Baruch F., C. Hohenemser, R. E. Kasperson, and R. W. Kates, 1978. "Handling Hazards", Environment 20, pp. 16-20, 32-37.

Handling

Can hazard management be improved?

IF A TREE FALLS in a forest far from human ears, is there a sound? This is a classic philosophical problem. In hazard management, the analogous question is: If a tree falls, is there a hazard? Trees fall from a variety of causes—disease, lightning, flood, fire, the sharp teeth of beavers, and the axes and chain saws of humans. Such occurrences may have no immediate human implications and we call them *events*. But trees may also crush people, maim livestock, and destory buildings, dam streams, cause floods, and accelerate erosion. These and other impacts on humans and what they value we call *consequences*. As threats to humans and what they value, hazards consist at minimum of events and consequences, just as sound in the perceptual sense requires at minimum the physical excitation of sound waves and the receipt and perception of these by human ears and brains.

The division of hazards into events and consequences strongly implies three possible strategies of hazard management: (1) prevention of hazard events; (2) prevention of hazard consequences once events have taken place; and (3) mitigation of consequences once these have occurred. Prevention of events appears to be the most fundamental item in this scheme in that it occurs earliest in the causal chain. Mitigation, which takes place after consequences are experienced, is sometimes regarded as unsatisfactory in the sense that "an ounce of prevention is worth a pound of cure." Yet, in any particular case any one of the three strategies may be the most appropriate. Consider the following examples.

For catastrophic nuclear power accidents involving the release of massive amounts of radioactivity into the environment, neither consequence prevention nor consequence mitigation is especially feasible, for once the release has occurred unacceptably high losses are inevitable. As a result most regulatory and engineering efforts concentrate on activities designed to make the occurrence of an accident "incredible" or of "very low probability." Thus, hazard management follows strategy one above, the prevention of hazardous events.

In contrast, for geophysical hazards such as tropical cyclones, strategy one currently has little value since no one can as yet reliably prevent or significantly alter tropical storms. Even strategy two is of only limited utility for a cyclone will, once it has occurred, inevitably produce large losses, especially in developing countries.[1] Thus societies practice strategy three, consequence mitigation, in the form of property damage relief, medical attention to survivors, and reconstruction.

Most hazard management falls between the poles represented by catastrophic nuclear accidents and tropical cyclones. In the case of automobiles, for example, events (accidents) are preventable in principle, and

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Hazards

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OSHA

society has expended much effort in this direction (by eliminating curves in highways or building divided highways, for example). Yet the high cost and relative ineffectiveness of accident prevention makes consequence prevention (strategy two) equally, if not more, relevant. Particularly in the last ten years it has become clear that much can be done to block consequences (for instance, the use of seatbelts) in the one-half second between the beginning of an automobile crash and the moment that the occupant's head strikes the dashboard or windshield.[2] Finally, auto accident management involves a heavy dose of mitigation (strategy three), usually in the form of insurance designed to distribute the burden of loss.

How, specifically, do prevention and mitigation take place? First, it is possible to expand the simple model based on events and consequences by recognizing two classes of events, *initiating events* and higher-order events which we denote for clarity as *outcomes*. Outcomes lead in turn to *exposure* and then to *consequences*. All the stages are connected by *pathways*. These pathways are logical points for blocking actions designed to control the hazard. Pathways may connect several nearly simultaneous prior stages to several nearly simultaneous subsequent stages. For example, in Figure 1 a number of initiating events—a loose,

The original regulatory agencies tended to have narrowly drawn objectives but today agencies with limited resources are being charged with repsonsibility for extensive and varied hazard domains. OSHA, for example, has to regulate *all* technological hazards in the workplace.

