whose objective is capturing the interactions and dynamic behavior of complex systems. Cost-benefit analysis attempts to quantify the prospective gains and losses from some proposed action, usually in terms of dollars. If the calculated gain from an act or project is positive, it is said that the benefits outweigh the costs and its acceptance is recommended (see, for example, the application of cost-benefit analysis to the study of auto-safety features by Lave & Weber, 1970).

Decision analysis. What systems-analysis and operations-research approaches lacked for many years was an effective normative framework for dealing either with the uncertainty in the world or with the subjectivity of decision makers' values and expectations. The emergence of decision theory provided the general normative rationale missing from these early analytic approaches. By the same token, systems analysis and operations research had something to offer applied decision theory. There is an awesome gap between the simple decisions that are typically used to illustrate decision theoretic principles (e.g., whether or not to carry an umbrella) and the complex real-world problems one wishes to address. Systems analysis attempts to provide the sophisticated modeling of the decision situation needed to bridge the gap. The result of the natural merger between decision theory and engineering approaches has been labeled "decision analysis." Our review of decision analysis will be brief. For further details, see the tutorial papers by Howard (1968a, 1968b), Matheson (1969), and the books by Raiffa (1968), and Schlaifer (1969).

A thorough decision analysis takes a great deal of time and effort and thus should be applied only to problems important enough to justify this. Typically, these problems involve a complex structure where many interrelated factors affect the decision, and where uncertainty, long-run implications, and complex tradeoffs among outcomes further complicate matters.

A key element of decision analysis is its emphasis upon structuring the decision problem and decomposing it into a number of more elementary problems. In this sense, it attempts a simplification process that, unlike the potentially detrimental simplifications the unaided decision maker might employ, maintains all the essential ingredients that are necessary to make the decision and insures that they are used in a manner logically consistent with the decision maker's basic preferences. Raiffa (1968) expresses this attitude well in the following statement:

"The spirit of decision analysis is divide and conquer: Decompose a complex problem into simpler problems, get your thinking straight in these simpler problems, paste these analyses together with a logical glue, and come out with a program for action for the complex problem. Experts are not asked complicated, fuzzy questions, but crystal clear, unambiguous, elemental hypothetical questions [p. 271]."

Decision analysis of hurricane modification. The technique of decision analysis is best communicated via a specific example. Fortunately, there is a detailed example available in the analysis of hurricane modification prepared by the decision-analysis group of Stanford Research Institute (SRI) on behalf of the National Oceanic and Atmospheric Administration (Boyd, Howard, Matheson, & North, 1971; Howard, Matheson, & North, 1972). An overview of this analysis is presented below.

In the case of hurricane modification, one important decision is strategic--"Should cloud seeding ever be performed?" If the answer is yes, then tactical decisions concerning which hurricanes are to be seeded become

important. The SRI analysis focuses on the strategic decision.

The basic approach is to consider a representative severe hurricane bearing down on a coastal area and to analyze the decision to seed or not to seed this hurricane. Maximum sustained surface wind speed is used as the measure of the storm's intensity, since it is this characteristic (which is the primary cause of destruction) that seeding is expected to influence. The analysis assumes that the direct consequence of a decision on seeding is the property damage caused by the hurricane.

However, property damage alone is insufficient to describe the consequences of hurricane seeding. There are indirect social and legal effects that arise from the fact of human intervention; thus the government might have some legal responsibility for the damage from a seeded hurricane. The tradeoff between accepting the responsibility for seeding and accepting higher probabilities of severe property damage is viewed as the crucial issue in this decision.

The first step in the SRI analysis was to merge current experimental evidence with the best prior scientific opinion to obtain a probability distribution over changes in the intensity of the representative hurricane as measured by its maximum surface wind speed. This was done for both alternatives--seeding and not seeding. Then, data from past hurricanes were used to infer the relationship between wind speed and property damage. On the basis of this information, the expected loss in terms of property damage was calculated to be about 20% less if the hurricane was seeded. Varying the assumptions of the analysis over a wide range of values caused this reduction to vacillate between 10% and 30%, but did not change the preferred alternative.

