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UCLA School of Engineering and Applied Science

Prepared for the
National Science Foundation
under Grant PRA 79-10804

"Alternative Risk Management Policies for
State and Local Governments"

Principal Investigator: David Okrent

UCLA-ENG-8240
JUNE 1982

FINAL REPORT

UCLA SCHOOL OF ENGINEERING AND APPLIED SCIENCE

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This material is based upon research supported by the National Science Foundation under Grant No. PRA 79-10804. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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16. Abstract (Limit: 200 words)

A study of risk management at the state and local levels is described and some proposals for improvement are considered. Risk management is distinguished from insurance management in that it is unconcerned with fault in the legal sense and tries to anticipate losses to life and health as a means of devising corrective strategies. Two case studies, one of seismically substandard buildings in Los Angeles and one involving risks from drinking water, are presented. A wide variation in risk management is shown to exist among states and within states and, at the local level, the variation is shown to be even greater. It is found that quantitative grasp of risk seldom exists in state and local government.

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ALTERNATIVE RISK MANAGEMENT POLICIES FOR STATE AND LOCAL GOVERNMENTS

Supported by National Science Foundation
Grant PRA 79-10804

David Okrent
Principal Investigator

FINAL REPORT

June 1982

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PREFACE AND ACKNOWLEDGEMENTS

This is the final report for the project entitled "Alternative Risk Management Policies for State and Local Governments" which was performed by the University of California, Los Angeles under Grant No. PRA 79-10804 from the National Science Foundation, beginning in the summer of 1979. The project had the benefit of an Advisory Committee, the membership of which is listed in Appendix A. Five topical reports have been prepared separately as part of this project; the titles and numbers of these reports are listed in Appendix B. The principal results and conclusions emanating from these topical reports are included in the final report.

The research team for the project, which is listed in Appendix C, included participants from Decision Research and from the University of California, Riverside, and the University of Southern California.

We wish to thank the National Science Foundation for its support. We also wish to thank the members of the Advisory Committee and the personnel of the National Science Foundation for the wide-ranging suggestions, comments, and criticisms received during the course of the project, including preparation of the topical reports and the final report.

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EXECUTIVE SUMMARY

1. INTRODUCTION

A study of current practice at the state and local level with regard to the management of risk to public health and safety is described and some proposals for possible improvement in current practice are considered. Only risk management in the preventive mode, as distinct from the emergency response mode, is considered herein, and only involuntary risks, as distinct from occupational or voluntary risks, are considered. Risk management, in our usage, is distinguished from insurance management in that the latter anticipates financial liabilities arising from nonfeasance or malfeasance affecting both lives and property. Risk management, in our usage, is unconcerned with fault in the legal sense and tries to anticipate losses to life and health, but not property, as a means of devising corrective strategies.

The study of current practice included unstructured interviews and a questionnaire posed to a limited sample of state and local officials. It also included two case studies, one of seismically substandard buildings in Los Angeles, and one involving risks from drinking water and some associated problems arising from the disposal of hazardous chemical wastes.

As should be anticipated, a wide variation in risk management practice exists among states, and within states, with regard to the attention given to various risks. At the local level, the variation is still wider, ranging from a sophisticated handling of at least some risk issues in a large city like Los Angeles, to the absence of any risk management (except for the police and fire departments and similar community functions) in a sparsely settled county or small town or city.

Society's knowledge of risk is far from complete. There are significant gaps in societal knowledge of risks from both chronic exposure to a multitude of chemicals and from accidents having a very low probability but possibly high consequences. A fundamental finding of this study is that a quantitative grasp of risk seldom exists in state and local government. The information that is available to society as a whole is frequently not part of the background of responsible local officials, and the concept of managing risk to reduce ill effects on health and safety is sometimes foreign to local governments which are organized to respond only to crises.

2. CASE STUDIES

The two hazards chosen for case studies differ widely in their characteristics. As a result they led to contrasting conclusions concerning the proper role of local government.

Drinking water introduces a small, difficult-to-quantify risk to essentially all members of the community. The risk is chronic, not catastrophic, and is common. The contaminants which are likely to be harmful have not all been identified. They are usually invisible. They are not all easily measured. The federal government has prescribed standards for "safe" water, but the risks at these or higher levels of contamination are poorly known, and the potential sources of contamination are multiple and not readily managed. A better scientific resolution of the risks from drinking water is beyond the capabilities of local government. Furthermore, management of this hazard conflicts with, rather than augments, the traditional service delivery function of local government.

The study group concludes that these characteristics tend to diminish the local role in risk management. Chronic risks of low magnitude do not ordinarily stimulate immediate demands for protection; risks common to many localities and concentrated in none are not viewed as principally local problems; hazards eluding easy detection exceed the technical capacity of local governments; highly uncertain risk estimates pose political perils for local officials; and risk management practices impeding or increasing the cost of service delivery may also be perilous.

It is concluded that local government can usually do little beyond monitoring for federally identified contaminants, unless local government happens to be in a position to regulate potential polluters of its own water supply. The responsibility for controlling contamination of drinking water appears to fall on state government; however, resource limitations require a major federal role in providing the necessary scientific information.

Seismically substandard buildings, on the other hand, introduce a significant risk primarily to an identifiable subset of the total population. The risk is catastrophic. At least in Los Angeles, the risk to these individuals is substantially larger than that posed by drinking water to any individual in the same city. The risk may be large compared to other accidental risks. This is a risk which can be and has been evaluated by the local government involved; furthermore, the responsibility for building safety clearly lies with local government.

The risk from earthquakes is not unique to residents of Los Angeles or even California. It may be less in most other parts of the country, but whether the matter has been evaluated and on what basis judgment concerning the need for seismic upgrading would be made is uncertain.

Seismically substandard buildings exemplify a class of risks of accidental death which local government is generally not consciously managing. Similarly, risks from the storage of large quantities of explosive, flammable or toxic chemicals have usually not been evaluated by or for local government in terms of possible low probability causes of a major accident.

Water and air pollution risks are also managed unevenly, or even poorly on occasion. Although federal regulations exist for drinking water and on air quality, there is a frequent incidence of the discovery of intolerable contamination of water or an unacceptable, even dangerous, degree of pollution of the ground and/or air in the vicinity of a smelter, waste disposal dump, factory, or some other technological aspect of society.

One might define a formal process of risk-management as normally involving the following:

- hazard identification
- risk quantification
- comparison with other risks, assessment of benefits, and assessment of risk acceptability and options for risk reduction
- policy formulation and implementation
- risk monitoring and intervention

The study group found that where any of these steps were practiced at the local level, it was typically the last step, that of monitoring, performed in response to regulations usually established by federal authorities. This practice was termed "management by compliance". The other form of risk management found in local government is risk management by reaction, usually stimulated by an emergency or some newsworthy event.

States differ widely in their resources and in their attitudes toward regulation of industry, agriculture, mining, etc. Based on a limited survey, the study group finds that where states practice risk management, they tend not to use formal methods, such as cost-benefit analysis and decision analysis, to structure the problem, define the alternatives and their consequences, and provide measures of the worth or desirability of each alternative.

The decision analysis performed on seismic hazards to occupants of unreinforced masonry buildings in Los Angeles indicates that this risk may be between ten and 100 times greater than the risk from fire. Some amount of seismic upgrading of these buildings to improve their capabilities to withstand earthquakes appears to be cost-effective with almost any reasonable set of assumptions, and the real question is how much and who should bear the cost (a question which is complicated by the existence of rent control). The study group concludes that the risk in the unreinforced masonry residential buildings is too large and an improvement in safety is required. The study group also favors improvement for the non-residential buildings; if this is not done, the group believes the city has an obligation to inform the public of the risks involved.

The decision analysis used a measure of society's willingness to pay to reduce the likelihood of a statistical death that increases non-linearly with higher probability of death to the individual. However, in a very limited survey of individual opinion, it was found, not surprisingly, that the older residents (>70 years of age) are less willing to pay an increased rent to reduce seismic risk, and that the general public do not distinguish critically between a risk of one in 100 and one in 10,000 per year when deciding what increment in rent is acceptable to eliminate such a risk.

The study group believes that the regulatory approach for such a problem needs to consider who benefits directly from a planned action and to provide incentives to those bearing the costs, if possible.

The study group notes that, even in Los Angeles, which has an acute, well-defined problem and knowledgeable employees, there is evidence that the city has been unable to fully enforce seismic design regulations because of financial and trained manpower shortages. The shortage of knowledgeable manpower is far more acute in most other places.

3. ON THE METHODOLOGY OF RISK MANAGEMENT

From the decision analysis of the case of seismically substandard buildings, it was possible to derive a short series of questions to help guide the management of an identified risk, as follows:

- Is the risk significant?
- What are the mitigation alternatives?
- What are the costs and benefits?
- What are the legal, social, and political ramifications?
- What constitutes a balanced approach?
- What are the enforcement and implementation issues?

Of course, there are many risks of potential interest. The study group investigated several different approaches to the classification of risks and concluded that no single taxonomy is likely to be used by an office of risk management. The group believes that multiple taxonomies (and their associated risk profiles), if completed and fleshed out, would provide a portion of the framework needed for decision making by identifying a more complete array of risks and by profiling these risks for several geographic regions and sub-regions.

The study group also argues that a set of appropriate risk taxonomies and profiles may introduce the person(s) responsible for risk management to a new way to quantitatively represent risk. The favored risk classification approaches included the following:

- situation in which the hazard or risk is encountered
- cause of the hazard or risk
- the kind of hazard or risk
- geographic division of risk management responsibility

The study group recommends the development of a national risk management information system. The group argues that there is a need for risk classification not only in order to help accumulate and retrieve information, but also to help think about risks. The group feels that classification permits comparison; it insures that some categories of risks are not altogether ignored; and it is a prolegomenon to systematic thinking about risks.

The study group believes that the responsibility for initiation of a national risk management information system must fall on the federal government, since no state or local community has the authority or resources. The group feels that the existence of a national risk management information system could overcome several of the weaknesses of local government in dealing with hazards, and that by providing local governments the information wherewithall on which to base risk management decisions, the federal government would reinforce the political process in states, counties, and cities. The group does not argue that this would or should necessarily lead to a more nearly uniform approach to risk management among the states.

The study group takes the point of view that while the elected representatives will ultimately need to make the policy decisions concerning risk, the structuring of the alternatives and the assessment of the probabilities of uncertain outcomes is largely a highly technical enterprise and should be done by a technocratic agency (or agencies). The group concludes that the task is too formidable for local government and is inappropriate for the federal government, and that hence, the management of risk must start at the state level with the possibility of strong regional offices which would interact both with the central office and with local officials.

There will exist a need for criteria by which such a technical agency can judge whether a hazard requires attention; the setting of such criteria will involve socio-political decisions.

Given the necessary leadership and support by the state, one can envisage a possible functional mode for the office of risk management of a large city, assuming that the office was given responsibility for trying to prevent or reduce unnecessary yet significant risks and had a reasonable amount of resources available. The outline of such a function might be as follows:

(1) Develop tentative threshold criteria for action appropriate to identification of potential sources for each category of hazard or risk developed from the taxonomy. For example, for health effects from pollutants in drinking water, there might be five or more thresholds for each chemical or pollutant. Some threshold quantity of waste disposed of per year would require notification of the responsible agency, including means of disposal. For some larger quantity of a chemical, a risk evaluation would be required to be provided by the disposer to the agency. Each chemical that could pose a threat to drinking water in an accident would require notification of an agency. For each of these, some larger quantity might require a risk evaluation.

(2) Develop ordinances to identify hazard and risk sources which meet threshold criteria.

(3) Formulate a basis whereby governmental entities can, in practical ways, assess risks that may exceed "acceptable" limits.

(4) Prepare evaluation processes, methodologies, etc. whereby source identification methods can be checked for adequacy. For example, how would PCB-containing transformers be detected; how would asbestos in buildings, specifically schools, have been thought of as a possible source of air pollution; and how would the use of uranium tailings for

home building material have been identified and detected?

(5) Arrive at a methodology for determining other attributes which may be relevant to decision-making for risk sources which exceed threshold criteria for possible action. For example, such factors would include the benefit associated with the technology responsible for the risk, the dollar cost of reducing the risk, and various socio-economic political issues.

(6) Suggest methods for acquiring appropriate information about other attributes.

(7) Identify and bring forth factors which will potentially enter in judgment on risk acceptance and risk management.

(8) Formulate a proposed risk management policy for each hazard class.

4. ON POLICY ALTERNATIVES

The study group postulates several constraints which, in its opinion, should guide the formulation of alternative risk management systems, as follows:

- o Risk judgments are comparative and comparison entails quantification.
- o Risk judgments may vary across localities.
- o Risk judgments need legitimacy.
- o Risk judgments may need revision in light of information concerning new hazards and new information concerning the riskiness of known hazards.
- o The costs of obtaining the information needed for risk management judgments can be high and should be distributed equitably.

The study group defines and discusses the following five models of risk management:

- o the existing system, which is largely dominated by the federal government
- o the "weak" risk manager, in which the existing system is buttressed by strengthening local capacities to utilize competent professional judgment in managing diverse risks
- o the network of risk managers, whereby relatively weak offices at the state and local level tie into a network that facilitates sharing of data on hazards, risks, risk acceptance criteria, and risk policies
- o the "strong" local risk manager who is charged with the full spectrum of risk management activities, from risk identification to policy and implementation
- o a radical decentralization of risk management, whereby prima facie evidence of riskiness above a low threshold compels the source of risk, no matter whom, to obtain appropriate risk studies showing the acceptability of the safety of proposed activities before proceeding with them.

At the local level, the study group has arrived at a preference for the approach involving a network of "weak" risk managers. The group suggests that the basic elements of a network approach would involve the following:

- o a system of classifying risks
- o central storage of risk information

- means of developing needed information
- the maintenance of risk profiles for localities
- risk managers trained in the utilization of the information.

The study group cautions that the network concept is novel and relies upon information technologies not heretofore utilized. They state that developmental work would be required prior to its implementation and that studies would be needed of the appropriate changes in federal role and policy.

The study group favors a major role in risk management by the states employing an approach lying somewhere between the "strong risk manager" and the network of "weak risk managers". While the states have some resources to devote to the task and should take a strong, leadership role, the overall task of developing methodology, data, and criteria, and of performing complex analyses is too large for any state, and will require a wide variety of assistance from the federal government and the benefit of cooperation and the interchange of information among the states.

By way of some specific steps which should be of value in advancing the task of risk management, the study group makes several recommendations, including the following:

- the development and use of multiple risk taxonomies to serve as a background information source and as a working tool for an office of risk management
- the examination of economic incentives, such as making full liability insurance available
- the examination of a risk tax as a means of internalizing the cost of risk and of providing an incentive for cost-effective risk reduction measures
- the holding of workshops on risk management to inform state and local officials.

If the network approach is to receive serious consideration, several studies may be appropriate as a next step, including the following:

- a policy study to identify changes in federal regulations needed for an effective network
- an effort to construct alternative models of information systems
- an experimental effort aimed at determining the likely utilization and effectiveness of a risk management information network.

It seems that studies such as these might best involve groups like the National Conference of State Legislatures and National Governors' Association.

Each state will have its own special risks to consider. Each state will have its own strengths and its own limitations on resources. One cannot expect to deal with all of these problems simultaneously. However, a joint examination of the feasibility and desirability of a network approach by several state and local governmental entities, together with an examination of the implications for a changing federal role, could provide the necessary information for a judgment on whether there is merit in some version of the network alternative to risk management.

An important finding, which is central to an improvement in local risk management, is the need for introducing quantitative conceptions of risk at the local level, to complement the traditional political and social conceptions. The absence of thinking of risk in quantitative terms, of necessity, limits the adequacy of the information which enters the decision making process; this must be remedied if an improved approach to risk management at the local level is to be developed.

An equivalent, albeit different, effort should be devoted to the identification, categorization, and measure of the benefits associated with the societal activities which introduce these risks. This is a field in which relatively little solid information exists.