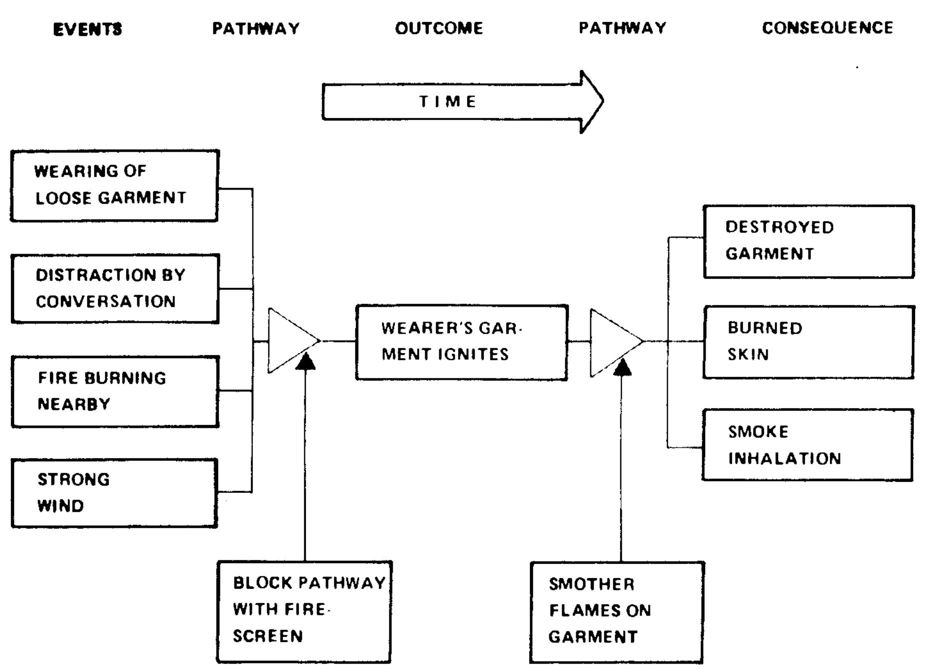


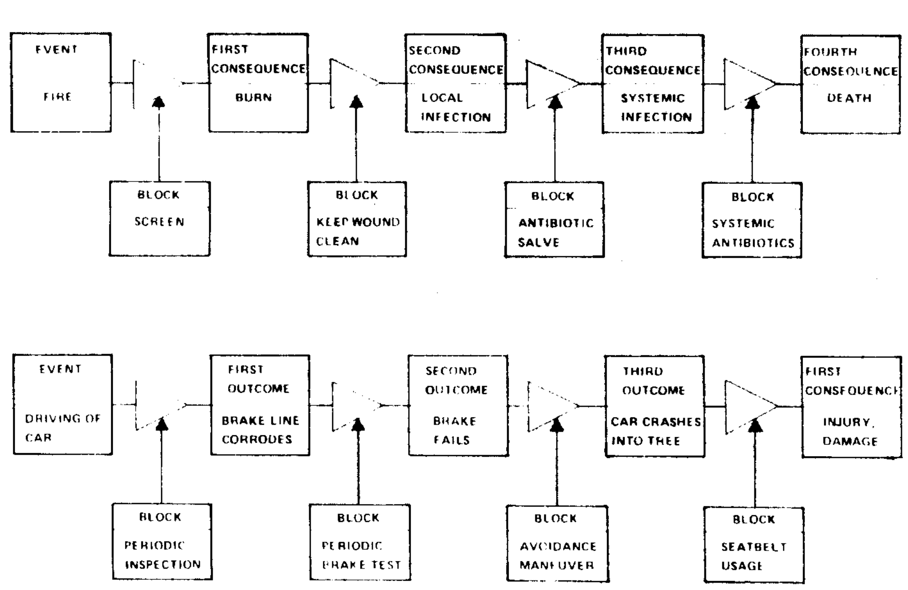
FIGURE 1. Three-stage model of hazard causation. The specific case illustrated involves a garment that accidentally ignites when the wearer stands too near an open fire. Four initiating events contribute to the outcome of garment ignition and three consequences flow from this. Logically, each initiating event serves as a necessary condition for the outcome and subsequent consequences. Control of the consequences involves blocking the outcome, or blocking the consequences once the outcome has occurred.

flammable garment, the wearer's distraction by conversation, a nearby fire, and a strong wind—are all required to ignite the wearer's garment. Each component initiating event constitutes a necessary condition for the subsequent outcome and each may be blocked to prevent the outcome.

It is possible to expand the pathway model presented in Figure 1 still further. Just as various outcomes follow initiating events, *higher order consequences* follow *first order consequences,* all appropriately linked by pathways. The degree of expansion is, in a fundamental sense, arbitrary. From a practical point of view, additional stages are introduced to the extent that they define meaningful hazard management opportunities. Figure 2 provides two explicit examples. In the first, several orders of consequences show how a burn may lead to eventual death. In the second, several orders of outcomes illustrate the process by which a corroded brake lining results in an auto crash. In both examples, diagraming the hazard defines the opportunities for hazard control.

Figure 3 uses the example of pesticides to illustrate the full scope of the model. It demonstrates that the chain of hazard evolution stretches upstream well beyond events to stages which we designate as *choice of technology* and *human needs and wants.* Diagraming the full scope of hazard in this way is particularly important for those cases in which some of the conventional "downstream" stages (such as events and consequences) are poorly understood. In the case of pesticides, for example, there is usually at best only circumstantial evidence of carcinogenic potential, and specific means of intervention between events and consequences are often unknown. In such a situation, prudent hazard management recognizes the ineffectiveness of downstream blocks and concentrates on upstream options such as choice of technology or modification of human wants. Examples of such strategies are the use of biodegradable, nonpersistent pesti-

FIGURE 2. Top: Expansion of the model of hazard causation into several orders of consequences. The case illustrated is an elaboration of the case shown in Figure 1, and corresponds to the potential medical developments that can occur in the case of unmitigated direct consequences of an accidentally ignited garment. Note that each stage of consequences is followed by a pathway that may be blocked to prevent further consequences. Bottom: Expansion of the model of hazard causation into several orders of outcomes. The case illustrated involves the stages of development that causally connect a corroded brake line in an automobile to an eventual crash followed by injury and damage. The degree of exapnsion in both cases is determined by the hazard management opportunities that may be realized at each stage. In this sense the model encourages clear thinking about hazard management opportunities.



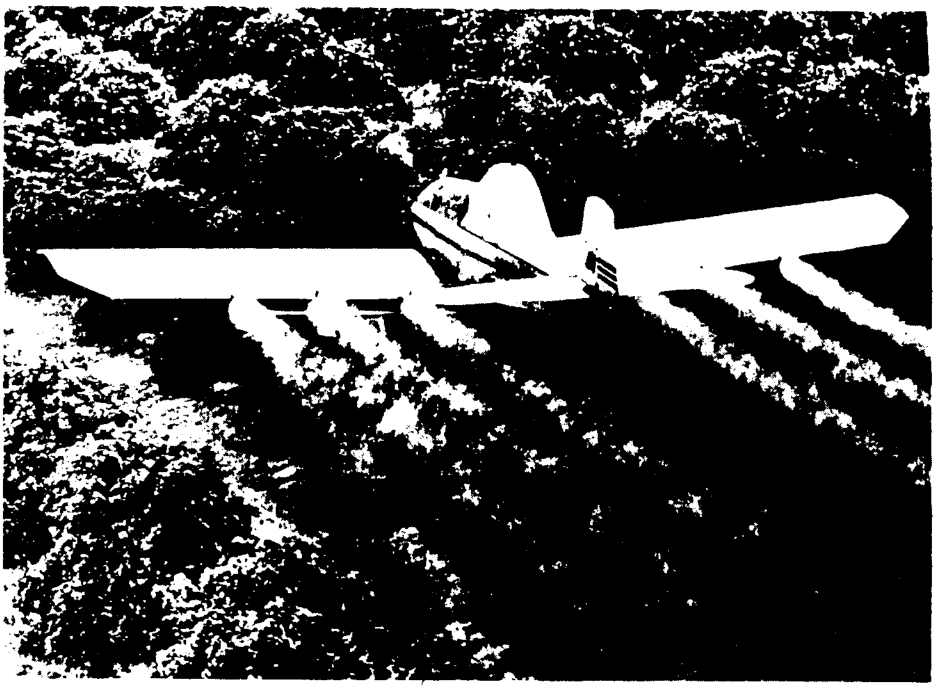
cides and the toleration of blemished fruit.

Applying the Model

There are many ways of thinking about hazards. The model presented above, by identifying the causal chain of hazard evolution, focuses on the various opportunities available to society for controlling hazards. It thereby offers at least three basic insights into hazard management.