The above analysis favors seeding but does not take the negative utility of government responsibility into account. The assessment of responsibility

costs entails considerable introspective effort on the part of the decision maker who must make judgments such as, "Estimate X such that the government would be indifferent between a seeded hurricane that intensifies 16% between time of seeding and landfall and an unseeded hurricane that produces X% more damage than that of the seeded hurricane."

On the basis of estimates such as the above, it was inferred that the responsibility costs needed to change the decision were a substantial fraction (about 20%) of the property damage caused by the hurricane. This and further analyses led to the conclusion that, on the basis of present information, the probability of severe damage is less if a hurricane is seeded, and that seeding should be permitted on an emergency basis and encouraged on an experimental basis.

Critique of decision analysis. It is difficult to convey in a summary such as that given above the depth of thinking and the logic underlying the decision analysis. The brief description necessarily simplifies the analysis and highlights a chief objection to decision analysis in general--the claim that it oversimplifies the situation and thus misleads. Nevertheless, even those who read the complete analysis may have concerns over its validity. They may note that Howard et al. have constrained their analysis to ignore the beneficial and detrimental aspects of hurricanes in their major contribution to the water balance of the areas affected. The analysis also ignores the possibility that knowledge of an operational seeding program will give residents a false sense of security, thus inviting even greater damages than might occur without seeding. The critics argue that such decision analyses are inevitably constrained by time, effort, and imagination, and must systematically exclude many considerations.

A second major objection to decision analysis is the possibility that it may be used to justify, and give a gloss of respectability to, decisions made on other, and perhaps less rational, grounds.

Decision analysts counter these attacks by invoking one of their basic tenets--namely, that any alternative must be considered in the context of other alternatives. What, they ask, are the alternatives to decision analysis, and are they any more immune to the criticisms raised above? The analysts point out that traditional modes of decision making are equally constrained by limits of time, effort, and imagination, and are even more likely to induce systematic biases (as is illustrated earlier in this paper). Such biases will be much harder to detect and minimize than the deficiencies in the explicit inputs to decision analysis. Furthermore, they argue, if some factors are unknown or poorly understood, can traditional methods deal with them more adequately than decision analysis? Traditional methods also are susceptible to the "gloss of respectability" criticism noted above. We often resort to expertise to buttress our decisions without really knowing the assumptions and logic underlying the experts' judgments. Decision analysis makes these assumptions explicit. Such explicit data are easy for knowledgeable persons to criticize and the explicitness thus focuses debate on the right issues.

Decision analysts would agree that their craft is no panacea, that incomplete or poorly-designed analyses may be worse than no analyses at all, and that analysis may be used to overwhelm the "opposition." It seems clear, however, that the main task for the future is less to criticize decision analysis than to see how it can be used most appropriately.

V. Summary and Conclusions

In coping with the hazard of natural events, man enlarges the social costs of those events and tends to make himself more vulnerable to the consequences of the great extremes. His response to uncertainty in the timing and magnitude of droughts, earthquakes, floods, and similar unusual events has led to increases in the toll of life and property which they take.

Understanding why this is the case is essential to the wise design of new policies. Much of the improved policy necessarily will depend upon action by individuals within public constraints. Here it is important to recognize how people make their choices in the face of uncertainty in nature and how they might be expected to respond within a different set of constraints.

Enough is known about the process of choice to be sure that it cannot be accurately described as a simple effort to maximize net marginal returns. Nor can it be explained solely in terms of the culture or the personality of the decision makers. It is not easily predicted as a product of particular environmental conditions. It is a complex, multidetermined phenomenon. The need for relatively clear analysis of its essential elements is urgent, and is at the heart of systematic improvement of public policy.

In the present paper, we attempted to show that: (a) convergent evidence from psychology, business, governmental policy making, and geography documents the usefulness of bounded rationality as a framework for conceptualizing decision processes; (b) an understanding of the workings of bounded rationality can be exploited to improve adjustment to natural hazards; and (c) decision analysis, though still in an early stage of development, promises to be a valuable aid for the important decisions man must make regarding natural hazards.