A considerable number of specific issues which require further study have been raised during this project. Several of these are discussed briefly below:

- How should state and local governments approach the question, "How safe is safe enough?", for those hazards for which they have responsibility and for which guidance has not been provided by federal regulatory agencies or other recognized authoritative groups? Benefits and societal needs, among other attributes, may enter into a judgment that something is "safe" or "unsafe". Thus, there will not be a unique definition of "safe". Nevertheless, decisions are continually being made by state or local governments which directly involve an imposition of risk on their constituents. And, frequently, by acts of omission, they permit risks later judged to be intolerable to be imposed on their constituents. How should society ascertain whether the upper threshold of acceptable risk is being violated for some of the people? At what point would resources expended to do this exceed the benefit obtained? Are there risks which are flatly unacceptable and which require a mechanism to assure their identification and correction?
- British law imposes a requirement on technological facilities to keep them as safe as practical. Is there a similar requirement in the United States? If not, should there be, and how should it be

instituted? Would such a risk requirement provide the appropriate incentives for risk management, or is it limited to "attributable effects"? Is there a workable mechanism which achieves the transfer of the cost of risk from the public to the liable party for non-attributable risks?

- Is there a mechanism for achieving a more cost-effective expenditure of societal resources committed to risk reduction? Should cost-effective expenditure for risk reduction be a goal of state and local government, or should socio-political factors dominate?

- The safety of the storage of large quantities of hazardous chemicals appears to be the responsibility of local government for the most part. This is largely handled via regulations imposed by the fire and building departments, or their equivalent. Experience in the United States and elsewhere indicates strongly that catastrophic accidents are rarely evaluated in this process, and that the risks involved to individuals living or working nearby can vary widely and sometimes be quite large. If local governments generally lack the resources and expertise to regulate adequately the storage of large quantities of hazardous chemicals, what, if anything, should be changed? Should a federal or state approach similar to that under adoption in the United Kingdom be pursued?

- Are the current federal regulations with regard to the disposal of hazardous wastes and to local sources of ground, water and air pollution adequate? If not, how should they be changed? If adequate in principle, do they work in practice? What does it take at the state and local level to assure the necessary compliance?

- How should limitations on total available societal resources be factored into risk management at the state and local level? Can analysis provide meaningful answers on when further expenditures on direct risk reduction may lead to a net increase in societal risk because of economic or political disruptions? Are such considerations of importance only in a national sense, or do they apply at the state and local level? If so, how?

- Frequently, measures taken to reduce one risk introduce a new risk, possibly of a different nature. Can the matter of competing risks be included into risk management at the state and local level?

If so, how and under what circumstances?

- If the state has jurisdiction and responsibility for managing risks that can impact strongly on a local government entity, either from the point of view of health or economics (e.g., the costs of cleanup, or of alternate and expensive facilities such as new wells made necessary because of contamination of the old ones), how should local government assure itself of the adequacy of the steps taken by others on its behalf?

The problems in developing a more systematic and more nearly optimal approach to risk management at the state and local level are difficult, to say the least. Nevertheless, the continuing series of episodes of local ground, air and water pollution reported almost weekly in the press are only one piece of evidence that all is not well in this regard.

A Congressional examination of the feasibility and usefulness of steps by the federal government to assist the development of improved risk management at the state and local level may warrant consideration.

Part I: A Perspective on Risks and a Review of Current Practice in Risk Management

Chapter 1. Introduction (Okrent)

Chapter 2. The Concept of Risk Management (Meyer)

Chapter 1. INTRODUCTION

1.1. Outline and Definitions

This is the final report for NSF Grant PRA 79-10804, entitled "Alternative Approaches to Risk Management at the State and Local Level". Although several topical reports have also been prepared as part of this study, this final report is intended to provide a summary of the entire project and a synthesis of the various efforts.

The original proposal to perform this study provided the following summary of the contemplated effort:

> "The last decade has seen a very rapid expansion of activity by the federal government with regard to societal hazards and risks. And although federal regulatory decisions have tended to avoid quantifying the question 'How safe is safe enough?', there is growing attention on the federal level to efforts to quantify risks and to examine various possible policies concerning 'acceptable' or 'assumable' risk. Many hazards and risks in society fall directly under the control of state, county or municipal governments and, although there exists much current effort on risk quantification and risk management at the federal level, rather little information is available on the extent and magnitude of risks subject to local control and little has been done to examine the ramifications of various possible risk management policies at the state or municipal level. The objective of this study is to make advances in our knowledge and understanding of hazards and risks subject to state and municipal control, and to make an evaluation of alternate approaches to quantitative risk acceptance criteria that could form a basis for choice in decision making or risk management policy by state and municipal authorities. A two-step, case-study-focused approach is planned: 1) Define and quantify as is possible, several actual 'locally-controlled' situations involving 'involuntary' risk to individuals and society; 2) Pose several, alternate hypothetical sets of risk management policies, and examine them in terms of the benefits, costs, risks and constraints arising from the above situations, all within a broader perspective of societal risk on a local and national level. As a minimum, the product of the study would be several case-study examinations of the consequences (socio-economic-political, as well as direct health and safety) of alternate risk management policies.

Optimistically, the product may be the beginnings of a general approach to risk management at the state and municipal level".

We shall see that the proposed agenda for the study was followed to a considerable degree, but that, as in much research, variations from the original plan developed as the study progressed.

The report is divided into ten chapters which can be envisaged as being grouped into four parts. The first part of the report consists of a long introductory chapter and a chapter which reviews the status of current practice in risk management at the state and local level. The second part of the report consists of Chapters 3 and 4, each of which provides a fairly lengthy summary of the results of a case study of a particular risk. The third part of the report consists of five chapters, each of which provides findings and recommendations by individual participants in the study (or a team of two) as they have arisen either from the particular discipline of the author or from the particular subject matter discussed in the chapter. The fourth part consists of Chapter 10, which is intended to provide a synthesis and partial summary of the work, to present some general recommendations, and to raise some questions for further consideration.

We shall see later that one of the principal findings of the study is that only a limited knowledge of quantitative information about societal risks usually is to be found within the responsible state and local governmental entities and that a quantitative approach to risk management is rare. Similarly, rather little background is available within many such entities with regard to prior considerations of quantitative risk criteria or to the kinds of societal expenditures which are made to prevent a premature death for various hazards. Hence, a review is provided in the introductory chapter in order to place the overall subject in perspective with regard to topics such as these.

In view of the subject of this grant, it was relevant early in the study to examine how and to what extent risk management is practiced at the state and local government level. This matter was pursued in a few ways, including informal, ad-hoc personal discussions with responsible officials, and by means of a limited set of brief, organized interviews employing a specific questionnaire. The results of these studies and some conclusions resulting therefrom are summarized in Chapter 2 by M. Meyer, including the contributions of W. Bordas and K. Solomon.

In order to provide a greater depth of insight into the problems of risk management, two case studies were undertaken as part of the overall study. The first dealt with a chronic risk to public health, namely that from contaminants in drinking water, and a potentially associated problem, namely the disposal of hazardous chemical wastes. This is a risk faced by essentially all members of society, and while it may be statistically a small risk to each individually, it may pose a relatively large risk to society as a whole. This study and the conclusions emanating from it are summarized in Chapter 3 by K. Solomon and M. Meyer.

The second case study dealt with a radically different hazard, namely that of death to inhabitants or occupiers of seismically substandard buildings in Los Angeles as the result of a large earthquake in the vicinity. Here, the population at a relatively large risk represents only a subset of the overall population. The costs of backfitting safety measures are high; low-cost housing is relatively scarce; and a multiple set of decision paths can be generated, depending on whether one takes the point of view of the city regulator, the landlord, or the renter. This study is summarized in Chapter 4 by R. Sarin.

We shall see that these two studies pose very different kinds of risk management questions. The small, chronic and ubiquitous nature of the risk from drinking water, coupled with the technical difficulties in identifying serious contaminants and quantifying the risk, together with the conflict between the service and protection functions of local government, make this a poor candidate for strong local control. The seismic risk, on the other hand, is potentially catastrophic, imposes relatively large risk on a subset of the inhabitants, and traditionally falls in a category regulated by local government. Hence, it is a good candidate for local risk management. However, there will be complex problems in its management, and the problems will not be unique to Los Angeles or California, except in degree.

Having reviewed the results from the case studies, the report next goes into an examination of some possible approaches to risk management at the state and local level. In Chapter 5, K. Solomon and M. Meyer present a summary of a third topical report prepared as part of this overall study, namely a description of several different ways in which it is possible to characterize risks into a taxonomy, together with an evaluation of those taxonomies most likely to be useful for the task of risk management. They also provide some recommendations which arose from this study.

The next four chapters present varying points of view on how one might approach risk management at the state and local level. In Chapter 6, G. Apostolakis presents a definition and structure of an "Office of Risk Assessor" in which he discusses a somewhat idealized, decision-theoretic approach of how risk management might proceed if it was not constrained by resources, or by political, economic and social factors. In Chapter 7, M. Meyer and K. Solomon present and discuss several policy alternatives to risk management, primarily from a politico-sociological point of view. In Chapter 8, using a combined psychological-political point of view, W. Bordas presents some findings and makes some general policy recommendations for improved state and local risk management.

Most approaches to risk management envisage the adoption of ordinances, laws, regulations, etc., to accomplish the desired end. In Chapter 9, P. Gordon presents a possible alternative or complementary approach to risk management, one which provides incentives to those responsible for sources of risk to reduce their impact.

Finally, in Chapter 10, a synthesis of the efforts and a set of conclusions resulting from the overall study are presented by D. Okrent.

We complete this first section of the introduction by defining several terms which are frequently used throughout the report.

o *Risk.* The term risk is used in the literature in many ways. In this study we shall use risk to describe the likelihood per unit time of death, injury or illness to people. This will usually be represented in terms of the product of the frequency (or probability per unit time of an event) multiplied by the consequence of the event, summed over all relevant events. However, it is sometimes argued this compression of many possible contributing events, having a wide range of frequencies and/or consequences, loses much information, and that a proper description of risk will display a curve of frequency versus consequences.

Some use the term risk when the results are uncertain. For many of the matters of interest to this study, the likelihood of death, illness or injury to an individual or to society will be quite uncertain. We would call it a risk, however, even if it were known without a doubt that 50,000 people will be killed in automobile accidents next year. The fact that the risk is usually not known precisely we will treat or allude to in terms of some level of uncertainty in our results or in terms of confidence limits.

We will not be discussing investment risk or other risks.

o *Hazard.* We shall generally use the term hazard to describe a source of risk. Thus a dam poses the hazard of drowning should it fail; however, the risk of drowning because of dam failure depends on the likelihood of failure per year and the conditional probability that a particular individual (or each individual downstream) will drown, given that the dam has failed.

o *Risk acceptance and risk acceptability.* A distinction has been made in the literature between accepted risks and acceptable risks. Thus, a risk may be accepted by an individual or by society, even though the risk fails to "pass" when compared against some standard of acceptability. Many risks are "tolerated" rather than "accepted". Many are accepted in the belief that they are much smaller than they actually are.

o *Risk analysis, risk estimation, risk assessment, and risk evaluation.* Some papers in the literature distinguish between risk assessment and risk evaluation, attributing the act of quantification to "assessment" and a judgment on its acceptability to "evaluation". However, within the context of this study we shall not try to differentiate among these terms; we shall use such terms to indicate the process of attempting to quantify a risk.

o *Risk management.* We shall define risk management as the act of attempting to identify all significant hazardous activities; obtaining information concerning the nature of their risks (e.g., their magnitude and frequency) and benefits; and developing and adopting actions to deal with the risks as judged appropriate. Much of the existing activity with regard to risk management within state or local government relates to preparation for emergencies such as flood or fire and other reactive kinds of action. In this study, we emphasize the preventive aspect of risk management.

o *Risk manager.* The risk manager is envisioned as a person (or group of people) who undertakes to get done all the tasks of risk management identified above, except that of adopting actions such as new ordinances, which would be the task of the elected officials. The risk manager may also oversee the adequacy of the job being done by those responsible for observing or enforcing applicable laws or ordinances.

1.2. Hazards and Risks in Society

The subject of this study is risk management policy. However, prior to examining matters related to risk management, it is useful to discuss some of the hazards and risk found in our society.

Society has available a large body of information of a fairly general nature concerning hazards and risks. For example, as shown in Tables 1.1, 1.2 and 1.3, there exist actuarial statistics on the general causes of death and disabilities for the entire population of the United States. The death statistics can be subdivided into the mortality rate among different age groups, and a further division can be made between accidents and sickness, as is shown in Figure 1.1.

Similarly, statistics exist on major catastrophes, as is shown in Table 1.4.