• The model provides a fairly concise common language for characterizing the myriad of hazards facing society. This language expands our understanding of hazards and forces us to look at all available management options. Thus looking "upstream" may reveal some wants, such as having blemish-free crops or particular cosmetic dyes, that can readily be foregone once the attendant risks are acknowledged.

• The model serves as a way of evaluating existing management strategies and can be useful in optimizing the manner of control intervention and coping. Specifically, it alerts us to strategies that overlook important means of control, or that tend to concentrate on single rather than multiple solutions, or that merely shift the distribution of risk along the causal chain rather than actually reducing it.



A crop-dusting plane spraying an orchard with pesticides. In the case of hazards such as pesticides, where "downstream" blocks are ineffective or poorly understood, prudent hazard management must concentrate on "upstream" options such as choice of technology or modification of human wants.

• Finally, the model provides, in principle, a way of relating management strategies to the characteristics of particular technologies, and thus may allow us to prescribe what management approaches are likely to work for a particular technology.

Yet, so far, little of the potential of the model has been realized in actual management situations. Thus there are few cases in which hazards are managed by "far-upstream" coping methods—the partial banning of the SST and the virtual elimination of DDT being two striking exceptions. Most present regulation is a patchwork of intervention that makes little sense as a coherent hazard policy focused on the most effective stage of

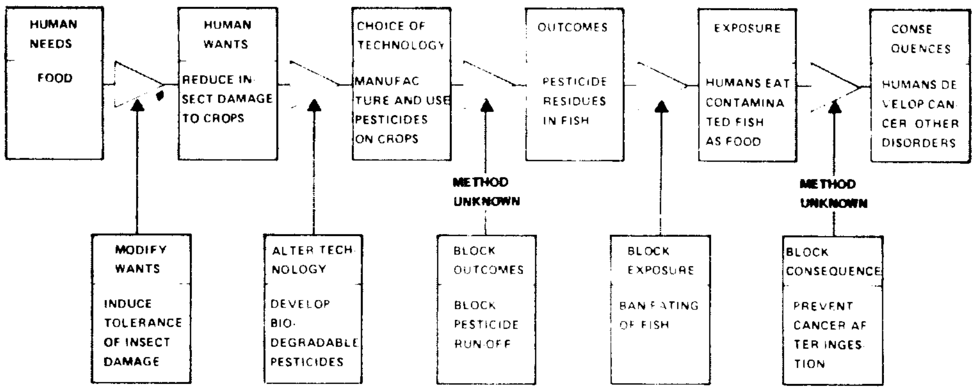


FIGURE 3. Expansion of the model of hazard causation into the full range of stages extending from human needs to consequences. The case illustrated involves the use of pesticides to suppress crop damage. It serves as a good example of the situation in which "down-stream" management options involving events and consequences are not very promising or even possible and "up-stream" options involving human wants and choice of technology are most likely to succeed.

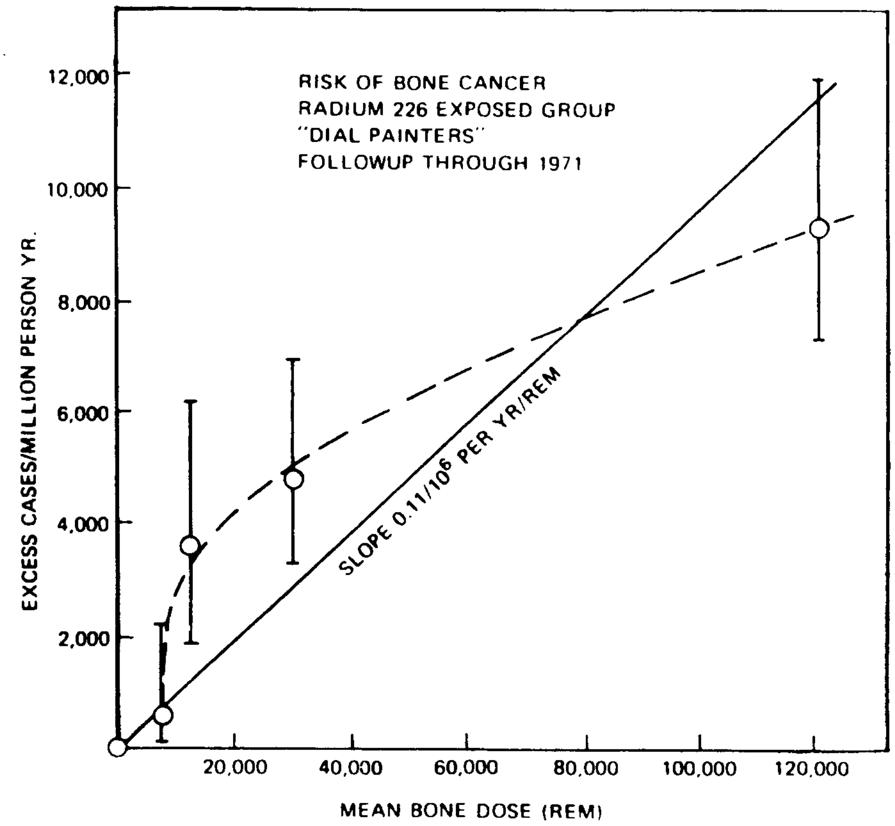


FIGURE 4. Illustration of a typical dose-response curve for ionizing radiation effects. The graph shows excess cases of bone cancer observed for various levels of mean bone dose, measured in REM. The exposed individuals were workers who painted watches with radium during the years 1915-1935. Note that the data is characterized by large error flags, and that it is not clear whether a straight line without a threshold, or a curved line with a threshold, best fits the data. Most exposures of individuals today fall in the region below 10,000 REM mean bone dose. It is therefore critical whether the solid or dashed curve is correct. The first predicts harm at any level of exposure; the second suggests that below about 10,000 REM mean bone dose there is not excess mortality. By itself the graph does not provide an answer. The most conservative assumption, and the one usually adopted, is that the straight line is correct. The graph and its interpretation is reproduced from the Report of the Committee on the Biological Effects of Ionizing Radiation (National Academy of Sciences, 1972).

hazard causation. In regard to the establishment of a predictive theory of management, in which certain kinds of strategies are uniformly applied to certain types of hazards, there is little if anything that managers can agree on, and less that has reached the stage of implementation.