Measures needed to increase understanding of the decision processes and provide opportunities for improving it require a combination of theoretical, laboratory, and empirical approaches. Determining a rationale for optimal behavior in the face of a capricious nature requires theoretical development. The basic modes of assessing probabilities of rare natural events and of assigning values to consequences involve cognitive processes that may be discerned most clearly in controlled laboratory experiments. The recognition of ways in which cultural and situational factors may influence decisions calls for observation in field settings.

References

- Alpert, M., & Raiffa, H. A progress report on the training of probability assessors. Unpublished manuscript, Harvard University, 1968.
- Bakan, P. Response tendencies in attempts to generate random binary series. American Journal of Psychology, 1960, 73, 127-131.
- Bauman, D. D., & Sims, J. H. The tornado threat: Coping styles of the North and South. Science, 1972, 176, 1386-1392.
- Becker, G. M., De Groot, M. H., & Marschak, J. Measuring utility by a single-response sequential method. Behavioral Science, 1964, 9, 226-232.
- Boyd, D. W., Howard, R. A., Matheson, J. E., & North, D. W. Decision analysis of hurricane modification. Final Report: Project 8503, Stanford Research Institute, Menlo Park, California. (This report is available through the National Technical Information Service, U.S. Department of Commerce, Washington, D. C., accession number COM-71-00784.)
- Burton, I. Cultural and personality variables in the perception of natural hazards. In J. F. Wohlwill & D. H. Carson (Eds.), Environment and the social sciences: Perspectives and applications. Washington, D.C.: American Psychological Association, 1972. Pp. 184-195.
- Burton, I., & Kates, R. W. The perception of natural hazards in resource management. Natural Resources Journal, 1964, 3, 412-441.
- Burton, I., Kates, R. W., & White, G. F. The human ecology of extreme geographical events. Working Paper No. 1, Natural Hazard Research, Department of Geography, University of Toronto, 1968.

- Chapanis, A. Random number guessing behavior. American Psychologist, 1953, 8, 332. (Abstract)
- Chapman, L. J., & Chapman, J. P. Illusory correlation as an obstacle to the use of valid psychodiagnostic signs. Journal of Abnormal Psychology, 1969, 74, 271-280.
- Cohen, J., & Hansel, C. E. M. Risk and gambling. London: Longmans Green, 1956.
- Cook, H. C., & White, G. F. Making wise use of flood plains. United States Papers for United Nations Conference on Science and Technology, 1963, 2, 343-359.
- Coombs, C. H., Dawes, R. M., & Tversky, A. Mathematical psychology. Englewood Cliffs: Prentice-Hall, 1970.
- Cyert, R. M., & March, J. G. A behavioral theory of the firm. Englewood Cliffs, N. J.: Prentice-Hall, 1963.
- Dacy, D. C., & Kunreuther, H. The economics of natural disasters. New York: Free Press, 1969.
- Dillon, J. L. An expository review of Bernoullian decision theory in agriculture: Is utility futility? Review of Marketing and Agricultural Economics, 1971,
- Edwards, W. Conservatism in human information processing. In B. Kleinmuntz (Ed.), Formal representation of human judgment. New York: Wiley, 1968. Pp. 17-52.
- Gillette, R., & Walsh, J. San Fernando earthquake study: NRC panel sees premonitory lessons. Science, 1971, 172, 140-143.
- Herrero, S. Human injury inflicted by grizzly bears. Science, 1970, 170, 593-597.