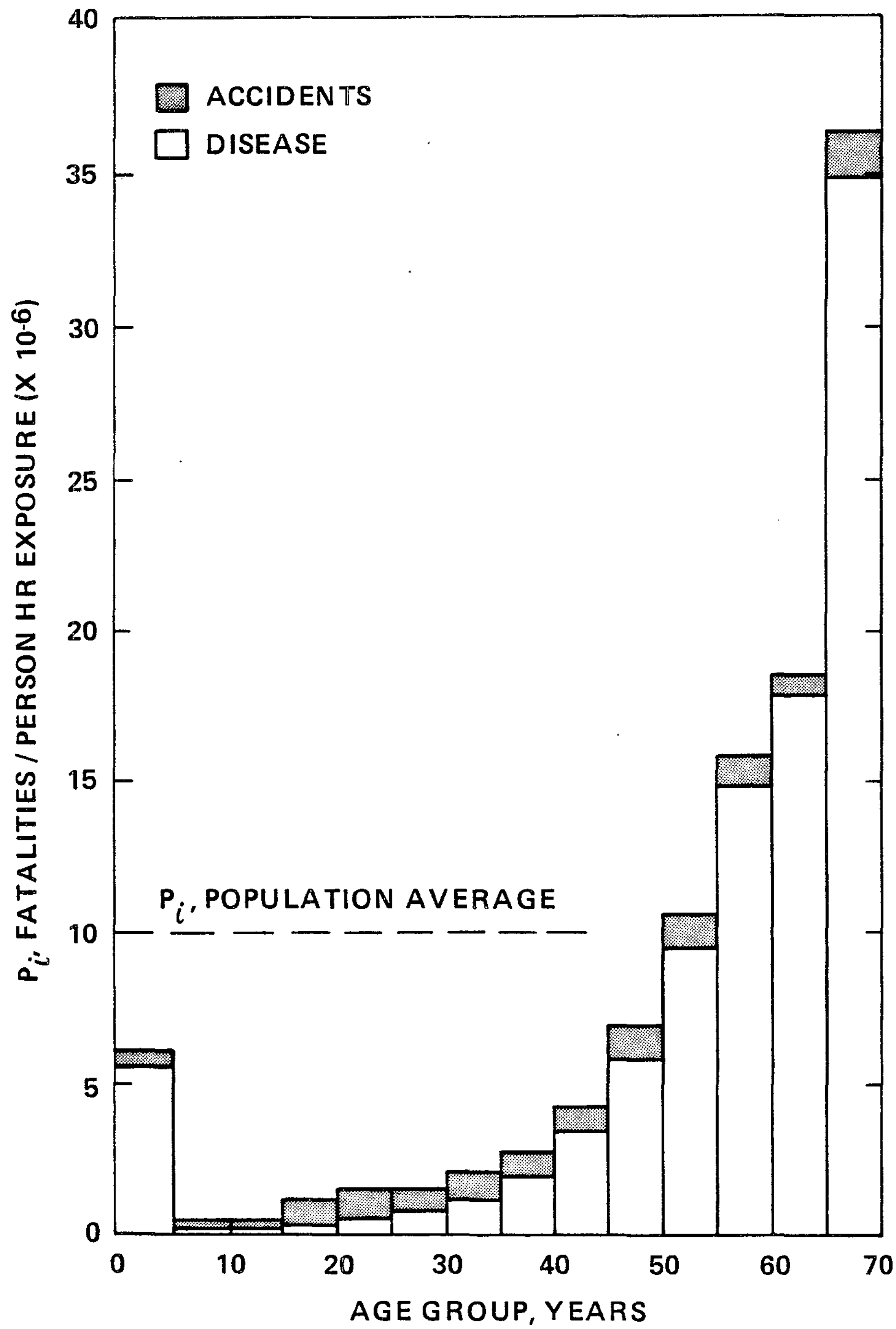

FIGURE 1.1. Risk versus Age Group for Accidents and Disease

TABLE 1.1 ACCIDENTAL DEATHS

TYPE OF ACCIDENT OR MANNER OF INJURY	1977†	1976	1975	1974
ALL ACCIDENTAL DEATHS	103,202	100,761	103,030	104,622
TRANSPORT ACCIDENTS	53,286	50,644	49,838	50,659
RAILWAY ACCIDENTS	576	552	608	716
MOTOR VEHICLE	49,510	47,038	45,853	46,402
TRAFFIC	48,457	46,012	44,820	45,314
NONTRAFFIC	1,053	1,026	1,033	1,088
OTHER ROAD VEHICLE	200	238	255	275
WATER TRANSPORT	1,357	1,371	1,570	1,579
DROWNING (EXCLUDED FROM DROWNINGS BELOW)	1,165	1,182	1,360	1,413
OTHER WATER TRANSPORT	192	189	210	166
AIR AND SPACE TRANSPORT	1,643	1,445	1,552	1,687
POISONING BY SOLIDS AND LIQUIDS (SEE ALSO PAGE 82)	3,374	4,161	4,694	4,016
POISONING BY DRUGS AND MEDICAMENTS	2,214	2,839	3,132	2,742
POISONING BY OTHER SOLID AND LIQUID SUBSTANCES	1,160	1,322	1,562	1,274
POISONING BY GASES AND VAPORS (SEE ALSO PAGE 82)	1,596	1,569	1,577	1,518
FALLS	13,773	14,136	14,896	16,339
FIRES AND FLAMES	6,357	6,338	6,071	6,236
CONFLAGRATION IN PRIVATE DWELLINGS	4,649	4,716	4,424	4,369
CONFLAGRATION IN OTHER BUILDINGS OR STRUCTURES	395	249	203	224
CONFLAGRATION NOT IN BUILDINGS OR STRUCTURES	95	113	76	75
IGNITION OF CLOTHING	376	425	429	445
IGNITION OF HIGHLY INFLAMMABLE MATERIALS	163	153	146	185
OTHER AND UNSPECIFIED FIRES AND FLAMES	679	682	793	938
NATURAL AND ENVIRONMENTAL FACTORS	1,751	1,299	1,268	1,427
EXCESSIVE HEAT	308	100	190	140
EXCESSIVE COLD	634	424	359	348
HUNGER, THIRST, EXPOSURE AND NEGLECT	264	247	257	201
BITES AND STINGS OF VENOMOUS ANIMALS AND INSECTS	55	53	50	53
OTHER ACCIDENTS CAUSED BY ANIMALS	109	143	128	139
LIGHTNING	116	81	124	112
CATACLYSM (TORNADO, FLOOD, EARTHQUAKE, ETC.)	202	212	103	384
OTHER NATURAL AND ENVIRONMENTAL FACTORS	63	39	57	50
OTHER ACCIDENTS	19,158	18,827	20,737	20,711
DROWNING, SUBMERSION (EXCL. WATER TRANS. DROWNINGS ABOVE)	5,961	5,645	6,640	6,463
INHALATION AND INGESTION OF FOOD	2,041	2,144	2,238	2,181
INHALATION AND INGESTION OF OTHER OBJECT	996	889	868	810
MECHANICAL SUFFOCATION	969	911	998	1,083
IN BED OR CRADLE	202	159	214	234
OTHER AND UNSPECIFIED MECHANICAL SUFFOCATION	767	752	784	849
STRUCK ACCIDENTALLY BY FALLING OBJECT	1,096	1,060	1,063	1,143
STRIKING AGAINST OR STRUCK ACCIDENTALLY BY OBJECTS	851	815	834	927
CAUGHT ACCIDENTALLY IN OR BETWEEN OBJECTS	443	471	493	521
CUTTING OR PIERCING INSTRUMENTS	127	135	140	112
EXPLOSION OF PRESSURE VESSEL	58	69	64	57
FIREARMS	1,982	2,059	2,380	2,513
SELF-INFLICTED	450	448	520	512
OTHER AND UNSPECIFIED FIREARMS	1,532	1,611	1,860	2,001
EXPLOSIVE MATERIAL	439	442	389	459
FIRWORKS	3	4	0	3
BLASTING MATERIALS	11	13	17	24
EXPLOSIVE GASES	174	203	192	230
OTHER AND UNSPECIFIED EXPLOSIVE MATERIAL	251	222	180	202
HOT SUBSTANCE, CORROSIVE LIQUID, AND STEAM	181	210	209	216
ELECTRIC CURRENT	1,183	1,041	1,224	1,157
HOME WIRING AND APPLIANCES	212	203	258	203
INDUSTRIAL WIRING AND APPLIANCES	153	113	158	163
OTHER ELECTRIC CURRENT	673	608	662	636
UNSPECIFIED ELECTRIC CURRENT	145	117	146	155
RADIATION	0	0	0	1
MACHINERY ACCIDENTS NOT ELSEWHERE CLASSIFIED	703	768	865	783
OTHER AND UNSPECIFIED	2,128	2,168	2,332	2,285
SURGICAL AND MEDICAL COMPLICATIONS AND MISADVENTURES	3,107	3,009	3,184	3,021
OPERATIVE THERAPEUTIC PROCEDURES	1,964	1,944	2,158	2,151
OTHER AND UNSPECIFIED THERAPEUTIC PROCEDURES	794	718	704	638
OTHER AND UNSPECIFIED NONTHERAPEUTIC PROCEDURES	349	347	322	232
LATE EFFECTS (DEATH MORE THAN A YEAR AFTER ACCIDENT)	800	778	765	695
MOTOR VEHICLE	156	148	133	166
FALLS	173	172	174	172
OTHER AND UNSPECIFIED LATE EFFECTS	471	458	458	357

†LATEST OFFICIAL FIGURES

SOURCE: NATIONAL CENTER FOR HEALTH STATISTICS AND ACCIDENT FACTS, 1980 EDITION, NATIONAL SAFETY COUNCIL

TABLE 1.2 MAJOR CAUSES OF DEATH IN THE U.S., 1975

	NUMBER
CARDIOVASCULAR DISEASES	979,180
ACUTE HEART ATTACK	328,670
SUBACUTE AND CHRONIC HEART DISEASE	319,740
CEREBROVASCULAR DISEASES (E.G., STROKES)	195,630
ARTERIOSCLEROSIS AND OTHER ARTERIAL AND CAPILLARY DISEASES	54,610
HYPERTENSIVE DISEASES	17,570
ACTIVE RHEUMATIC FEVER AND CHRONIC RHEUMATIC HEART DISEASE	12,460
HEART DISEASES NOT OTHERWISE CLASSIFIED	50,500
CANCER	371,740
DIGESTIVE ORGANS AND PERITONEUM	101,880
RESPIRATORY SYSTEM	88,460
GENITAL ORGANS	43,160
BREAST	32,570
LYMPHATIC AND HEMATOPOIETIC TISSUES	20,430
URINARY ORGANS	16,790
LEUKEMIA	15,000
MOUTH AND THROAT	8,230
NOT OTHERWISE CLASSIFIED OR SPECIFIED	45,220
INFECTIVE AND PARISITIC DISEASES	72,760
PNEUMONIA	52,740
BLOOD POISONING	5,270
INFLUENZA	4,780
TUBERCULOSIS	3,300
MENINGITIS AND MENINGOCOCCAL INFECTIONS	2,120
OTHER INFECTIVE AND PARASITIC DISEASES	4,550
DIABETES MELLITUS	35,890
SYMPTOMS AND ILL-DEFINED CONDITIONS	32,610
RESPIRATORY DISEASES	26,120
EMPHYSEMA	18,410
ACUTE AND CHRONIC BRONCHITIS AND BRONCHIOLITIS	5,670
ASTHMA	2,040
BIRTH INJURY, DIFFICULT LABOR, ETC.	15,200
CONGENITAL ANOMALIES	14,380
GASTROINTESTINAL DISEASES (ULCERS, APPENDICITIS, ETC.)	14,150
KIDNEY DISEASES	12,830
OTHER CAUSES IN EARLY INFANCY	12,150
BENIGN TUMORS AND UNSPECIFIED TUMORS	4,580
ANEMIAS	3,400
GALL STONES AND OTHER GALL BLADDER AILMENTS	3,000
VITAMIN AND OTHER NUTRITIONAL DEFICIENCIES	2,510
ALL OTHER DISEASES	122,640
DISEASE SUBTOTAL	1,755,220
ACCIDENTS	101,400
SUICIDES	26,960
HOMICIDE	21,730
OTHER EXTERNAL CAUSES	4,940
NONDISEASE SUBTOTAL	155,030
TOTAL ALL CAUSES	1,910,250

SOURCE: DEPARTMENT OF HEALTH, EDUCATION & WELFARE

TABLE 1.3 PREVALENCE OF DISABILITIES IN THE U.S.*

	NUMBER
INFECTIOUS	240,000,000
COMMOM COLD	100,000,000
INFLUENZA	80,000,000
PNEUMONIA	3,000,000
GONORRHEA	840,000
STREPTOCOCCAL SORE THROAT, SCARLET FEVER	430,000
TUBERCULOSIS	215,000
MUMPS	125,000
MEASLES	120,000
SYPHILIS	95,000
CARDIOVASCULAR	28,410,000
HIGH BLOOD PRESSURE, HYPERTENSIVE HEART DISEASE	22,950,000
CORONARY HEART DISEASE (HEART ATTACK, ANGINA PECTORIS)	3,940,000
RHEUMATIC HEART DISEASE	1,730,000
CEREBROVASCULAR DISEASE (STROKE)	1,680,000
GASTROINTESTINAL	21,900,000
STOMACH AND DUODENAL ULCERS**	--
ILEITIS AND COLITIS	1,000,000
CHRONIC AND ACUTE HEPATITIS	70,000
RESPIRATORY	--
CHRONIC SINUSITIS	20,600,000
HAY FEVER	10,800,000
BRONCHITIS AND BRONCHIOLITIS	6,500,000
ASTHMA WITH OR WITHOUT HAY FEVER	6,000,000
EMPHYSEMA	1,300,000
MENTAL AND EMOTIONAL	20,000,000
ARTHRITIC	20,250,000
OSTEOARTHRITIS	12,500,000
RHEUMATOID ARTHRITIS	5,000,000
GOUTY ARTHRITIS	1,000,000
OTHER ARTHRITIC DISEASES	2,500,000
NEUROLOGIC, NEUROMUSCULAR, AND BRAIN	9,300,000
MENTAL RETARDATION	6,000,000
IDOPATHIC EPILEPSY	1,500,000
PARKINSONISM	1,000,000
CEREBRAL PALSY	600,000
PROGRESSIVE MUSCULAR DYSTROPHY	200,000
ALCOHOLISM	9,000,000
DENTAL CONDITIONS	6,500,000
SKIN	6,100,000
DIABETES	4,400,000
CANCER	1,000,000
DRUG ABUSE	460,000

*FIGURES ARE ROUNDED ESTIMATES FOR ANNUAL CASES AND ARE AMONG THE MOST RECENT AVAILABLE (MOSTLY FOR 1970 AND 1971, ALTHOUGH A FEW ARE AS RECENT AS 1973 AND 1974). THEY HAVE BEEN COMPILED BY THE DEPARTMENT OF HEALTH, EDUCATION & WELFARE AND ALSO BY CHARITABLE FOUNDATIONS DEVOTED TO ASSISTING IN ALLEVIATING OR CURING THE MAJOR ILLNESSES. BECAUSE OF DUPLICATIONS AND OMISSION, NUMBERS IN SUBCATEGORIES DO NOT NECESSARILY TOTAL TO NUMBERS IN MAJOR CATEGORIES. IN ADDITION, THE NUMBERS OF UNKNOWN SUFFERERS HAVE NOT NECESSARILY BEEN ESTIMATED WITH THE SAME ACCURACY IN ALL CASES. SOME ILLNESSES, THEREFORE, SUCH AS HIGH BLOOD PRESSURE, MAY BE SIGNIFICANTLY MORE PREVALENT THAN INDICATED. **ABOUT 10% OF THE POPULATION IS ESTIMATED TO SUFFER FROM STOMACH AND DUODENAL ULCERS AT SOME POINT DURING THEIR LIFETIMES.

TABLE 1.4. SINGLE EVENT MAJOR CATASTROPHES.

TYPE OF EVENT	TIME PERIOD	MAGNITUDE (DEATHS/EVENT)			FREQUENCY EVENTS/YEAR
		MODE	MAXIMUM	AVERAGE	
MAJOR AIR CRASHES	1965 - 1969	82	155	78	6.0
MAJOR AUTO CRASHES	1966	10	40	19	11.0
EARTHQUAKES	1920 - 1970	30,000	180,000	25,000	0.50
EXPLOSIONS	1950 - 1968	10	100	26	2.0
MAJOR FIRES	1960 - 1968	12	322	35	0.67
FLOOD, TIDAL WAVES	1887 - 1969	2,000	900,000	28,000	0.54
HURRICANES	1888 - 1969	400	11,000	1,105	0.41
MAJOR RAILROAD CRASHES	1950 - 1966	19	79	30	1.0
MAJOR MARINE ACCIDENTS	1965 - 1969	32	300	61	6.0
U.S. TORNADOS	1900 - 1969	72	689	78	0.74
TYPHOONS, CYCLONES, BLIZZARDS	1880 - 1970	10,000	300,000	37,240	0.18

There also exist fairly good statistics on the chance of attributable premature death for various industrial and non-industrial occupations. For example, Gibson has reported the fatal accident rates shown in Table 1.5 as being appropriate for the United Kingdom (1975), while the risk of accidental death in U.S. industries is shown in Table 1.6 (EPA 81). However, except for those limited things covered by actuarial statistics, society is remarkably deficient in its knowledge of the hazards and risks to which it is exposed. For example, there are thousands of large dams in the United States, many with large numbers of people living in their inundation plain, but there exists little information on the safety standards to which these dams were built. There exists no report which deals quantitatively with the risk from these dams collectively, and for very few individual dams is information available on the maximum hazard or on the estimated risk.

The same lack of quantitative information on safety standards, hazards and risks is equally true with regard to the storage of large quantities of dangerous chemicals. The transportation of dangerous chemicals is somewhat better off with regard to the quantification of risk, in that a limited set of risk studies has been performed.

In a sense, despite the large gaps in our knowledge mentioned above, the hazard from accidents, with its attendant risk of attributable death, is easier for society to deal with than the hazards arising from chronic pollution and contamination of our air, water and food. There has been fairly general acceptance that 60% to 90% of all cancer is environmentally produced (including effects found naturally in the environment) rather than hereditary (Doll, 1977). This acceptance, coupled with the fact that all accidents, including those related to motor vehicles, only cause about 5% of deaths, suggests that far more attention should be given to chronic effects. Here, as for low probability, large accidents, however, there are major gaps in societal knowledge, and there is frequently no clear path to obtaining the desired knowledge, even if a huge amount of resources were made available for the task. Hence, most societal decision making involving risk, whether by individuals, regulators, political representatives, or representatives of advocacy groups, is being made with inadequate knowledge of the risks under consideration. This is particularly true when the decision involves chronic risks, rather than accidents.

In the sections immediately following, some specific hazards and their risks are examined. The risks examined include earthquake effects on cities, the failure of dams, accidents involving large chemical storage and handling facilities, contamination of drinking water by disposal of hazardous chemical wastes, and sources of local ground and air pollution. All represent hazards for which state and/or local government have much or full responsibility. The hazards differ widely in their nature. Dams have the potential for truly major catastrophes involving the loss of as many as 100,000 lives.

VARIOUS INDUSTRIES		NON-INDUSTRIAL OCCUPATIONS	
CHEMICAL INDUSTRY	3.5	STAYING AT HOME	3
BRITISH INDUSTRY	4	TRAVELLING BY BUS	3
STEEL INDUSTRY	8	TRAVELLING BY TRAIN	5
FISHING	35	TRAVELLING BY CAR	57
COAL MINING	40	PEDAL CYCLING	96
RAILWAY SHUNTERS	45	TRAVELLING BY AIR	240
CONSTRUCTION WORKERS	67	MOPED RIDING	260
AIR CREW	250	MOTOR SCOOTER DRIVING	310
PROFESSIONAL BOXERS	7,000	MOTOR CYCLING	660
		CANOEING	1,000
JOCKEYS (NATIONAL HUNT RACING)	50,000	ROCK CLIMBING	4,000

TABLE 1.5.