What explains these inadequacies of hazard management? Why is the full range of management opportunities so under-utilized?

Constraints on Hazard Management

Incomplete Knowledge.

Characteristically, hazard management assumes that causality is or will soon be defined. It is increasingly clear, however, that our current knowledge of hazards is often insufficient for formulating the details of causal chains and hence effective control strategies. Further, this situation may not change in the foreseeable future for many of the hazards we face. We illustrate this through two examples.

Dose-response data. Many harmful effects are specified through dose-response relationships. When these are charted, the dose or exposure level of a chemical or other material suspected of being toxic is plotted on the horizontal axis; the response, measured in some form of human harm such as mortality, is plotted on the vertical axis (as in Figure 4). The central question is, what is the relation between the two variables? In general, the relationship is expected to increase with the degree of exposure. Usually the increase is specified in a statistical way; that is, at a particular exposure level human harm is given as a certain frequency, such as deaths/per 100,000, without any indication of just which persons are affected.

In addition, the experimental or empirical basis for dose-response curves is usually limited to high-dose cases and high frequencies of harm, leaving low-dose behavior unspecified. This ignorance gap is normally filled by plausible assumptions, such as linear extrapolation from actual data to levels of zero dose. Innocuous as this practice may seem, it is precisely the region of extrapolation that is most often critical in that it covers the dosage level at which the largest populations are exposed. For example, as disturbing as occupational exposure to asbestos may be for a limited number of asbestos workers, the effects of asbestos exposure on their health are predictable, based on the high-dose portion of the curve; but the exposure effects for the general population, which literally includes all of us, are possibly far more significant. Yet our knowledge of them depends on the behavior of the unknown portion of the dose-response relationship.

The problem of ill-defined dose-response data is well illustrated by the classical case of radiation exposure (Figure 4). The problem recurs with most chemicals and is further compounded by the necessity to use animal data as a surrogate for human data. Extrapolation to typical human exposures thus involves two independent assumptions. that animals are a good surrogate for human experience and that extrapolations in the low-dose region are correct. To date, there are only a few cases where dose-response data suffers from neither of these defects and where well-defined human data is available at the dosage level to which the majority of people are exposed. One of these is the dose-response curve relating cigarette smoking to lung cancer (Figure 5 on page 32).

Large-scale technological systems. A second example of incomplete knowledge in hazard management arises in connection with estimating the safety of complex

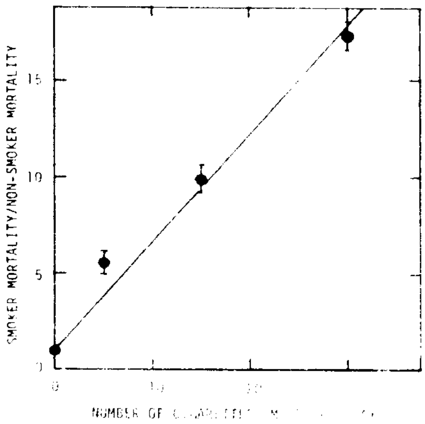
(continued on page 32)

Handling Hazards

(continued from page 20)

and massive technological activities such as nuclear power generation, oil refining and transport, large hydroelectric dams, and liquid natural gas storage and transport. All of these activities are associated with the potential of catastrophic accidents, yet in most cases we know far too little about the probability of failure or about its consequences. Safety systems must therefore be designed and installed while knowledge of their effectiveness remains incomplete or absent. The key question in all these cases is: How safe is safe enough or, equivalently, what is an acceptable risk? In the case of nuclear plants, a probability of a core meltdown of one per 20,000 reactor years might be acceptable while a probability of one in 500 years

FIGURE 5. Illustration of typical dose-response data linking cigarette smoking and lung cancer. The vertical axis (or response) is measured by the ratio of smoker mortality to non-smoker mortality. Thus the data indicate that at 10 cigarettes per day, smokers experience five times the lung cancer death rate as non-smokers, and at 30 cigarettes a day, smokers have 15 times the lung cancer death rate. Unlike the case of ionizing radiation no extrapolation is required to the region which covers most frequently encountered exposures. Instead, the no-threshold or linear response hypothesis is directly verified for commonly experienced doses. The data are taken from the work of Dorn as quoted in *The Health Consequence of Smoking* (United States Department of Health, Education, and Welfare, Public Health Service, Atlanta, 1976), p 268.



would not be. Yet science cannot at present distinguish the two cases.[3] And even when such experience is finally accumulated, it may not be a valid predictor of future risk unless the system and its surrounding conditions remain the same. For example, even though the design of an aircraft or a reactor may remain the same, a rapid increase in terrorism or a decrease in trained personel running the technology may substantially alter the risks involved.

Foregoing Benefits.

Controlling hazards often requires foregoing benefits. The benefits of a technology are the reason for its existence. Customarily the benefits are as clear and tangible as the risks are ambiguous and elusive. Moreover, the sponsors of a technology, workers, and consumers all have a sizable stake in its existence. It is not surprising, therefore, that hazard management is not practiced to the fullest extent possible. For some groups benefits may outweigh corresponding risks, and thus it often happens that the beneficiaries of technologies are at political loggerheads with hazard managers concerned with the general welfare.

The importance of benefits also accounts for the paucity of "upstream" hazard management. Intervention of this type tends to conflict much more fundamentally with benefits than does more conventional "downstream" management. In the case of pesticides, illustrated in Figure 3, non-use of pesticides may substantially reduce usable crop yield. For nuclear power, controlling hazards by shutting down the technology requires foregoing the benefits of nuclear energy.

The intertwining of hazards and benefits ultimately requires weighing the relative importance of each. Industry, as the largest manager of hazards, must assess its likely profits against possible liability for harm and its social responsibilities as a corporation. The public official in turn must determine the tradeoff between benefits and risks in deciding "how safe is safe enough?" Unfortunately this tradeoff involves incommensurate values: health effects or ecological damage are difficult to compare with the dollar value of technological benefits. Although formal methods of benefit/cost and benefit/risk evaluation have progressed, each has serious limitations in theory, applicability, and acceptance.[4]

A Limited Capacity to React.