- High, C., & Richards, P. The random walk drainage simulation model as a teaching exercise. The Journal of Geography, 1972, 71, 41-51.
- Holmes, R. C. Composition and size of flood losses. In G. F. White (Ed.), Papers on flood problems. Department of Geography Research Paper No. 70, University of Chicago, 1961. Pp. 7-20.
- Howard, R. A. The foundations of decision analysis. IEEE Transactions on Systems Science and Cybernetics, 1968, 4(3), 211-219. (a)
- Howard, R. A. Decision analysis: Applied decision theory. In D. B. Hertz & J. Melese (Eds.), Proceedings of the Fourth International Conference on Operational Research. New York: Wiley, 1966 (1968). Pp. 55-71. (b)
- Howard, R. A., Matheson, J. E., & North, D. W. The decision to seed hurricanes. Science, 1972, 176, 1191-1202.
- Jarvik, M. E. Probability learning and a negative recency effect in the serial anticipation of alternative symbols. Journal of Experimental Psychology, 1951, 41, 291-297.
- Jenkins, H. M., & Ward, W. C. Judgment of contingency between responses and outcomes. Psychological Monographs, 1965, 79 (Whole No. 594).
- Kahneman, D., & Tversky, A. Subjective probability: A judgment of representativeness. Cognitive Psychology, 1972, 3, 430-454. (a)
- Kahneman, D., & Tversky, A. On the psychology of prediction. Oregon Research Institute Research Bulletin, 1972, Vol. 12, No. 4. (b)
- Kates, R. W. Hazard and choice perception in flood plain management. Department of Geography Research Paper No. 78, University of Chicago, 1962.
- Kates, R. W. Natural hazard in ecological perspective: Hypotheses and models. Working Paper No. 14, Natural Hazard Research, Department of Geography, University of Toronto, 1970.

- Kirkby, A. V. Perception of rainfall variability and agricultural and social adaptation to hazard by peasant cultivators in the valley of Daxaca, Mexico. Paper presented at the 22nd International Geographical Congress, Calgary, July 1972.
- Knight, F. H. Risk, uncertainty, and profit. New York: Harper & Row, 1965.
- Kunreuther, H., The case for comprehensive disaster insurance. Journal of Law and Economics, 1968, 11, 133-163.
- Kunreuther, H. Risk-taking and farmer's crop growing decisions. Center for Mathematical Studies in Business and Economics, Report No. 7219, University of Chicago, May 1972.
- Kunreuther, H. (Howard please supply title for your Companion Paper--formerly titled Bounded Rationality and Natural Hazards), 1973.
- Lave, L. B. Safety in transportation: The role of government. Law and Contemporary Problems, 1968, 33, 512-535.
- Lave, L. B., & Weber, W. E. A benefit-cost analysis of auto safety features. Applied Economics, 1970, 2, 265-275.
- Lichtenstein, S., & Slovic, P. Reversals of preference between bids and choices in gambling decisions. Journal of Experimental Psychology, 1971, 89, 46-55.
- Lichtenstein, S., & Slovic, P. Response-induced reversals of preference in gambling: An extended replication in Las Vegas. Oregon Research Institute Research Bulletin, 1972, Vol. 12, No. 6.
- Lichtenstein, S. C., Slovic, P., & Zink, D. Effect of instruction in expected value on optimality of gambling decisions. Journal of Experimental Psychology, 1969, 79, 236-240.
- Lindblom, C. E. The science of muddling through. In W. J. Gore, & J. W. Dyson (Eds.), The making of decisions. New York: Free Press, 1964. Pp. 155-169.

- Luce, D., & Raiffa, H. Games and decisions. New York: Wiley, 1957.
- Matheson, J. E. Decision analysis practice: Examples and insights. In J. Lawrence (Ed.), Proceedings of the Fifth International Conference on Operational Research. London: Tavistock, 1969 (1970). Pp. 677-691.
- Murphy, A. H., & Winkler, R. H. Forecasters and probability forecasts: Some current problems. Bulletin of the American Meteorological Society, 1971, 52, 239-247.
- Parra, C. G. Perception of past draughts in Ticul, Yucatan. Proceedings of the Great Plains-Rocky Mountain Meeting of the American Association of Geographers, Colorado Springs, 1971.
- Patton, D. J. (Ed.) From geographic discipline to inquiring student: Final report on the high school geography project. Washington: Association of American Geographers, 1970.
- Raiffa, H. Decision analysis. Reading, Mass.: Addison-Wesley, 1968.
- Ross, B. M., & Levy, N. Patterned predictions of chance events by children and adults. Psychological Reports, 1958, 4, 87-124.
- Savage, L. J. The foundations of statistics. New York: Wiley, 1954.
- Schelling, T. C. The life you save may be your own. In S. B. Chase (Ed.), Problems in public expenditure analysis. Washington, D.C.: Brookings Institution, 1968. Pp. 127-176.
- Schiff, M. Some theoretical aspects of attitudes and perception. Natural Hazard Working Paper No. 15, Department of Geography, University of Toronto, 1970.