DEATHS PER 10^8 EXPOSURE HOURS
IN THE UNITED KINGDOM (GIBSON, 1975)

TABLE 1.6 ANNUAL RISK OF ACCIDENTAL DEATH IN U.S. INDUSTRIES

	DEATHS PER 100,000 WORKERS						
INDUSTRY/YEAR	1971	1972	1973	1974	1975	1976	1977
TRADE	7	7	7	6	6	6	6
MANUFACTURING	10	9	8	8	8	9	9
SERVICE INDUSTRIES	12	10	10	10	9	9	8
GOVERNMENT	13	13	13	13	12	11	11
TRANSPORTATION AND PUBLIC UTILITIES	36	36	35	34	33	31	33
AGRICULTURE	66	61	61	54	58	54	53
CONSTRUCTION	71	70	71	63	61	57	60
MINING, QUARRYING	100	117	117	71	63	63	63
TOTAL INDUSTRY AVERAGE	18	17	17	15	15	14	14

The threatened population can be identified but the risk is usually poorly known. Seismic effects are widely perceived to be primarily a threat in California. However, the difference in risk is only a matter of degree between California and most of the country. Hazardous chemical storage facilities have not been subject to federal regulation, and state regulation has been nominal or absent, for the most part. Except for some fire department awareness of what chemicals are stored, and regulations arising from fire and building departments, there has been little risk management and almost no public awareness of the risk potential.

The contamination of drinking water by hazardous chemical wastes has been perceived as an important matter, largely because the event has already occurred at many places in the U.S. Little was done in the preventive, risk management mode ten to thirty years ago to avoid the difficulties which are currently arising. Local sources of ground and air pollution are also perceived as a problem, but only where a severe health effect has occurred or potentially dangerous concentrations are measured.

All these hazards require a place in any overall risk management structure. Their differences in nature may suggest the need for more than one kind of structure.

1.2.1. Seismic Effects on our Cities

A very large uncertainty exists in society's ability to predict the likelihood of occurrence of damaging earthquakes. That this is the case for all portions of the United States was graphically illustrated by a survey of expert seismic opinion (Okrent, 1975) in which seven experts independently assessed the likelihood of increasingly severe earthquakes at eleven sites distributed around the United States. For each location, these experts usually differed by a factor ranging from 100 to 10,000, in their estimates of likelihood for severe earthquakes. Although by subsequent interaction among such experts, it might be possible for them to arrive at some consensus estimates, large residual uncertainties would necessarily remain. Such a large uncertainty in the likelihood of severe earthquakes poses safety questions for essentially all of our cities, for dams, for storage facilities for hazardous chemicals, and so forth. Except for nuclear power plants and some dams, seismic design requirements are usually rather modest for most structures.

The problem of seismically substandard buildings is clearly an acute one for the city of Los Angeles and for many other communities in California. Even in Los Angeles, only part of the problem is being addressed, namely pre-1933 masonry buildings which contain many dwelling units or are frequented by large numbers of people. There may be similarly high individual risks to people living in smaller, old, masonry buildings. And there may be many post-1933 buildings whose design is inadequate for the substantial seismic shaking which is likely to occur during the coming years.

Is this problem unique to Los Angeles, San Francisco and some other cities in California? Only in degree. Earthquakes can and do occur almost anywhere in the United States. Perhaps the single largest earthquake in recorded history in the United States occurred at New Madrid, Missouri in 1812. This earthquake had damaging intensity over a large area and was felt on the east coast. In 1886, a large earthquake damaged Charleston, South Carolina; the cause of this earthquake is ill known and the various theories lead to a wide range of possibilities for future earthquake sites from this source, including much of the east coast of the U.S. Earthquakes having a damage potential have occurred near Boston, in Ohio, and in the St. Lawrence Valley, among others. The Federal Disaster Assistance Administration has had earthquake loss studies prepared, not only for Los Angeles and San Francisco, but also for Salt Lake City and the Puget Sound area.

Interesting insight into the widespread nature of the problem can be obtained from a report, prepared in 1975, on earthquake-resistant design requirements for Veterans Administration (VA) hospital facilities. This report was prepared by a committee established as a result of actions taken following the 1971 San Fernando earthquake in which considerable loss of life was associated with failure of a VA hospital.

The scope of work for the Committee was defined in part as follows:

> "It has been the Veterans Administration policy to follow the professionally accepted local and national building codes as they have been progressively developed over the years for the design of new buildings and other structures to resist the forces of earthquakes and high intensity winds. It also has been the Veterans Administration policy to follow these codes as a basis for strengthening buildings when this work was done at existing stations. It should be noted that some buildings and other structures were designed and constructed prior to the inclusion of earthquake and high intensity wind resistance requirements in local and national codes for the area in which they were located. As a consequence, there is in the Veterans Administration's total plant a wide variety of buildings and other structures conforming to the code requirements which were designed and also some buildings that were strengthened on the basis of codes which came into being during later years.
>
> "The failure of the buildings and the consequent loss of life at the Veterans Administration San Fernando Hospital have given rise to questions, from both within the Veterans Administration and by members of the Congress and other public officials, as to whether the Veterans Administration should continue the policy of following local

and national codes or whether the Veterans Administration should establish its own codes for the design of new and for the strengthening of existing Veterans Administration hospital buildings and other structures to resist the forces of earthquakes and high intensity winds anywhere in the United States".

Some comments made by the Committee include the following:

"The definition of structural hazard from future earthquakes is quite a complicated one for a number of reasons:

"1. It is difficult to determine the seismic risk to a structure as a function of its lifetime. Seismic risk maps, such as the map prepared by S.T. Algermissen in the 1973 Edition of the Uniform Building Code, show that almost every area in the United States is subject to earthquakes. These maps classify large geographical areas as Zones 0, 1, 2, and 3, and the projected damage from earthquakes in the zones varies from "No Damage" in Zone 0 to "Major Damage" in Zone 3. The use of the Zone Factor does not consider, in relation to a specific site, geological structure, the proximity of active faults, or soils. Furthermore, available Seismic Risk Maps for the U.S. consider the intensity of shaking of earthquakes that have occurred in the past but give little weight to frequency of occurrence. Finally, the seismic risk maps do not distinguish between earthquakes in terms of their most damaging effects on structures of different types.

"2. The great majority of existing VA facilities, particularly those not in California, were not designed to resist earthquake forces. Such facilities might be hazardous in the event of a major nearby earthquake. Procedures for evaluating such facilities were developed.

"3. There were no precedents for a nationwide program to evaluate and strengthen existing buildings to resist seismic forces. Agencies in California have inaugurated such programs, but on a small scale. Many of the older VA stations are far below an acceptable level of seismic resistance as calculated by conventional methods, yet are in regions of very infrequent damaging earthquakes. A prudent program of corrective work had to be developed that would consider the strength of the structure and the level of ground-shaking expected during the life of the structure".

As part of the study, recommendations were obtained from consulting organizations for the appropriate earthquake intensity and the associated maximum acceleration in the ground that should be used for design of hospitals at various VA sites throughout the country. This is reproduced from the report in Table 1.7. The definition of earthquake intensity, which is a qualitative measure of the local effect of an earthquake, is given in Table 1.8.

It is of some interest to note that, while at many times, it was proposed that hospitals be designed for substantial accelerations, the values recommended are generally far less than the Nuclear Regulatory Commission requires for nuclear reactors at similar sites. For example, both the Los Angeles VA hospital and the San Onofre nuclear generating station are several miles from the Newport-Inglewood Fault (or an extension thereof). The recommended acceleration for the VA hospital is 0.25g, while San Onofre is designed for 0.67g, a major difference. Similarly, the recommended acceleration for the VA facility in Manchester, New Hampshire is only 0.12g while the required seismic design basis for the Seabrook nuclear plant is 0.25g. This provides a kind of calibration in that the design basis earthquakes for nuclear power plants are often estimated to have a frequency of exceedance falling between one in a thousand to one in ten thousand per year. Hence, presumably, for many of the VA sites in Table 1.7, the frequency of exceedance of the proposed design bases is substantially larger.

Hence, most if not all cities in the United States face some risk from earthquakes. Many have buildings lacking in any seismic design. Many do not have personnel who are cognizant either of seismic design or seismic safety matters. Nevertheless, some seismic risk exists. For individuals inhabiting highly substandard masonry buildings, seismic risk may be significant or even substantial compared to other risks which the community (or higher governmental entities) is taking active steps to control or reduce.

1.2.2. Dam Safety in the U.S.

According to a 1975 U.S. Army Corps of Engineers inventory, there are about 50,000 public and private dams in the U.S. which are 25 feet or more in height and have a maximum impounding capacity of 50 acre-feet or more. About 89% of the dams are non-federal and about 40% present a significant or high hazard potential to downstream life, if they should fail.

Of the order of 80 large dams in the United States have failed in the past one hundred years. Buffalo Creek and Canyon Lake Dams are two well-known dam failures from a long list which begins roughly with the South Fork Dam near Johnstown, Pennsylvania in 1889. Other failures include the Saint Francis Dam in 1928 and the Baldwin Hills Reservoir in 1963, both in California, the Teton Dam in Idaho in 1976, and the Barnes Lake Dam near Toccoa, Georgia

TABLE 1.7.

PEAK HORIZONTAL GROUND ACCELERATIONS AT VA SITES[1]

LOCATION (CONSULTANT)	INTENSITY (MM)	ACCELERATION (G)
ALBANY, N.Y. (E. D'APPOLONIA CONSULTING ENGRS.)	VI-VII	0.07
ALBUQUERQUE, N.M. (JOHN A. BLUME)	VIII-	0.20
AMERICAN LAKE, WA (DAMES & MOORE)	VIII	0.20
ATLANTA, GA (LAW ENGINEERING TESTING CO.)	VII	0.13
AUGUSTA, (F.H. DIV.), GA (LAW ENGINEERING TESTING CO.)	VII+	0.18
AUGUSTA (LENWOOD DIV.), GA (LAW ENGINEERING TESTING CO.)	VII+	0.18
BATAVIA, N.Y. (DAMES & MOORE)	VII-VIII	0.20
BATH, N.Y. (DAMES & MOORE)		0.05
BEDFORD, MA (DAMES & MOORE)	VII	0.10
BIRMINGHAM, AL (WOODWARD-LUNDGREN)	VII	0.11
BOISE, ID (WOODWARD-LUNDGREN)		0.15
BOSTON, MA (DAMES & MOORE)	VII	0.10
BROCKTON, MA (DAMES & MOORE)	VII	0.10
BUFFALO, N.Y. (DAMES & MOORE)	VI	0.07
CANANDAIGUA, N.Y. (DAMES & MOORE)		0.05
CHARLESTON, S.C. (WOODWARD & LUNDGREN)	VIII	0.25
CINCINNATTI, OH (WOODWARD-LUNDGREN)	VI	0.06
COLUMBIA, S.C. (LOVE & COBB ARCHITECTS & LOCKWOOD GREEN ENGINEERS, INC.)	VII	0.10
DAYTON, OH (WOODWARD-LUNDGREN)	VI	0.05
ERIE, PA (A.C. ACKENHEIL & ASSOCIATES)	VIII	0.15
FT. HARRISON, MT (JOHN A. BLUME & ASSOCS.)	VIII+	0.30
FRESNO, CA (WOODWARD-LUNDGREN)		0.23
INDIANAPOLIS (10TH ST.), IN (WOODWARD-LUNDGREN)	V	0.02
INDIANAPOLIS (COLD SPRING, IN (WOODWARD-LUNDGREN)	V	0.02
LINCOLN, NB (E. D'APPOLONIA CONSULTING ENGINEERS)	VI-VII	0.10
LIVERMORE, CA (DAMES & MOORE)	VIII	0.25
LONG BEACH, CA (WOODWARD-LUNDGREN)		0.39
LOS ANGELES, CA (DAMES & MOORE)	VIII	0.25
LOUISVILLE, KY (WOODWARD-LUNDGREN)	VII	0.11
MANCHESTER, N.H. (JOHN A. BLUME & ASSOCS.)	VII	0.12
MARION, IL (WOODWARD-LUNDGREN)	VII	0.11
MARTINEZ, CA (WOODWARD-LUNDGREN)		0.48
MARTINSBURG, W.VA. (E. D'APPOLONIA CONSULTING ENGINEERS)	VI-VII	0.07

[1] THE A_{MAX} VALUES ARE NOT DIRECTLY COMPARABLE WITHOUT ATTENTION TO THE ARGUMENTS PRESENTED IN THE SITE EVALUATION SURVEY.

TABLE 1.7. (CONT'D)

LOCATION (CONSULTANT)	INTENSITY (MM)	ACCELERATION (G)
MEMPHIS, TN (WOODWARD-LUNDGREN	VIII	0.25
MT. HOME, TN (E. D'APPOLONIA CONSULTING ENGRS.)	VII	0.10
NORTHAMPTON, MA (JOHN A. BLUME & ASSOCS.)	VII	0.10
OKLAHOMA CITY, OK (E. D'APPOLONIA CONSULTING ENGINEERS)	VII	0.10
OTEEN, N.C. (E. D'APPOLONIA CONSULTING ENGINEERS)	VI	0.07
PALO ALTO, CA (WOODWARD-LUNDGREN)		0.50
PALO ALTO (MENLO PARK), CA (DAMES & MOORE)	IX	0.40
PHOENIX, AZ (JOHN A. BLUME & ASSOCIATES)	IV	0.05
POPLAR BLUFF, MO (WOODWARD-LUNDGREN	VIII	0.25
PORTLAND, OR (DAMES & MOORE)	VII	0.12
PRESCOTT, AZ (JOHN A. BLUME & ASSOCIATES)	VII+	0.15
PROVIDENCE, R.I. (JOHN A. BLUME & ASSOCIATES)	VII+	0.10
RENO, NV (JOHN A. BLUME & ASSOCIATES)	IX+	0.50
ROSEBURG, OR (SHANNON & WILSON, INC.)	VI	0.08
SALEM, VA (E. D'APPOLONIA CONSULTING ENGINEERS)	VII-VIII	0.15
SALISBURY, N.C. (E. D'APPOLONIA CONSULTING ENGINEERS)	VI	0.07
SALT LAKE CITY, UT (DAMES & MOORE)	VIII	0.30
SAN DIEGO, CA (DAMES & MOORE)	VII	0.15
SAN FRANCISCO, CA (DAMES & MOORE)	VIII	0.30
SAN JUAN, P.R. (E. D'APPOLONIA ENGINEERS, INC.)	VII-VIII	0.12
SEATTLE, WA (DAMES & MOORE)	VIII	0.20
SEPULVEDA, CA (WOODWARD-LUNDGREN)		0.45
SPOKANE, WA (AGBABIAN-JACOBSEN ASSOCIATES)	VII	0.10
ST. LOUIS, MO (WOODWARD-LUNDGREN)	VII	0.11
ST. LOUIS (JEFF.BRKS.), MO (WOODWARD-LUNDGREN)	VII	0.11
SYRACUSE, N.Y. (E. D'APPOLONIA CONSULTING ENGINEERS)	VI	0.05
TOGUS, ME (JOHN A. BLUME & ASSOCIATES)	VII	0.10
TUCSON, AZ (JOHN A. BLUME & ASSOCIATES)	IV	0.05
TUSCALOOSA, AL (WOODWARD-LUNDGREN0	VI	0.06
VANCOUVER, WA (DAMES & MOORE)		0.12
WALLA WALLA, WA (DAMES & MOORE)	VI	0.15
WEST ROXBURY, MA (DAMES & MOORE)		0.10
WHITE CITY, OR (SHANNON & WILSON, INC.)	VI	0.07
WHITE RIVER JUNCTION, VT (DAMES & MOORE)	VI	0.07
WICHITA, KA (E. D'APPOLONIA CONSULTING ENGINEERS)	VI-VII	0.07

TABLE 1.8.