A myriad of hazards confront society. The American Chemical Society has registered some four million chemical compounds, some 32,000 chemical substances are already in commerce,[5] and hundreds of new substances enter the market each year. An unknown fraction of these chemicals are potentially hazardous. Consumer products cause an estimated 30,000 deaths and 20 million injuries each year, involving some 2.5 million firms. There are currently about 2.400 substances which may be causing cancer in the workplace.[6] A seemingly unending parade of "scares" in the mass media contributes to growing public concern over technological hazards.

Society is limited both in its ability to worry about hazards and in its financial capacity to combat them. Whether through space in the mass media, public opinion polls, attention of public interest

One of the limitations on hazard management is our inability to estimate the safety of such complex and massive technological activites as large hydroelectric dams.

Bureau of Reclamation

groups, or congressional hearings, society can fully attend to only a few issues at a time. Hazards compete with one another for attention. Those which can command mass media attention and the support of various interest groups get on society's agenda and those which cannot lose out. Much depends on how the public perceives and reacts to different kinds of hazards.

The physical and financial capacity of society to eliminate risk is also limited. Current annual expenditures on hazard management by the federal government are in the range of 0.7-2.1 percent of the gross national product (GNP), or about $1.4-$4.2 billion, depending on how budget allocations are interpreted.[7] If the government were to conduct standard 500-rat, $250,000 studies of carcinogenicity on each of the four million compounds currently in use, this would require an absurd $1,000 billion and two billion rats. And the price tag for hazard management extends well beyond the federal government, or even the public sector. Industry spends twenty times as much as the government on federally or otherwise mandated regulations.[8] General Motors estimates costs of environmental and safety regulations at $1 billion per year since 1974, and Dow Chemical budgets 27 percent of its total expenditures on agricultural chemicals for hazard evaluation and control. Like the federal expenditures, these costs are ultimately passed on to the consumer.

Thus the lesson is clear: for the foreseeable future hazard management will be severely restricted by these practical limitations. In applying managerial controls, it will continue to be necessary to pick and choose among a large number of potential hazards, and much that some feel should be attended to will escape attention.

The Perception of Hazards.

In one way or another, all citizens are hazard managers. It is the citizens who shape the politicians' agendas and the manufacturers' production schedules. Therefore citizens require information about the magnitude and types of threats posed by various hazards. Unfortunately, there are systematic biases in people's perceptions of risks, even ones from familiar sources, such as those listed in

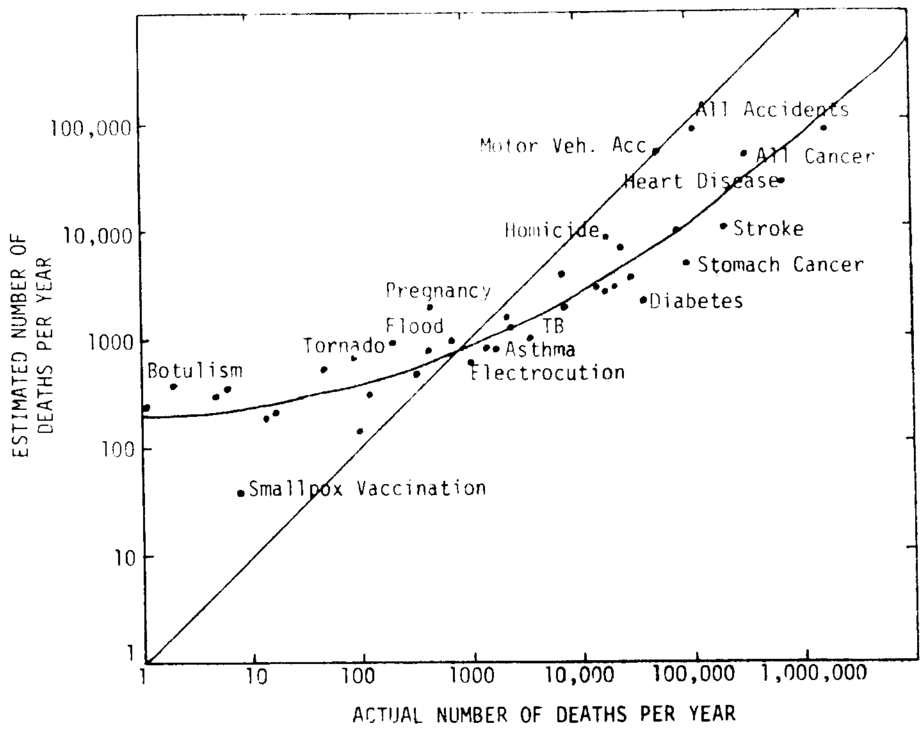


FIGURE 6. Comparison of perceived risk to actual risk. To obtain a measure of perceived risk, 40 young adults were asked to estimate the total number of deaths per year in the United States for 41 causes of death. The mean response is plotted on the vertical scale, while the number of deaths that actually occur are plotted on the horizontal scale. If people's perceptions were accurate, then the data should fall along the straight line, making a 45 degree angle with both axes. In fact people's perceptions err in at least two ways: (1) violent and dramatic causes of death are associated with greater than actual estimates; (2) most chronic causes of death are associated with lower than actual estimates. As a result, the full range of perceived risk is only about 10,000, while the corresponding range of actual risk is closer to 1,000,000. To assure that people in the experiment had some fixed point of reference for their estimated risk scale, they were told that there are 50,000 auto fatalities per year. Results similar to the above were obtained with several other groups, such as a sample taken from the League of Women Voters.