- Schlaifer, R. Analysis of decisions under uncertainty. New York: McGraw-Hill, 1969.
- Sheehan, L., & Hewitt, K. A pilot survey of global natural disasters of the past twenty years. Working Paper No. 11, Natural Hazards Research, Department of Geography, University of Toronto, 1969.
- Simon, H. A. Rational choice and the structure of the environment. Psychological Review, 1956, 63, 129-138.
- Simon, H. A. Theories of decision making in economics and behavioral science. American Economic Review, 1959, 49, 253-283.
- Simon, H. A. The new science of management decision. New York: Harper & Row, 1960.
- Slovic, P., & MacPhillamy, D. Dimensional commensurability and cue utilization in comparative judgment. Oregon Research Institute Research Bulletin, 1971, Vol. 11, No. 14.
- Smedslund, J. The concept of correlation in adults. Scandinavian Journal of Psychology, 1963, 4, 165-173.
- Starr, C. Social benefit versus technological risk. Science, 1969, 165, 1232-1238.
- Steinbrugge, K. V., McClure, F. E., & Snow, A. J. Studies in seismicity and earthquake damage statistics, 1969. U.S. Department of Commerce Report (Appendix A), COM-71-00053, March 1969.
- Tversky, A. Intransitivity of preferences. Psychological Review, 1969, 76, 31-48.

- Tversky, A., & Kahneman, D. Belief in the law of small numbers. Psychological Bulletin, 1971, 76, 105-110.
- Tversky, A., & Kahneman, D. The judgment of probability by retrieval and construction of instances. Cognitive Psychology, 1973, in press. (a)
- Tversky, A., & Kahneman, D. Anchoring and calibration in the assessment of uncertain quantities. Oregon Research Institute Research Bulletin, 1973. (in preparation) (b)
- U.S. 89th Congress, Second Session Task Force on Federal Flood Control Policy. A unified national program for managing flood losses. House Document, No. 465, 1966.
- von Neumann, J., & Morgenstern, O. Theory of games and economic behavior (3rd ed., 1953). Princeton: Princeton University Press, 1947.
- Ward, W. C., & Jenkins, H. M. The display of information and the judgment of contingency. Canadian Journal of Psychology, 1965, 19, 231-241.
- White, G. F. Human adjustment to floods: A geographical approach to the flood problem in the United States. Department of Geography Research Paper No. 29, University of Chicago, 1945.
- White, G. F. The choice of use in resource management. Natural Resources Journal, 1961, 1, 23-40.
- White, G. F. Choice of adjustment to floods. Department of Geography Research Paper No. 93, University of Chicago, 1964.
- White, G. F. Optimal flood damage management: Retrospect and prospect. In A. V. Kneese & S. C. Smith (Eds.), Water research. Baltimore: Johns Hopkins Press, 1966.

White, G. F. Flood-loss reduction: The integrated approach. Journal of Soil and Water Conservation, 1970, 25,

White, G. F., Bradley, D., & White, A. Drawers of water: Domestic water use in East Africa. Chicago: University of Chicago Press, 1972.

Wiggins, J. H., Jr. Earthquake safety in the city of Long Beach based on the concept of balanced risk. In Perspectives on benefit-risk decision making. Washington, D.C.: National Academy of Engineering, 1972.

Pp. 87-95.

York, H. Race to oblivion: A participant's view of the arms race. New York: Simon & Schuster, 1970.