MODIFIED MERCALLI INTENSITY (DAMAGE) SCALE
(ABRIDGED)

I. NOT FELT EXCEPT BY A VERY FEW UNDER ESPECIALLY FAVORABLE CIRCUMSTANCES. (I ROSSI-FOREL SCALE.)

II. FELT ONLY BY A FEW PERSONS AT REST, ESPECIALLY ON UPPER FLOORS OF BUILDINGS. DELICATELY SUSPENDED OBJECTS MAY SWING. (I TO II ROSSI-FOREL SCALE.)

III. FELT QUITE NOTICEABLY INDOORS, ESPECIALLY ON UPPER FLOORS OF BUILDINGS, BUT MANY PEOPLE DO NOT RECOGNIZE IT AS AN EARTHQUAKE. STANDING MOTORCARS MAY ROCK SLIGHTLY. VIBRATION LIKE PASSING OF TRUCK. DURATION ESTIMATED. (III ROSSI-FOREL SCALE.)

IV. DURING THE DAY FELT INDOORS BY MANY, OUTDOORS BY FEW. AT NIGHT SOME AWAKENED. DISHES, WINDOWS, DOORS DISTURBED; WALLS MAKE CREAKING SOUND. SENSATION LIKE HEAVY TRUCK STRIKING BUILDING. STANDING MOTORCARS ROCKED NOTICEABLY. (IV TO V ROSSI-FOREL SCALE).

V. FELT BY NEARLY EVERYONE, MANY AWAKENED. SOME DISHES, WINDOWS, ETC., BROKEN; A FEW INSTANCES OF CRACKED PLASTER; UNSTABLE OBJECTS OVERTURNED. DISTURBANCES OF TREES, POLES, AND OTHER TALL OBJECTS SOMETIMES NOTICED. PENDULUM CLOCKS MAY STOP. (V TO VI ROSSI-FOREL SCALE.)

VI. FELT BY ALL, MANY FRIGHTENED AND RUN OUTDOORS. SOME HEAVY FURNITURE MOVED; A FEW INSTANCES OF FALLEN PLASTER OR DAMAGED CHIMNEYS. DAMAGE SLIGHT. (VI TO VII ROSSI-FOREL SCALE.)

VII. EVERYBODY RUNS OUTDOORS. DAMAGE NEGLIGIBLE IN BUILDINGS OF GOOD DESIGN AND CONSTRUCTION; SLIGHT TO MODERATE IN WELL-BUILT ORDINARY STRUCTURES; CONSIDERABLE IN POORLY BUILT OR BADLY DESIGNED STRUCTURES; SOME CHIMNEYS BROKEN. NOTICED BY PERSONS DRIVING MOTORCARS. (VIII ROSSI-FOREL SCALE.)

VIII. DAMAGE SLIGHT IN SPECIALLY DESIGNED STRUCTURES; CONSIDERABLE IN ORDINARY SUBSTANTIAL BUILDINGS WITH PARTIAL COLLAPSE; GREAT IN POORLY BUILT STRUCTURES. PANEL WALLS THROWN OUT OF FRAME STRUCTURES. FALL OF CHIMNEYS, FACTORY STACKS, COLUMNS, MONUMENTS, WALLS. HEAVY FURNITURE OVERTURNED. SAND AND MUD EJECTED IN SMALL AMOUNTS. CHANGES IN WELL WATER. PERSONS DRIVING MOTORCARS DISTURBED. (VIII+ TO IX ROSSI-FOREL SCALE.)

IX. DAMAGE CONSIDERABLE IN SPECIALLY DESIGNED STRUCTURES; WELL-DESIGNED FRAME STRUCTURES THROWN OUT OF PLUMB; GREAT IN SUBSTANTIAL BUILDINGS, WITH PARTIAL COLLAPSE. BUILDINGS SHIFTED OFF FOUNDATIONS.

TABLE 1.8. (CONT'D)

GROUND CRACKED CONSPICUOUSLY. UNDERGROUND PIPES BROKEN. (IX+ ROSSI-FOREL SCALE.)

X. SOME WELL-BUILT WOODEN STRUCTUES DESTROYED; MOST MASONRY AND FRAME STRUCTURES DESTROYED WITH FOUNDATIONS; GROUND BADLY CRACKED. RAILS BENT. LANDSLIDES CONSIDERABLE FROM RIVER BANKS AND STEEP SLOPES. SHIFTED SAND AND MUD. WATER SPLASHED (SLOPPED OVER BANKS.) (X ROSSI-FOREL SCALE.)

XI. FEW, IF ANY, (MASONRY) STRUCTURES REMAIN STANDING. BRIDGES DESTROYED. BROAD FISSURES IN GROUND. UNDERGROUND PIPELINES COMPLETELY OUT OF SERVICE. EARTH SLUMPS AND LAND SLIPS IN SOFT GROUND. RAILS BENT GREATLY.

XII. DAMAGE TOTAL. WAVES SEEN ON GROUND SURFACE. LINES OF SIGHT AND LEVEL DISTORTED. OBJECTS THROWN UPWARD INTO THE AIR.

in 1977 (Comptroller General 1979). A listing of major dam failures leading to loss of life in the United States since 1974 is given in Table 1.9 (Hall, 1981).

Dam disasters in the early 1970s caused about 355 deaths and extensive property damage. This situation led to passage of the 1972 National Dam Inspection Act which directed the Corps of Engineers to inspect the majority of the nation's dams and to recommend a comprehensive national program for dam safety. By November, 1976, no money had been appropriated and no inspections had been conducted. The Teton Dam failed in June, 1976, prompting a number of government actions including the development of guidelines for federal dams and appropriation of a modest amount of money for beginning the inspection of non-federal dams. In December, 1977, following failure of the Barnes Lake Dam which killed 39 persons, a higher priority and greater resources were devoted to the effort. A very considerable number of non-federal dams have since been termed as unsafe by the Corps of Engineers, but, for the most part, little action has been taken by the states in which they are located, because of a lack of public concern and a lack of resources.

During the San Fernando earthquake in 1971, the hydraulical fill, earthen Lower Van Norman dam in Los Angeles was subject to extensive liquefaction and nearly failed by breaching. It was half-full. Had it been full, experts believe it would have failed suddenly (Seed and Lee, 1973) with the possibility of drowning 80,000 or more people living in its inundation plain (Ayyaswamy et al. 1974). Following the near failure of Lower Van Norman dam, the State of California's Division of Safety of Dams ordered all owners of hydraulic fill dams to investigate their dams for seismic stability and correct any deficiency. This was followed by a continuing program of re-evaluation of other selected dams for seismic stability.

The data for dams in the United States suggest a rate of failure of all kinds of approximately 8×10^{-4} per dam-year and a major disaster rate, leading to a high likelihood of fatalities of approximately 1.3×10^{-4} per dam-year. Between 1959 and 1965, nine major dams of the world failed in some manner, indicating a similar worldwide failure rate, (Engineering News Record, 1967).

Project-specific as well as generalized failure probabilities can be estimated by "fault-tree" analysis of the probabilities of causal events (such as major earthquakes, floods, etc.) and failure mechanisms. In considering the earthquake hazards to embankment dams, Sherard [1966] reported a consensus that ". . .if, hypothetically, all the dams presently existing in any seismic area were shaken by the worst earthquake which is possible, some would fail . . . ." For example, the Hebgen Dam, Montana, very nearly failed as the result of a Richter magnitude 7.1 earthquake. The East Bay Municipal Utility District [1976] has concluded that the San Pablo Dam, California

TABLE 1.9.

DAM AND LEVEE FAILURES IN THE U.S.

YEAR	LOCATION	STRUCTURE	LIVES LOST
1874	WILLIAMSBURG, MASS.	EARTH DAM	144
1889	JOHNSTOWN, PA.	EARTH DAM	~2000(2209)
1890	WALNUT GROVE, PRESCOTT, ARIZ.	DAM	150
1894	MILL RIVER, MASS.	DAM	143
1900	AUSTIN/AUSTIN, PA.	DAM	8
1928	ST. FRANCIS DAM/CA.	DAM	~450(UP TO 700)
1955	YUBA CITY, CA.	LEVEE	38
1963	BALDWIN HILLS, LOS. ANG., CA.	EARTH DAM RESERVOIR	5(3)
1972	BUFFALO CREEK, W. VA.	SLAGHEAP DAM	125
1972	RAPID CITY, S.D.	DAM	200
1976	NEWFOUND, N.C.	EARTH DAM	4
1976	TETON, IDAHO	EARTH DAM	14
1977	TOCCOA, GA.	EARTH DAM	35
1874-PRESENT			3525-3775

(FROM: "A RISK COMPARISON," NUREG/CR-1916, BNL-NUREG-51338 (FEBRUARY, 1981)

(43,000 acre-foot capacity)" . . . is not sufficiently stable to withstand a major earthquake on the San Andreas Fault." This dam has since been strengthened to withstand a "maximum creditable earthquake". This type of evidence suggests that the failure probability for seismic causes for some dams may approach the probability of severe local earthquakes. The probability of failure of a particular dam is difficult to estimate, but can be expected to be strongly dependent upon geologic setting, surface faulting and seismicity, type and size of dam, specific engineering and construction, flood frequency, and so forth. Of course, there are other possible causes of dam failure, for example, inadequate spillway capacity, which may be more likely causes of failure than earthquakes for most dams in the U.S.

A very preliminary study of the worst consequences of failure of 12 dams in California due to a severe earthquake has been performed at UCLA (Ayyaswamy, et al., 1974). Probability estimates for earthquakes of various sizes are presented in Table 1.10, but there is no good way of estimating the failure probability. Estimated maximum fatalities and damages are presented in Table 1.11. These fatality and damage estimates are based on the assumption of total and instantaneous failure of dams filled to capacity.

The UCLA study is one of the few published reports giving estimates of the maximum hazard and a very crude failure probability for specific dams. The maximum number of casualties is very large, ranging up to a quarter of a million. However, in connection with federal hearings on March 21, 1977 by the Water Projects Review Committee, U.S. Department of the Interior, H. Cedergren (1977) testified that sudden failure of the proposed Auburn dam in California could kill up to three-quarters of a million people. Hence, dams clearly pose great hazards.

Probabilistic, predictive analysis of the failure rate of dams is in a very early stage of development and it is likely to be many years before a substantial body of results exists. Also unavailable are the quantitative criteria for acceptable failure probabilities for dams, which are inherent in the judgment made by responsible governmental authorities that a dam is "safe".

1.2.3. Storage of Hazardous Chemicals

One of the most interesting and significant accident-risk studies available is that released in June, 1978, by the Health and Safety Executive (1978) of the British government entitled "Canvey: Summary of an Investigation of Potential Hazards from Operations in the Canvey Island/Thurrock area".

Canvey Island lies in the Thames River and is about nine miles long and 2-1/2 miles wide. It contains about 33,000 residents and about seven large industrial complexes, including petroleum, ammonium nitrate and a liquified natural gas facility.

TABLE 1.10. PREDICTION OF EARTHQUAKE PROBABILITY FOR SEVERAL DAM SITES IN CALIFORNIA

NAME OF DAM	ESTIMATED PROBABILITY OF MM VIII PER YEAR[A]	ESTIMATED PROBABILITY OF MM IX PER YEAR[B]	ESTIMATED PROBABILITY OF MM X PER YEAR[C]
VAN NORMAN	0.014	0.0049	.00003
SAN ANDREAS	0.44	0.014	0.003
LOWER CRYSTAL SPRINGS*	NC	NC	NC
STONE CANYON	0.012	0.0014	0.0003
ENCINO	0.012	0.0013	0.0002
SAN PABLO	0.076	0.032	0.011
FOLSOM*	NC	NC	NC
SHASTA*	NC	NC	NC
CHATSWORTH	0.013	0.0028	0.00003
MULHOLLAND*	NC	NC	NC
UPPER SAN LEANDRO	0.12	0.063	0.023
LAKE CHABOT	0.12	0.057	0.021

[A] SIGNIFICANT PROBABILITY OF FAILURE

[B] SUBSTANTIAL PROBABILITY OF FAILURE

[C] HIGH PROBABILITY OF FAILURE

NC = NOT CALCULATED

* THESE ARE GRAVITY TYPE CONCRETE DAMS. GAST HAS PROVIDED AN ESTIMATE OF 10^{-4} PER YEAR FOR WORLD-WIDE CONCRETE DAMS DUE TO ALL CAUSES.

TABLE 1.11. ESTIMATED EFFECTS OF TOTAL AND INSTANTANEOUS FAILURE OF DAMS FILLED TO CAPACITY

NAME OF DAM	FATALITIES* DAY	FATALITIES* NIGHT	DAMAGE ASSESSED IN U.S. DOLLARS
VAN NORMAN+	72,000	123,000	3×10^8
SAN ANDREAS / LOWER CRYSTAL SPRINGS	21,000	33,000	1.1×10^8
STONE CANYON	125,000	207,000	5.3×10^8
ENCINO	11,000	18,000	5×10^7
SAN PABLO	24,000	36,000	7.7×10^7
FOLSOM	260,000	260,000	6.7×10^8
CHATSWORTH++	14,000	22,000	6×10^7
MULHOLLAND	180,000	180,000	7.2×10^8
UPPER SAN LEANDRO / LAKE CABOT	36,000	55,000	1.5×10^8
SHASTA	34,000	34,000	1.4×10^8

*NO ALLOWANCE FOR EVACUATION

+ THE VAN NORMAN DAM IS NO LONGER UTILIZED AS A STORAGE FACILITY

++THE CHATSWORTH DAM IS KEPT EMPTY

The largest risk of death to Canvey residents arising from an accident at one of the industrial facilities was estimated to be about 1.3×10^{-3} (one in 800) per year for some of the nearest residents. This risk is about five times as large as the average risk of dying in an automobile accident in the U.S. The average risk of death arising from an accident at these industrial installations was estimated to be about 5×10^{-4} (one in 2000) for all the island's residents. This is about twice the risk in the U.S. of death from an auto accident.

The chance of 1500 people being killed in a single accident was given as more than one in 1000 per year. The chance of 18,000 being killed in a single accident was given as 1 in 12,000 per year.

These estimates were stated to probably err on the side of pessimism by a factor of 2 or 3, but probably not by a factor of 10.

The Health and Safety Executive recommended that improvements be made, improvements that should reduce the likelihood of each of the above estimates by a factor of 2 or 3. With these improvements, the Health and Safety Executive judged that the risk would be acceptable.

While Canvey Island represents a location with a high concentration of industrial complexes, there is good reason to believe that the general hazards and risks posed there are not unique, either in the United Kingdom or the United States. There is also reason to question the practicality of obtaining a factor-of-ten improvement in the risks to the individual estimated for Canvey for the entire chemical industry in either country.

The British appear to be close to making it a matter of national law that safety assessment reports be submitted by each industrial facility storing or utilizing at one time more than some threshold quantity of a hazardous chemical. Notification would be required if some specified lesser quantity is stored or used. The Health and Safety Executive will have the responsibility for evaluation of the risk assessment and a decision on the acceptability of the risk.

The Health and Safety Executive also serves in an important advisory capacity to local governmental entities with regards to the planning for land utilization in the vicinity of hazardous chemical installations.

Except for a few, recent proposed facilities for the importation of liquified natural gas (LNG), there has not been published in the United States a risk analysis of a chemical installation similar to that performed for Canvey Island. Nor does the U.S. have a regulatory approach for acute hazards to the public from chemical installations similar to that being developed in the U.K. LNG facilities are subject to stringent siting regulations in the State of California. However, in California and elsewhere, other chemical plants, including LPG which may be more hazardous than LNG, have generally been subject only to relatively modest regulation by local fire departments and building safety departments. Some chemical companies have taken relatively costly steps to improve the safety of their installations or have even given up specific plants where the potential accident liability was large compared to the net profit. Such matters are kept proprietary and little has been published in this regard.

Some insight into the status of regulation of hazardous chemical storage facilities by states and local communities in the mid 1970s is provided in the brief study by Solomon, et al. (1976). Letters were written to the governors of all fifty states asking for information concerning the means used by their state in regulating and evaluating the risks from the storage of potentially hazardous chemicals. In general, the knowledge and regulation of such hazards appeared not to be very detailed and frequently minimal. Two cities in California (Los Angeles and El Segundo) were then surveyed with regard to measures employed in regulating the construction and use of facilities to store hazardous materials. Of particular interest in this study was whether there were, in proximity to a relatively high housing density, places where hazardous chemicals might be used, and, if so:

- o What safety criteria were used in evaluating the adequacy of container design?
- o What magnitude of risk was considered to be acceptable?
- o What controls were exercised and by whom?
- o How were the safety evaluations made?
- o What magnitude of risk actually exists?