U.S. Public Health Statistics. Figure 6, drawn from a forthcoming article in this series, contrasts the perceived with the actual mortality rates for various familiar causes of death.[9] Two specific findings are: people overestimate the death rates for a few much-feared and well-publicized causes of death such as botulism, tornadoes, and floods; they underestimate the death rates for most chronic causes of death. These two findings together further imply that the full range of perceived annual mortality (about 10,000) is much smaller than the full range of actual mortality (about 1,000,000). Other studies have shown that there is greater public concern about hazards that kill people in a catastrophic way rather than in a chronic one-at-a-time fashion, or which are new, or involuntary.[10]

Such conceptions and misconceptions govern the way we think about and respond to hazards and, in turn, shape the agendas of public interest groups, the responses by politicians to their constituents, and the attempts of laypeople to manage the hazards in their everyday lives. Studies of how people respond to natural hazards betray many maladaptive tendencies, both in the short run (decisions to evacuate) and in the long-run (land-use planning, insurance purchase).[11] When hazards can only be managed at the individual level, people's perceptions may place a limit on the degree of safety attainable. For example, the finding in various countries that the vast majority of drivers consider themselves to be safer than average may explain their failure to use seat belts.[12]

Traditionally we have relied upon experts for assessing the risks of technology. Technical experts, we have assumed, should be immune to such biases—and in some respects doubtlessly are. Yet at some point even the experts must go beyond their formal methods and rely on judgment, guess at missing numbers, and assess the applicability of their models to the real problem. Are their judgments any better than those made by laypeople? No one really knows. They probably often are, but experts are prone to their own problems, such as over-confidence and reliance on formal methods. The radioactive waste problem, for example, still remains unsolved more than three decades after the birth of nuclear power, in large part because of the confidence of technical experts that, when the time of need arrived, they could readily produce an acceptable technological solution.[13]

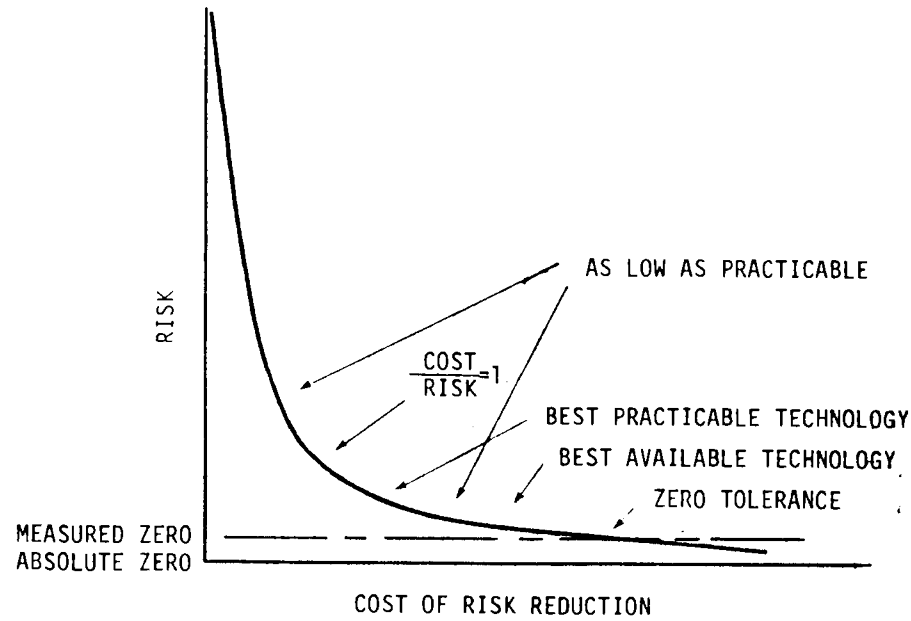


FIGURE 7. Social criteria for risk reduction. The theoretical curve illustrates the increase of cost with decline of risk. In practice such smooth and well defined curves are not available. Nevertheless, hazard managers must choose what level of risk and what corresponding cost they wish to have. Various commonly used criteria for dealing with this choice are indicated by labels on the graph. "As low as practicable," "best practicable technology," and "best available technology" are three commonly used criteria which are independent of level of risk or cost, and may occur anywhere along the curve. "Zero tolerance" indicates that risk is to be reduced to the vanishing point, independent of cost; this vanishing point in practice does not imply "absolutely zero," but a level below which no risk can be measured. The criterion "Δ risk/Δ cost = 1" implies that when risk and cost of reduction are measured in the same units (for instance, dollars) an incremental increase of cost leads to an equal incremental decrease in risk. This is the only criterion for acceptable risk which links risk and cost. However, like other criteria mentioned, it is more or less arbitrary. The figure is a modification of that appearing in William Rowe, An Anatomy of Risk (Wiley Interscience, New York, 1977), p. 78.

Value Tradeoffs.

Hazard reduction inevitably confronts the manager with difficult value decisions. Involved are such issues as the proper tradeoffs between present and future lives, between cases of sterility and mutation, between a large exposure of a small number of workers and a small exposure of a large public, between the need for energy and the elimination of an endangered species. In some cases, reducing a hazard may conflict directly with some other widely held value or political goal. Potential infringement on First Amendment rights, for example, has undermined efforts to reduce violence and stereotyping in television programing. Recently President Carter intervened to weaken proposed regulations to protect some 150,000 to 800,000 workers from cotton dust disease on the grounds that the regulations added to inflation.[14] The difficulties posed by such tradeoffs will undoubtedly continue to limit the effectiveness of schemes (such as our model) for hazard management.

Our tolerance of risk varies widely among activities or technologies. We tolerate, for example, 50,000 fatalities annually on our highways but demand extremely high safety standards for air travel. We spend $1 million to save a life in the nuclear industry, but only a fraction of that for fossil-fueled plants or liquefied natural gas facilities. We expend more funds on combating cancer than on heart disease, though the latter is a greater killer.

The inconsistency of public values toward different hazards greatly complicates hazard management. Normally Congress provides only very general guidelines for judging safety: risk should be "as low as feasible," "as low as reasonably achievable," or "not unreasonable considering the benefits." Faced with varying standards for risk reduction (Figure 7), the decision-maker must somehow pinpoint the level at which acceptable safety has been achieved. Although a variety of methods are available for determining the acceptability of risk (see box), none provides a completely adequate solution. Further, risk to human health is only one value dimension of acceptability; a variety of other considerations (equity, impact upon institutions, ecological impacts) may take on greater importance in any given case. Finally, the manager must anticipate that societal values change, and that what is considered safe today may be viewed as unsafe tomorrow.