For these two cities the fire and building departments impose certain requirements. However, no detailed hazard or risk evaluations are made and the knowledge and regulation of hazardous chemicals appeared to be less than complete. One interesting aspect that arose in the survey of these two cities is that an industrial area in one city may be located next to a heavily populated region in a neighboring city without any systematic recognition of this juxtaposition. In addition to sudden accidental death, another risk issue arises from hazardous chemical storage facilities, namely, delayed health effects arising either from a large accidental spill or from chronic releases. Little has been published on this matter.

1.2.4. Drinking Water and Hazardous Chemical Waste Disposal

The matter of disposal of hazardous chemical waste, both as it represents a potential local source of hazardous emissions and as a pollutant of drinking water or food, is rapidly becoming one of the major public issues in the United States. In this regard, one might pose several questions to provide a partial focus for further consideration.

- What are the average effects on health of the currently used drinking water? Where do health effects occur which are much larger than average, how large are they, why do they occur? What are uncertainties and what are the gaps in our knowledge in this regard? What constitutes adequate knowledge and when and how can we get it?
- What are the potential future effects on drinking water, and thus on health, of the wastes which were dumped or otherwise disposed of in the past? Has this been quantified? Can it? In assessing health effects arising from these wastes, do we need to consider other uses of water, e.g., for irrigation? Are there synergistic effects?
- How should EPA, the states, and other interested parties judge whether the controls that EPA has promulgated or is planning to promulgate on the disposal of hazardous wastes and on drinking water quality are appropriate?

Although epidemiological studies and animal studies both have limitations, they can shed light on some of these questions. About a dozen epidemiological studies almost all show an association between cancer rates and some aspect of drinking water, particularly organic contaminants (Kimm, 1980). Two ecologic studies (whole population) involving 88 Ohio and 64 Louisiana counties suggested that contaminated surface water was responsible for approximately 8% and 15%, respectively, of the cancer mortality rate. (Page, 1976, Harris, 1977). That is a large effect, if true.

In its final rule on control of trihalomethanes in drinking water, EPA (1979a) summarizes many of the risk estimates made for this carcinogen, and arrives at a lifetime incremental risk of $4x10^{-4}$ of cancer, assuming one drank two liters of water daily containing 0.10 mg/liter, the newly promulgated maximum level for this contaminant for community water systems serving more than 10,000 persons. A lifetime risk of $4x10^{-4}$ seems to be a tolerable number, at least at first glance. However, this rule does not address the potentially large quantity of chemicals to which one may be exposed. And other possible health effects, including reproductive effects, remain to be understood (CEQ 1981).

What is the magnitude of the hazardous waste which is disposed of annually? The U.S. Environmental Protection Agency (EPA) estimates that approximately 75 million tons of the 380 million tons of liquid and solid industrial waste generated in the U.S. in 1978 were hazardous wastes and that about 80% of these hazardous wastes are improperly disposed of in land fills or lagoons and pose a threat of ground water contamination (EPA 1980a). Very few land disposal sites are lined, and few have leachate collection systems. From their surface impoundment assessment, EPA estimated that 5000 to 6000 industrial impoundments may contain hazardous wastes; few have a liner, and virtually no monitoring of groundwater is conducted to detect contamination beneath the sites; almost one-third have a high potential to contaminate usable aquifers; and a third may endanger water supply wells.

Industrial waste, of course, is not the whole story. Agriculture and mining provide potentially large, additional sources of contamination of drinking water.

EPA has recently promulgated cradle-to-grave regulations for hazardous wastes (EPA 1980b); however, implementation of these regulations is left primarily to the states. The magnitude of the source is so large, diverse, and complex that compliance will be difficult to accomplish. Equally important, quantitative knowledge of the magnitude of the current and future risk does not now exist and will be difficult to obtain.

One can get some very rough insight into the potential for risk from the disposal of hazardous chemical wastes by comparing them with radioactive waste. Cohen (1977) has estimated that the toxicity of hazardous chemical wastes is large compared to that of the radioactive waste generated by a 1000 MWe nuclear reactor. McKone and Szabo, and Solomon (Okrent, 1980) have estimated that waste arsenic and chromium are probably more carcinogenic than the radioactive waste from a 1000 MWe reactor.

It remains to be seen what level of safety the new EPA regulations for disposal of hazardous chemical wastes will achieve and whether this will ultimately be judged to be uniformly acceptable.

1.2.5. Sources of Local Air and Ground Pollution

A type of hazard and risk which may arise in relatively remote areas as well as within the heart of cities, and which has probably received insufficient attention in the past, is the source of local air and ground pollution. In recent years Love Canal has afforded a highly publicized example of such a potential hazard. However, there are a host of such potential hazards, many of which appear to surface publicly only after serious real or potential adverse effects on health and safety have come to light. Three examples which have arisen in the past few years include the kepone release in Virginia, an asbestos mine in Arizona, and a lead smelter in Idaho.

In an increasing number of instances, specific real or hypothetical sources have been analyzed for their effects. Two examples are mentioned here, for illustrative purposes.

1) As part of a study of the health and environmental effects of a projected growth in the use of batteries, R.K. Sharwa, et al. (1980), reported the following with regard to potential adverse effects of cadmium on kidney function.

"In the case of cadmium, an increased excess risk of developing renal tubular proteinuria is indicated with increasing cadmium levels associated both by proximity to a lead mine-mill complex and accumulation in the body over time. At the 5-km distance there is a considerable increase in risk after ten years (1-3 persons per 1000). After a period of 30 years, the excess risk is about 2 per 100, which would imply a significant level of risk. A considerable degree of risk, approximately 2 per 1000, is experienced by those persons at the farthest distance only after a period of 30 years. For those at the middle distance, risk also is most noteworthy at the 30-year point (3-4 per 1000), and is moderate (2-4 per 10,000) at the ten-year point. The excess risk becomes insignificant (defined as 1 per 10^6) at 85 km from the site. Effects due to dispersal of cadmium through air at great distances from the site are therefore not anticipated. Significant increases in mining and milling of lead anticipated by the year 2000 could result in local areas of increased exposure to cadmium with accompanying excess risk of developing renal tubular proteinuria."

2. In a preliminary report by its Carcinogenic Assessment Group, EPA (1978) estimated that the additional annual probability of death to the 100,000 most exposed individuals living near U.S. coke-oven facilities ranged from 10^{-4} per year to $3x10^{-5}$ per year. The estimated additional premature deaths arising from such facilities was 150 per year.

1.3. The Federal Role in Risk Management

Almost all risk management policy in the U.S. that is the result of analytic approaches derives from federal action. For the most part, identification of hazards, estimation of risks, risk acceptance, and articulation of risk-management policies as rules and regulations occur centrally, while implementation of policies is delegated to local authorities. Standards governing safety (e.g., transportation, clothing, and other consumer products), health (e.g., contamination of food and drinking water, and drug safety), the environment (e.g., control of air and water pollution), protection from natural disasters (e.g., floods and tornadoes), and occupational conditions are determined through lengthy and sometimes tortuous policy making procedures. Federal funding of various state programs is then made contingent upon compliance, and compliance by local authorities is, in turn, mandated directly by the states. The states retain primacy in this process, however, as they are free to impose standards more stringent than most at the federal level.

Just as it is impossible to delineate all risks, it is impossible to delineate all risks for which policy is set federally, and all for which there is local discretion. Generally, the greater the extent to which identification of a risk depends upon scientific (i.e., epidemiological or experimental) determination as opposed to casual observation, and the greater the extent to which risk acceptance depends upon, again, scientific determination rather than the political process, the greater the federal role in risk management policy. Thus, automobile safety inspection standards are left to the states while federal standards govern automobile emissions, and restaurant sanitation is a local responsibility, whereas contamination of drinking water is regulated by the EPA. There are exceptions to these broad generalizations, however. For example, a hazard that is both localized geographically and amenable to mitigation through extension of normal city or state service functions may be managed wholly at the local level even though extensive scientific and engineering studies may be required to formulate policy. Such is the case with seismic safety standards in building codes. Indeed, the more localized the hazard, the greater the acceptance of analytic approaches to risk so long as they are consistent with the service orientation of local government. In San Bernardino County, California, for example, usage of land abutting the San Andreas fault is restricted to non-occupied structures, but a property owner may obtain an exemption if he secures a favorable report from a consulting geologist at his own expense. Such circumstances -- again, highly localized risks that can be managed through extension of existing service activities -- are rare, and for this reason the forces that sustained federal dominance of risk management policy need to be analyzed in order to learn how the pattern might be changed were it desired to do so. Our concern is less with the historical reasons for present risk management policies than with the balance of benefits and costs of maintaining the current system.

Advantages of federal preemption of risk management policy. Federal preemption of risk identification, acceptance, and policy appear to overcome some obstacles that would be posed by purely local control. These obstacles include local inaction, externalities in information, uncertainties in risk analysis, and what we call the pattern of pluralistic ignorance whereby some uncertainties are overcome. Each will be discussed seriatim:

--Local inaction. As noted above, the history and structure of local government tends against policy formation and implementation concerning intangible risks whose effects operate over years and are uncertain.

--Externalities in information. Substantial costs are incurred in risk identification, acceptance, and policy formation. Should risk data developed locally remain proprietary, then substantial duplication of effort and expenditure would occur. Should these data be widely disseminated, then the costs of developing this information could be equitably shared, given the necessary cooperative arrangements. The problem of externalities compels some centralization of risk management activities at the federal level although not necessarily the present form of centralization.

--Uncertainties associated with risk data. For broad classes of hazards, there is no scientific consensus as to their "no-effect" levels. Additionally, there is dissensus as to trade-offs between risks and costs of mitigation. These uncertainties render justification of any local risk management policy difficult should a contiguous jurisdiction impose different standards. Uniform federal standards do not remove actual uncertainty from risk estimates, but they do offer the possibility of a definitive judgment as to what levels of risk are acceptable and what are not.

--Pluralistic ignorance. By obscuring substantial uncertainty as to their effectiveness, regulations set centrally ease the task of local officials charged with monitoring and enforcing compliance. Local officials and citizens need not understand the scientific basis, or lack of same, for federal policies in order to understand that they are authoritative. Presumably, the best scientific talent has contributed its understanding to the formation of federal policy, and the federal political process adds to its legitimacy. A degree of rationality and acceptability is therefore attributed to federal regulations that might not, in fact, be warranted and might not hold, were the same regulations developed locally.

Disadvantages of federal preemption. The preponderant federal role in risk management activities incurs an array of disadvantages, including lacunae in risk identification, erosion of local decision making capacity, and insensitivity to local performances.

--Lacunae and risk identification. Many hazards, while ubiquitous, first manifest themselves in localized settings, especially industrial locations where the work force is exposed to much higher levels of contaminants and pollutants than the general public. High rates of morbidity and mortality affecting relatively small populations are likely to be obscured by low prevalence of a hazard, hence ignored. No data exist concerning the relative risk of highly localized sources of air pollution and water contamination compared to risks caused by more widespread hazards.

--Erosion of local decision making capacity. Both the scientific and political capacities of local communities to make risk management decisions are diminished by federal preemption. Tolerance levels determined by local or state authorities may be revised (usually downward) by federal agencies once they have completed independent studies of a hazard, leading local officials to be disinclined to address the issue of risk other than by complying with federal statutes and regulations. A parallel problem operates in the political context: Local officials who initiate risk management policies may be severely embarrassed when their judgments are questioned or countermanded at the federal level.

--Insensitivity to local preferences. Risk management entails balancing of quantities that are non-commensurable -- expenditures and regulations against lives and health. For this reason, there will be substantial variance in risk acceptance. How much risk is tolerable and at what cost will differ substantially across localities. This is partially a matter of the economics of health and safety, but not completely so as it also involves the balancing of certain costs with uncertain benefits. Variations in preferences as well as variations in local conditions to which the federal policy making apparatus may be insensitive yield substantial nonoptimalities at the local level when uniform risk acceptance standards are imposed.

The question posed. The fundamental issue facing local governments with respect to risks to human life and health is, then, not the determination and implementation of risk management policy. The issue is, instead, much more basic, namely whether or not risk is to be conceptualized quantitatively and decisions based on data rather than haphazardly or by compliance with regulations. If one assumes that quantitative risk estimates might inform rather than overwhelm local decision makers, then a further issue is how the advantages of the existing system might be preserved while at the same time strengthening analytic capabilities at the local level. In other words, we need to explore whether an overall pattern of risk management can be devised that, on the one hand, overcomes externalities in information and produces reasonable consensus as to risk estimates while allowing for correction or "fine tuning" of them, and, on the other hand, enhances the capacities of localities to identify risks as well as to make risk decisions consistent with citizen preferences. A number of alternatives toward this end will be explored in the concluding sections of the report. Before these alternatives can be considered, however, systematic evidence on local risk management practice and perceptions should be introduced.

1.4. On Past Approaches to Quantitative Safety Goals

While zero risk would be desirable in theory, it is rarely, if ever, demonstrable or attainable for societal activities. Our natural habitat contains radiation. Many foods contain carcinogens which are present naturally. Drinking water unspoiled by human activities may contain hazardous contaminants.

If zero risk is generally unattainable, the word "safe" must connote a situation involving some risk, and to some, a quantification of the degree of risk which is being judged to be safe is desirable. However, few, if any regulatory and risk management groups have defined quantitative safety goals or criteria that they are striving to meet. Nevertheless, those responsible for managing and regulating risks to the public might establish quantitative safety goals for particular risks, goals which might provide the basis for establishing specific safety requirements.

Several proposals for quantitative safety goals have been made in the past, and some of these are reviewed below to provide some background and perspective on the matter.

1.4.1. Some Previous Proposals

The overall philosophy and intent of the particular policies toward risk determine the form and scope of the various risk acceptance criteria reviewed below as well as the proposed numerical parameters. The criteria may deal with effects such as deaths or property damage, with exposures to harmful agents such as radiation or pollutants, or with the frequency of certain types of accidents.

The risk criteria described below can be roughly categorized into three groups: those that set limits on individual risk of death only; those that consider frequency of accidents and magnitude of the consequences; and those that imbed the criteria in risk management frameworks that, at least in part, consider risks from alternatives or other societal endeavors. Some, but not all, of the criteria apply specifically to nuclear reactors.

1.4.1.1. Individual Risk Criteria

One of the early proposals for quantitative risk criteria for nuclear reactors was made by Adams and Stone (1967) of the Central Electricity Generating Board of Great Britain at an International Atomic Energy Agency (IAEA) Symposium on Siting and Containment. They proposed that the parameter determining acceptable siting be taken as individual risk. Although the numerical limit would be a matter for governmental decision, they suggested that an incremental increase in an individual's chance for death per year that is smaller than the demographic variation in the United Kingdom of that chance of death per year would be inappreciable and acceptable on those grounds. Differences significantly greater than 10^{-5} per year occur between England, Wales, Scotland and Ireland, and they proposed that an incremental individual risk of 10^{-5} chance of death per year would be acceptable. For immediate deaths and a plant lifetime of 30 years this would correspond to a statistical loss of life expectancy of about 6 days, while for death delayed until 10 years after exposure the statistical loss is about 3 days. Of course, the loss is much larger for the actual victims and zero for all the others.

Adams and Stone arrived at a siting policy based on the above criterion which requires the following: an exclusion area; a controlled area, where development that would prevent emergency action would not be allowed; and then an area of unrestricted population. They did not, however, discuss how one should demonstrate that the criterion had been satisfied. In fact, they argued that community or aggregate risk criteria based on the total potential number of casualties would not be useful because the uncertainty in that number, due to the magnitude and conditions of release in an accident, is far greater than the differences that choice of site could make. The policy did not consider property or other resource damage.

The apparently positive correlation between standard of living and health has been used by Bowen (1975) to develop a general risk acceptance criterion for technological activities in the United Kingdom. He suggests that the risks imposed upon society should be negligible or balanced by benefits. However, risk levels that can be scientifically supported, say a 10^{-5} chance of death per year, cannot be considered negligible in all situations, and balancing by direct individual benefits is not possible in cases where the victim cannot be readily identified in advance, for example, the one excess cancer fatality that might be expected from the TMI accident. Bowen argues that the balance should be done macroscopically.

He assumes that the observed annual increase in life expectancy in the U.K. is due to overall societal efforts, i.e., its investment in "the industrial machine" of which any technological facility forms a part. An additional yearly risk of death of 10^{-5} from a new facility roughly balances the expected increase of an individual's life expectancy during one year. Bowen asserts that if no investment is made in the industrial machine, the annual increase in life expectancy may stop altogether. Hence, he chooses 10^{-5} per year as a reasonable limit on the individual risk of death from a single facility and assumes that no individual is exposed to more than a very few technological facilities.* If the increase in life expectancy per year is larger than that in the U.K. (i.e., 0.05 years/year), a country might accept technological activities involving a correspondingly larger risk, at least for accidents which are not truly catastrophic.

*In a personal communication he has since indicated that a larger level of risk, more like 10^{-4} per plant per year, may be more practical for the individual living near a large chemical facility (Okrent, 1977).

With regard to accidents having a potential for a major disaster, Bowen argued against requiring a lower frequency limit for which compliance would be difficult to demonstrate or even achieve. He suggested that the 10^{-5} limit should be demonstrated to a high confidence level when there is potential for a large catastrophe. He felt that if a large accident were to occur, it would not be easy to distinguish between just being "unlucky" or having accepted a risk analysis that greatly underestimated the risk. Being "unlucky" could be prevented by achieving a lower probability for large accidents but at the expense of investments into the industrial machine. Bowen argued that, if the aim is to have a small chance (i.e. 1%) of having a large catastrophe in one's lifetime, a limit of 10^{-5} events/year demonstrated to high confidence, say 99% or so, would be adequate; it would not help to restate the aim as 10^{-7} events/year, and besides, it might divert resources, attention and effort.

Bowen did not distinguish between deaths occurring immediately after an accident and those that are delayed for a few years, nor did he consider risks other than individual fatalities.

1.4.1.2. Frequency-Consequence Approaches

The previous criteria dealt specifically with individual fatality risks without directly including limits on other types of risk or addressing the effects of a large scale accident. In the four following proposals, special attention is given to the magnitude of an accident. A basic common assumption is that the limiting frequency of a particular accident should depend in some way upon its magnitude. Three of the sets of risk criteria deal with nuclear power plant risk. The first proposal suggests a limit on the frequency of accidental release of radioactive material, the second, on frequency of individual exposure, and the third is concerned with limits on the fatalities due to accidental exposure. The final proposal in this section relates the required structural integrity of a building to the intended use of the building and the number of expected injuries, should it fail

At an IAEA Symposium on Siting and Containment, F.R. Farmer (1967) of Great Britain, presented a much-to-be quoted paper, "Siting Criteria - A New Approach." In it he proposed that probabilistic analysis be employed in reactor safety assessment and suggested that the safety criterion of less than 0.01 premature deaths per reactor year be adopted. In addition, he proposed that a risk acceptance limit line be used to judge the acceptability of the estimated occurrence frequency for any particular accident. The severity of the accident was measured by the release in curies of iodine-131, one of the volatile fission products of greatest importance in thermal reactor accidents.

The Farmer limit line is reproduced in Figure 1.2. The acceptable frequency of occurrence of an accident falls off as the

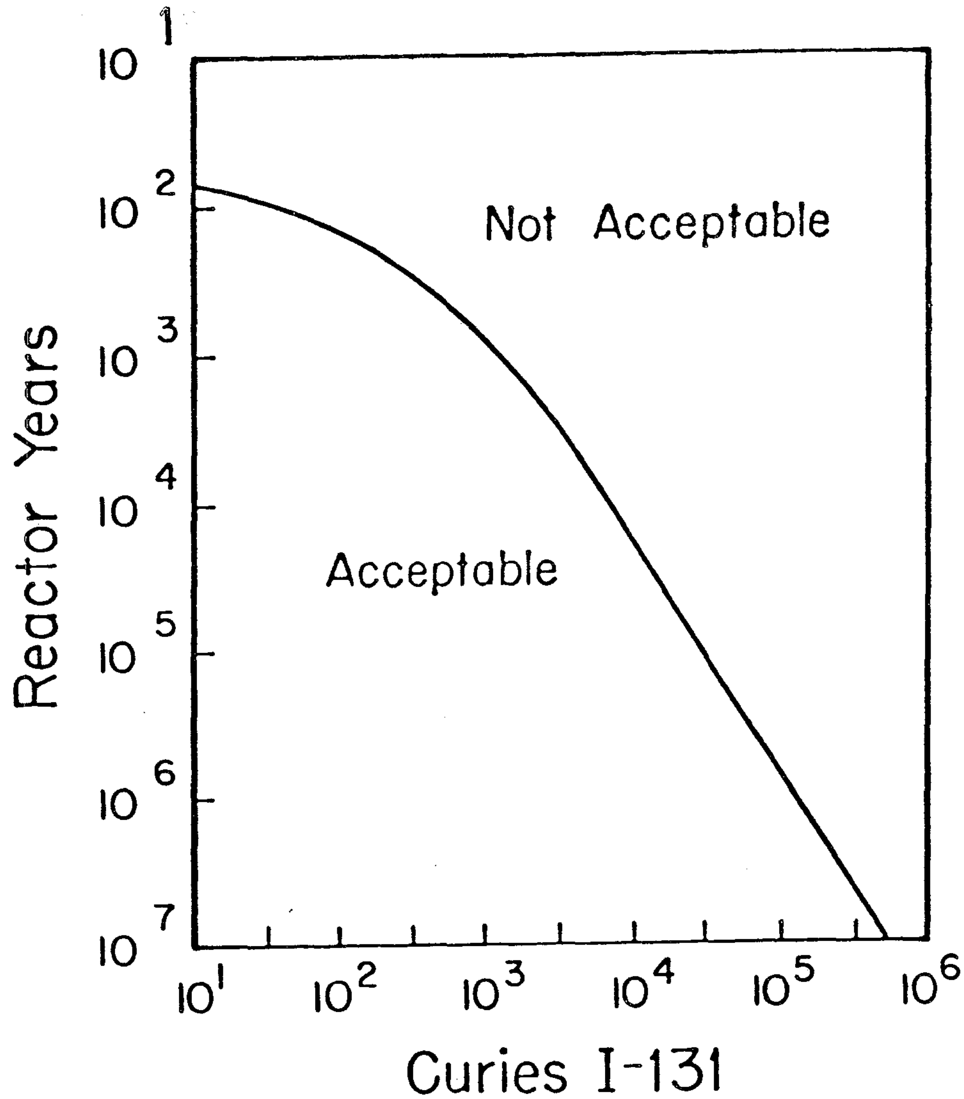

FIGURE 1.2. Farmer release frequency limit line.
(Farmer, 1967)

consequences increased with a rate such that the expected contribution to risk (frequency times consequence) was less for very large accidents than for smaller ones (a negative slope of -1.5 on a log-log plot). Farmer suggested that only a relatively few events would be near the line for any reactor, and that these would lead to the principal contribution to premature deaths.

The Farmer limit line does not deal specifically with effects dependent upon population density or other conditions around the site. Therefore, the actual limits on effects, such as risk to individual, property damage, or number of expected fatalities, must be estimated from site specific analyses.

In late 1978, a proposal for probabilistic safety requirements for use in licensing CANDU nuclear power plants was submitted by the Inter-Organizational Working Group to the Atomic Energy Control Board of Canada for general public comment (AECB, 1978). The requirements are in the form of quantitative frequency dose limits and were intended to be conservative in ensuring that the likelihood of a lethal dose (200-400 whole body rem) to any nearby resident would be less than 10^{-6} per reactor year. The criteria do not directly address the total number of immediate fatalities that might be caused by the accident. The report does not discuss latent effects such as cancer, but individual latent risk limits are implied by the frequency dose criteria.

G.H. Kinchin of the Safety and Reliability Directorate of the UKAEA has proposed a quantitative set of public health and safety criteria for nuclear reactors (1978; 1979). Because of the difficulty in balancing economic advantages against health risks, he suggested that the criteria should be conservative. Unlike the previous two sets of criteria, Kinchin proposes limits on the expected effects rather than on the magnitude of release or expected dose. The criteria put limits on individual and aggregate societal risks of both immediate and delayed death due to reactor accidents.

The conservative objective was to make the risk of immediate death to an individual member of the public small compared with other involuntary risks, and a value of 10^{-6} per reactor year was suggested. Kinchin stated that possibly a higher value would be acceptable.

Kinchin suggested that in the attempt

> "to arrive at the criterion for the risk of delayed deaths, the following thoughts might be kept in mind:
>
> (a) death at some relatively distant date in the future is preferable to immediate death;
>
> (b) the effect of radiation-induced cancers on the life expectancy of a young person is greater than on that of an older person;

(c) an annual death rate of 10^{-6}/year, as proposed above, would be caused by an accident giving a total probability of delayed deaths of 3×10^{-5};

(d) it seems that radiation exposure just insufficient to cause immediate death may not give rise to fatal malignancy;

(e) for the specific malignancies induced by irradiation, comparison should be made with some of the figures for cancer...rather than with the lower probabilities of early death due to, say, electrocution or drowning." (Kinchin, 1978)

Taking these points into account, he proposed that the limit on the annual accidental probability of inducing delayed death to the individual should be 3×10^{-5}/year. Although noting that this was a factor of 3 higher than the upper end of the range suggested by ICRP, he felt it difficult to justify a relative acceptable limit factor of less than 30 between death in 10 years' time and death today (Kinchin, 1979).

Limits on aggregrate societal risk of immediate and delayed deaths are specified by a pair of frequency versus consequence curves. The rationale for the early death limit curve was: "It would not seem unreasonable to propose a criterion that the total risk from nuclear reactors should be roughly comparable with that from meteorites." Each of an assumed population of 100 reactors in the U.K. was assigned 1/100 of the total risk. The societal delayed death curve was formed using the same factor of 30 used to set the limit on individual delayed death risk. The limit curves for light water reactors (LWRs) are shown in Figure 1.3 redrawn from Kinchin's 1979 proposal.

Specification of limits on effects allows comparisons with other risks and flexibility in design and siting to achieve the safety goals. Kinchin emphasized that the design goals have to be supplemented by good engineering practice and quality assurance programs to ensure that the safety goals are met. For any particular case, individual risk of early and delayed death at the site boundary and the corresponding societal risks of early and delayed deaths would be examined. The most limiting criteria would then be applied.

The Construction Industry Research and Information Association (CIRIA) of the U.K. has attempted to rationalize the safety and serviceability factors for structures such as buildings and bridges by relating them to social and economic criteria (CIRIA, 1977).

These criteria were expected to vary with the size and intended use of the structure and with the prevailing social and economic climate in the country in which it would be built. They found it convenient to consider human life and economic consequences

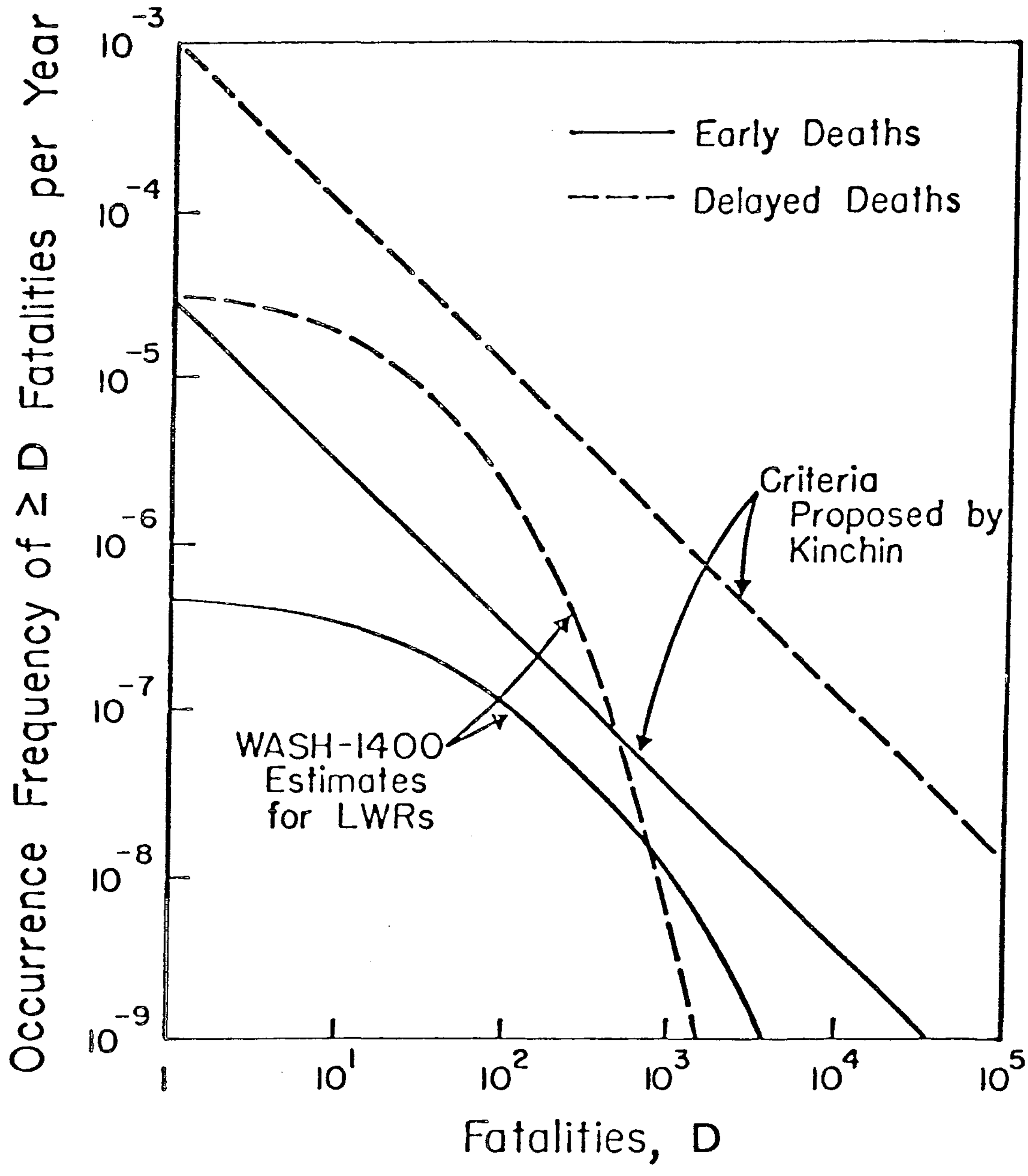

FIGURE 1.3. Criteria proposed by Kinchin (1979).

of failure separately, but acceptable risk levels in heavily populated buildings may be found by a combined socio-economic criterion.

Historically, the annual risk of death to any person in the U.K. due to collapse of a structure is on the order of 1.4×10^{-7} per year. This was taken to indicate that the public expects these risks to be small compared to other risks to which they are exposed. The degree of safety required also was intended to reflect the public aversion to the failure of each class of structure.

By reference to statistics on each class of structure, the yearly acceptable risk of failure, R_f, was deduced to have the form

$$R_f = \frac{10^{-4} K_s}{N_r}$$

where N_r is the average number of people expected to be within or near the structure if it were to collapse and K_s is the social criterion factor, given in Table 1.12 for various types of structures. The failure risk limit in each class is inversely proportional to the number of people affected by the failure. However, the social criterion factor is also seen to be smaller for structures that generally involve more people or serve important public functions, so that there would be a very strong aversion to failures that could injure a large number of people if the criterion were to be used.

Table 1.12. Social Criterion factors, K_s (CIRIA, 1977)

Nature of Structure	
Places of assembly, dams	0.005
Domestic, office or trade and industry	0.05
Bridges	0.5
Towers, masts, offshore structures	5.0

The economic criterion was formed by minimizing a total cost function E_t, given by

$$E_t = E_i + E_f R_f n_d$$

where E_i is the initial cost, E_f is the consequential cost of failure, and n_d is the design life in years.