Institutional Weaknesses

Existing institutions limit in several ways the comprehensive management of hazards suggested by the model. Institutions, whether regulatory agencies, congressional committees, or public interest groups, grow helter-skelter, creatures of the concerns that are dominant at the time of their genesis. A host of federal agencies, for example, share the task of regulating environmental carcinogens. A dozen congressional committees exercise oversight responsibility for nuclear energy. At times a single institution (such as the Joint Committee on Atomic Energy or the Bureau of Reclamation) has responsibility both for promoting a technology and for controlling its hazards, and conflicts of interest are the inevitable result. In other cases, a regulatory agency has jurisdiction over only part of the hazard causal chain, encouraging a piecemeal approach to hazard management. Alternatively, one agency may be responsible for one pathway of a hazard (FDA's responsibility for carcinogens in food) while a different agency, often with a different legislative mission, is responsible for a different pathway (EPA's responsibility for carcinogens in air and water). Finally, the fact that American institutions are federal rather than unitary ensures that policies made at one level must frequently be implemented at others. It is one thing, for example, to announce a national 55-mile-per-hour speed limit and another to secure state and local police enforcement; similarly, it is useless to mandate water pollution abatement when states lack the technical resources required for effective implementation and enforcement.

Increased societal concern about the hazards of technology has led to increasingly heavy demands on this quiltwork of institutions. Early health and safety laws and the original regulatory agencies in the United States tended to have narrowly drawn objectives, such as ensuring the safety of particular products (meat, drugs, cosmetics, food additives), of particular industries (electricity, highways), or particularly vulnerable groups (children swallowing poisons or riding school buses). Increasingly, agencies with limited resources are being charged with responsibility for extensive and varied hazard domains: the Occupational Safety and Health Administration has to regulate *all* technological hazards in the workplace microcosm; the chronically under-funded Consumer Product Safety Commission must deal with the hazards associated with *all* consumer products; the new EPA Office of Toxic Substances has to be concerned with thousands of potentially toxic substances.

Perhaps the single greatest failing of our institutions has been their frequent inability to deal with the most important hazards first. Instead, massive attacks are often made on what are clearly problems of secondary importance. A forthcoming article in this series will describe the way in which the Consumer Products Safety Commission, charged with regulating a wide range of consumer products, concentrated much of its initial effort on setting standards for swimming pool slides, despite the fact that it had clear evidence that other areas offered much greater potential for saving lives.[15] Similarly, the Department of Transportation has spent large sums of money on highway safety countermeasures that save only a few lives, while it has waffled for more than ten years on the single most effective countermeasure known—mandatory seat-belt use and/or installation of air-bags in all new cars.[16]

Given a fragmented institutional structure that has great difficulty getting its priorities straight, the question arises, who should be entrusted with the responsibility for protecting the public from the full scope of the hazards of technology? In many respects industry would appear to be the logical candidate. Positioned at the source of the evolution of many hazards, industry possesses an imposing array of technical resources which the public sector can hardly expect to replicate, as well as having immediate access to proprietary information often unavailable to the public official. Yet such a role for industry would appear to be fatally flawed because of its inevitable ambivalence between profit maximization and social responsibility.

The current adversarial system of regulation entails its own problems: unending litigation, delay, and continuing enmity between hazard manager and technology sponsor. And yet, cumbersome as it is, the system does not assure independence of regulatory agencies from industry. Many agencies were either established to be, or have become over time, the protectors and allies of the very industries they are supposed to regulate. Government agencies frequently depend upon the technical expertise of industry for information and analysis or recruit their staffs from the ranks of the regulated. A recent Common Cause study found that of the top 429 employees of the Nuclear Regulatory Commission, 279 came from NRC licensees or contractors; of 162 NRC consultants, 105 were also being retained by NRC licensees and contractors.[17] Perennially subjected to the charge that it has been "captured" by the drug industry, the FDA has undergone, in a little less than forty years, more than twenty formal reviews of its operations.[18] Hazard managers, in short, may become more concerned with the potential adverse impacts of hazard control upon the technology sponsor than with the public consequences of hazards.

FOUR METHODS FOR DETERMINING ACCEPTABLE RISK

Risk Aversion—involves the maximum reduction of risk possible with little or no comparison with other risks or with benefits. Standards of zero tolerance (e.g., the Delaney Amendment) and dose-consequence threshold levels are examples.

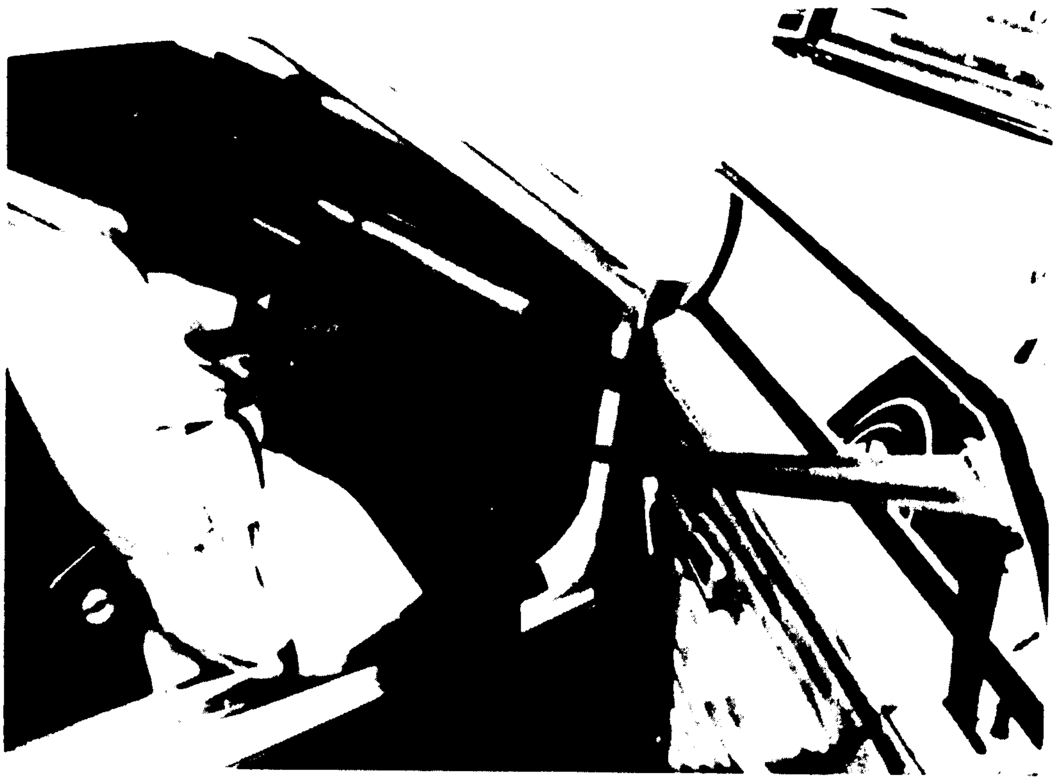
Risk Balancing—assumes that some level of risk above zero is acceptable and defines the level through comparison with appropriate reference cases, such as similar technologies, natural background levels, or risks previously determined to be acceptable.

Cost-Effectiveness—seeks to maximize the reduction of risk for each dollar expenditure for safety. Acceptable risk may be set by breaks in the slope of risk reduction efficiency for a given hazard or by allocating public funds among hazards for maximum risk reduction to society as a whole.

Cost-Benefit Balancing—recognizes some level of risk above zero. Acceptable risk is defined by balancing the benefits of an activity or technology against the level of risk it presents. The risk tolerated, therefore, increases proportionately with the magnitude of the benefits involved.

The Hazards of Hazard Management

The full range of hazard control strategies is often not utilized because of the possibility that such attempts at control will themselves create new hazards. In many instances, well-intentioned hazard control efforts have either exacerbated the hazard itself or created new ones. The numerous driver-education pro-



People's perceptions limit the level of hazard safety attainable. Perhaps it is because the vast majority of drivers consider themselves safer than average that they fail to use seat belts. One possible solution, the Volkswagon automatic seat belt.

grams, for example, designed to create safe drivers, have actually increased the number of high-risk persons entering the ranks of drivers, thus increasing the hazard of automobile accidents.[19] The use of TRIS-treated pajamas, designed to reduce a fire hazard for children, created a new, unforeseen cancer risk.[20] The widespread adoption of biodegradable pesticides, while reducing the public risk, has exacerbated the occupational hazard.[21] Effective hazard management must recognize the interconnectedness of hazards and specifically attempt to assess the hazards that will be generated by prospective solutions or the substitution of alternative technologies.

A number of problems attend the growing trend toward governmental regulation of hazards. It is extremely difficult to control the multitude of forms in which a hazard appears and the various pathways it assumes. EPA's task of formulating a set of generic standards under the Safe Drinking Water Act for the 40,000 local public water supplies in the United States exemplifies the complexity of the problem. In the absence of cooperation from industry or other technology sponsors, broad-scope regulation may in the end achieve little. Not without justification, industry fears that an ill-conceived regulation may blunt research and development, impede technological growth, and keep useful products off the market, with possible detriment to industry and public alike. Another effect of regulation could be to entail such high costs that only giant corporations will be able to survive. This in turn could lead to less competition and less potential for innovation. Finally and most importantly, there may be a danger that growing regulation will, in the long run, increase the vulnerability of society. It is possible that the more hazards are controlled by governmental institutions, the less competent the individual will become in hazard management.

Improving Hazard Management

Given the variety of constraints upon effective hazard management, the question is, can we do better?

The first answer must be that, despite the parade of hazards in the mass media, we are not doing all that badly. As is pointed out in the first paper in this series,[1] technology has on balance substantially improved the human condition. But the sources of the hazard burden are changing and are becoming increasingly difficult to manage.

The answer of hazard managers to the question is sanguine: Of course it is possible to do better, but we must work harder. We must allocate more of society's resources to the task, collect more data, conduct more experiments, develop better methods, educate the public, think more deeply about our own values, and create better social institutions. While an upbeat position, this tack can obscure the nature of the difficulties we face and lead us away from, rather than toward, sound strategies of hazard management. It reflects the hubris of science that all difficult problems are solvable, that science and technology can prescribe for the ills that beset us now and in the future.[22]

Two other fashionable answers which are even less promising are: (1) We will never be able to understand, much less control, the risks associated with new technologies, so let's do without them; they're really not all that necessary anyway. (2) We will never understand new technologies unless we use them and thus gain first-hand experience and, if we are committed to safety, we can provide adequate protection through due caution and conservative design. Those very limits to current hazard management which are the motivation for such solutions make it impossible to defend either of these solutions on scientific grounds. Each involves a political/ethical position which determines how uncertainties and value issues will be resolved. Each requires not only a leap of faith but a willingness to bear very substantial consequences. It seems likely that neither of these extreme positions will muster enough adherents to carry the day. Rather it is likely that we shall continue to muddle through in a somewhat incoherent and haphazard manner. But even in such a context, there appear to be some significant opportunities for improving hazard management.

Working harder is, of course, part of what is required. But beyond that, we need to recognize that while some limits may be reduced, others will prove relatively intractable. We must be realistic in our expectations of how soon science will be able to answer what is now unanswerable. Hazard management must assume that for many hazards an understanding of causality will continue to elude us for the foreseeable future. We may have to decide, therefore, to live with some hazards, reduce others, and do without some technologies which entail hazards; and these decisions will have to be made in the context of continuing substantial uncertainties. Society's capacity to deal with myriad hazards is unlikely to increase dramatically; but all societies have their taboos and we may have to forego some beneficial technologies in order to avoid some classes of hazards (as suggested by the Delaney Amendment) so that we can more effectively concentrate our efforts on others.

The conflict between benefits and risks is intrinsic to technological change--it cannot be resolved. But a more adequate conception of benefits is required, one which extends the notion of benefits to improved health, a safer home and work environment, and more livable natural and built surroundings. Greater understanding of perceptions and values will permit tradeoffs in hazard management that are consonant with the genuine but unarticulated preferences of the public. Methods which clarify the nature of these tradeoffs will permit more considered and reflective public policy.

No panaceas for our institutional difficulties are likely to appear. But as our understanding of hazards improves, more effective organizational structures will be possible. The current attempts to coordinate governmental efforts to combat environmental sources of carcinogenesis point to one such possibility. More fundamentally, we have yet to learn how to exploit the potential of industry as a powerful source of hazard control. Over the longer term, new institutions may be required as well as more effective means of enhancing the individual's capability as a hazard manager.

Finally, in seeking to control existing hazards we shall continue to create new ones. But the developing theory of hazard management holds promise for wiser selection among control strategies, for warning of new technological hazards, and for overcoming a case-by-case, trial-and-error approach to the hazards that beset our daily lives.

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NOTES

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