CIRIA noted that, historically, society has responded in a very risk averse manner to large consequence failures and this has led to disproportionate expenditures to reduce those risks. Although this aversion cannot be totally eliminated, they suggested that it could be rationalized somewhat by setting a limit on the expenditure, M, to prevent a failure:

$$M < \frac{\nu N_r}{K_s}$$

where ν is a constant and N_r and K_r are defined as above. If ν is set at £25000, this would imply an expenditure of about $\$10^6$ per life saved for low risk structures for which $K_s = 0.05$.

1.4.1.3. Risk Management Approaches

Two common premises of the following risk management approaches are: that society has a limited amount of resources to allocate for the reduction of the risks that accompany the benefits of its endeavors; and that these resources should be allocated wisely. They reflect concern that improper actions to reduce risks may not minimize risk and may even give rise to an increase in overall risks. The first two approaches are concerned with general societal risk while the last two deal specifically with nuclear power plant risks.

As a starting point for discussion on the subject of risk acceptance criteria, Okrent and Whipple (1977) described a simple quantitative approach to risk management which incorporated the following principal features:

Risk assessment

Each risk-producing facility, technology, etc., would have to undergo assessment both of risk to the individual and to society. The risk assessment would be performed under the auspices of the manufacturer, owners, etc. It would be independently reviewed and evaluated. The decision on acceptability would be made by a regulatory group. For practical reasons, there would be some risk threshold below which no review was required.

Graduated limits on individual risk

Societal activities would be divided into major facilities or technologies, all or part of which are categorized as essential, beneficial, or peripheral to society. There would be a decreasing level of acceptable risk to the most exposed individual (for example, 2×10^{-4} additional risk of death per year for the essential category, 2×10^{-5} for the beneficial category, and 2×10^{-6} for the peripheral category).

Allowance for uncertainties

The risk would be assessed at a high level of confidence (say 90 percent) which thereby reflected the uncertainties and provided an incentive to obtaining better data, since the expected value of risk must be smaller, the larger the uncertainty.

Internalization of residual risk costs

To provide incentive to reduce risk and balance some inequities between those who receive the benefits and those who are burdened by risk, the cost of the residual risk would have to be internalized, generally via a tax paid to the federal government, except for risks which are fully insurable and, like drowning, are readily attributable. The government would, in turn, redistribute the risk tax as national health insurance and/or reduced taxes to the individual.

Modest risk aversion

Risk aversion to large events would be built into the internalization of the cost of risk, but with a relatively modest penalty. If some technology or installation posed a very large hazard at some very low probability, and many do, a case by case decision would be required, with considerable emphasis on the essentiality of the venture.

Cost-effective reduction of residual risk

A limit on the marginal cost of risk reduction could be imposed. A safety improvement would be required if the marginal cost was lower than the limit, but not required if above. This would be a quantification of the ALARA (as low as reasonably achievable) criterion, although an incentive to reduce risk as well as the uncertainty in knowledge of risk would already have been provided by establishing a suitable level for the risk tax.

The authors realized that their approach may be both too complex and too simple but hoped it would stimulate discussion of the question, "How safe is safe enough?"

Also to promote discussion on risk management, the late C.L. Comar wrote an editorial for Science (1979) entitled: "Risk: A Pragmatic De Minimis Approach" which is reproduced in part below:

"Society is becoming well informed and anxiety-prone about technology-associated risks, which leads to desire their elimination. The logical and traditional approach is first to estimate the risk, a scientific task. Then comes the issue of risk acceptance, a most difficult step--moving from the world of facts to the world of values. Ideally, judgments involving risk acceptance should be made on society's behalf by a constitutionally appropriate body. But no such public decisionmaking process exists. We make do with disparate efforts of individuals, special-interest groups, self-appointed public interest groups, and legislative, judicial, and regulatory systems. However, if at least very large and very small risks were dealt with on the factual basis of effects, the individual and social value systems could be accommodated to some degree and much confusion avoided.

"Each person has a probability of dying in any particular year, the value depending mainly on age. The existing probabilities are well known for the United States. For example, in 1975, 1.89 million died out of a population of 213 million, giving an overall probability of 1 in 113. For some specific age groups the values were: 1 to 4 years, 1 in 1425; 5 to 14 years, 1 in 2349; 25 to 34 years, 1 in 692; 55 to 64 years, 1 in 67. We can now answer the question, "What does changing a risk do to a person's existing probability of dying?" For instance, if a young child were exposed to an additional risk of 1 in 100,000 (0.014 in 1425) in 1975, his overall risk for that year would be 1 in 1425 plus 0.014 in 1425, or 1.014 in 1425. For the purposes of discussion some guidelines, which may depend somewhat on age, can now be stated in terms of numerical risk:

(1) Eliminate any risk that carries no benefit or is easily avoided.

(2) Eliminate any large risk (about 1 in 10,000 per year or greater) that does not carry clearly over-riding benefits.

(3) Ignore for the time being any small risk (about 1 in 100,000 per year or less) that does not fall into category 1.

(4) Actively study risks falling between these limits, with the view that the risk of taking any proposed action should be weighted against the risk of not taking action.

Clearly these suggested guidelines are a gross oversimplification. The unfortunate, overtaken by a one-in-a-million catastrophe, have a 100 percent chance of harm. The hard fact is that attempts to eliminate risks for the unfortunate few tend to markedly increase them for the rest of a large population. This idea is most difficult to defend practically, especially when the unfortunate few are known and the unfortunate many are nameless. In addition, it is necessary to take into account such matters as validity and uncertainty in risk estimates, nonlethal and esthetic effects, voluntary versus involuntary risks, societal abhorrences, and the strange versus the familiar."

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The final example in this review arises in the proposed trial approach to quantitative safety goals for nuclear reactors forwarded by the Advisory Committee on Reactor Safeguards (ACRS 1980) to the U.S. Nuclear Regulatory Commission for consideration. In this approach the following safety criteria are proposed:

1) Limits are placed on the frequency of occurrence of certain hazardous conditions within the reactor.

2) Limits are placed on the risk to the individual of early death or delayed death due to cancer arising from an accident.

3) Limits are placed on the overall societal risk of early or delayed death.

4) An "as low as reasonably achievable" approach is applied with a cost-effectiveness criterion that includes both economic costs and a monetary value of preventing premature death.

5) A small element of risk aversion is applied to infrequent accidents involving large numbers of early deaths compared to a similar number of deaths caused by many accidents each involving one or two deaths.

1.4.2. A Critique of Past Proposals

Fischhoff, et al. (1980) recently published a critique of past proposed approaches to acceptable risk. We reproduce some excerpts from the abstract to that report below:

"Acceptable-risk decisions are an essential step in the management of technological hazards. In many situations, they constitute the weak (or missing) link in the management process. The absence of an adequate decision-making methodology often produces indecision, inconsistency, and dissatisfaction. The result is neither good for hazard management nor good for society."

The following conclusions emerge:

"(1) Acceptable-risk problems are decision problems, that is, they require a choice between alternatives. That choice depends upon the alternatives, values, and beliefs that are considered. As a result, there is no single all-purpose number that expresses 'acceptable risk' for a society.

(2) Values and uncertainties are an integral part of every acceptable-risk problem. As a result, there are no value-free processes for choosing between risky alternatives. The search for an 'objective method' is doomed to failure and may blind the searchers to the value-laden assumptions they are making.

(3) None of the approaches considered here offers an unfailing guide to selecting the most acceptable alternative. Each gives special attention to some features of acceptable-risk problems, while ignoring others. As a result, not only does each approach fail to give a definitive answer, but it is predisposed to representing particular interests and recommending particular solutions. Hence, choice of a method is a political decision with a distinct message about who should rule and what should matter.

(4) Acceptable-risk debates are greatly clarified when the participants are committed to separating issues of fact from issues of value. Yet, however sincere these attempts, a clearcut separation is often impossible. Beliefs about the facts of the matter shape our values; in turn, those values shape the facts we search for and how we interpret what we find.

(5) The controlling factor in many acceptable-risk decisions is how the problem is defined (i.e., which options and consequences are considered, what kinds of uncertainty are acknowledged, and how key terms are

operationalized). As a result, definitional disputes underlie some of the most rancorous political debates.

(6) Values, like beliefs, are acquired through experience and contemplation. Acceptable-risk problems raise many complex, novel, and subtle value issues, for which we may not have well-articulated preferences. In such situations, the values we express may be greatly influenced by transient factors, including subtle aspects of how the question is posed.

(7) Even the most knowledgeable experts may have an incomplete understanding of new and intricate hazards. Indeed, some limits on breadth of perspective may be a concommitant of acquiring a particular disciplinary or world outlook. In such cases, non-experts may possess important supplementary information or viewpoints on hazards and their consequences.

"Recommendations

No one solution to acceptable-risk problems is now available, nor is it likely that a single solution will ever be found. Nonetheless, the following recommendations, addressed to regulators, citizens, legislators, and professionals, should, if implemented, enhance society's ability to make decisions.

(1) Explicitly recognize the complexities of acceptable-risk problems. The value judgments and uncertainties encountered in specific decision problems should be acknowledged. More generally, we should realize that there are no easy solutions and not expect them from society's decision makers.

(2) Acknowledge the limits of currently available methods and expertise. Since we do not know how to get the right answers to these questions, we should concentrate on avoiding the mistakes to which various disciplines and people are attuned. The result would be a multi-method, multi-perspective approach to decision making that emphasized comprehensiveness.

(3) Improve the use of the present approaches. Develop guidelines for their conduct and review. Make their scope and presentation sensitive to all aspects of the problem and to the desires of as many shareholders as possible. Analyses

should be repeated in order to incorporate the insights they engender and the critiques they provoke.

(4) Make the decision-making process consistent with existing democratic institutions. The public and its representatives should be constructively involved in the process in order to legitimate its conclusions, facilitate their implementation, and increase the public's understanding of hazard issues.

(5) Strengthen non-governmental social mechanisms that regulate hazards. Decisions reached in the marketplace and political arena provide important guidance to most approaches. Their functioning can be improved by various measures including reform of the product liability system and increased communication of risk information to workers and consumers.

(6) Clarify government involvement. Legislations should offer clear, feasible, predictable mandates for regulatory agencies. The management of different hazards should be coordinated so as to build a legacy of dependable precedents and encourage consistent decisions."

1.5. Disparities in the "Value of Life"

Since societal resources available to help avert premature death are limited, whether it be due to a transportation accident, a heart attack, or cancer caused by a carcinogen in our air, water or food, governmental groups responsible for the allocation of resources intended to "save lives" will be establishing a "value of life" implicitly or explicitly each time they decide how much money they are willing to spend to avert a certain number of premature deaths due to each specific cause.

The "value of life" is a complicated and controversial subject, even when it is only the subject of academic studies. When the lives of identified individuals are at stake, the problem takes on emotional, moral and sociological overtones, among others.

More susceptible to evaluation and practical application is the amount of societal resources that are being (or should be) expended to reduce by a small amount the likelihood that each member of society, or a substantial segment thereof, will die prematurely due to some specific cause; for example, auto accidents. Interestingly, by examining society's allocation of resources to reduce specific risks and quantifying the expected effect of the measures taken, one can derive an implicit "value of life" that society has been, in effect, using, in judging how much to spend. When such studies are done, however, one finds a very wide disparity in the results.

Morlat (1970) estimated that, in France, $30,000 is spent per life saved in road accident prevention and $800,000 to $1 million in aviation accident prevention.

Sinclair, et al. (1972), examined a series of case studies and obtained the implicit life valuations for Great Britain. The implicit value of life, based on expenditures for safety, ranged from $10,000 per agricultural worker's life to $1 million for a nuclear power employee and $20 million for a high-rise apartment dweller.

Sinclair, et al., arrived at several main conclusions from their study including the following:

"(i) Risk levels and implicit life valuations differ widely from industry to industry.

(ii) It is possible to demonstrate numerical changes in valuation as they arise from the imposition of social controls--for example, the large increase in valuation caused by the legislative changes made after the disaster.

(iii) Life valuations appear to increase with the technical sophistication of an industry or with the recentness of its foundation.

(iv) Where risk levels can be determined at a national level, for social or technological reasons, valuations tend to be higher.

(v) Where risk levels are set nationally, relatively few individuals appear to be concerned in the technical determination.

(vi) Such risk levels are inconsistently set, even where the level is officially determined."

Conclusion (i) of Sinclair is similar to that of Morlat. Comparable conclusions can be drawn about the same inconsistency in implicit life valuations in the United States, as well as about conclusion (vi) of Sinclair, namely that risk levels are inconsistently set, even where the level is officially determined.

Among those who have reported on the disparities of implicit "value of life" in the U.S. are Schwing (1979), Cohen (1979), and Graham and Vaupel (1980). For example, Cohen provides the estimates of implicit "value of life" shown in Table 1.13.

In a similar vein, Graham and Vaupel found that, while within various regulatory agencies some spread in implicit value of life existed, median values were comparable for the National Highway Traffic Safety Administration (NHTSA), the Department of Health and Human Services (HHS), and the Consumer Product Safety Commission

TABLE 1.13.

VALUE PER FATALITY AVERTED (1975 DOLLARS) IMPLIED BY VARIOUS SOCIETAL ACTIVITIES

ITEM	$ PER FATALITY AVERTED
MEDICAL SCREENING AND CARE	
CERVICAL CANCER	$ 25,000
BREAST CANCER	80,000
LUNG CANCER	70,000
COLORECTAL CANCER;	
FECAL BLOOD TESTS	10,000
PROCTOSCOPY	30,000
MULTIPLE SCREENING	26,000
HYPERTENSION CONTROL	75,000
KIDNEY DIALYSIS	200,000
MOBILE INTENSIVE CARE UNITS	30,000
TRAFFIC SAFETY	
AUTO SAFETY EQUIPMENT--1966-70	130,000
STEERING COLUMN IMPROVEMENT	100,000
AIR BAGS (DRIVER ONLY)	320,000
TIRE INSPECTION	400,000
RESCUE HELICOPTERS	65,000
PASSIVE 3-POINT HARNESS	250,000
DRIVER EDUCATION	90,000
HIGHWAY CONSTRUC.-MAINT. PRACTICE	20,000
REGULATORY AND WARNING SIGNS	34,000
GUARDRAIL IMPROVEMENTS	34,000
SKID RESISTANCE	42,000
BRIDGE RAILS AND PARAPETS	46,000
WRONG WAY ENTRY AVOIDANCE	50,000
IMPACT ABSORBING ROADSIDE DEV.	108,000
BREAKAWAY SIGN, LIGHTING POSTS	116,000
MEDIAN BARRIER IMPROVEMENT	228,000
CLEAR ROADSIDE RECOVERY DATA	284,000
MISCELLANEOUS NON-RADIATION	
FOOD FOR OVERSEAS RELIEF	5,300
SULFUR SCRUBBERS IN POWER PLANTS	500,000
SMOKE ALARMS IN HOMES	240,000
COAL MINE SAFETY	22,000,000
OTHER MINE SAFETY	34,000,000
COKE FUME STANDARDS	4,500,000
AIR FORCE PILOT SAFETY	2,000,000
CIVILIAN AIRCRAFT (FRANCE)	1,200,000
RADIATION RELATED ACTIVITIES	
RADIUM IN DRINKING WATER	2,500,000
MEDICAL X-RAY EQUIPMENT	3,600

(CPSC): \$64 thousand, \$102 thousand, and \$50 thousand, respectively. For the Environmental Protection Agency (EPA), however, they found a median of \$2.6 million; and for the Occupational Safety and Health Administration (OSHA), they found a median of \$12.1 million. They found that the least expensive OSHA program is seven times more expensive per life-year saved than the most expensive NHTSA program.

Hence, consciously or not, society is permitting a wide disparity in the allocation of its resources used to define premature death. Not that all such resources need necessarily be allocated in the most cost-effective way, since there clearly are many other attributes which should enter into such decision-making. However, it may be that some of these decisions would be changed if the disparity were known by the decision makers.

1.6. Risk Perception and Hazard Management

People respond to the hazards they perceive. If their perceptions are faulty, efforts at personal, public and environmental protection are likely to be misdirected. As we have noted earlier, extensive statistical data are available to guide perceptions and decisions for many kinds of accidents and diseases (e.g., motor vehicle accidents; heart disease, etc.). For some familiar activities, such as the consumption of alcohol and tobacco, assessment of risk requires complex epidemiological and experimental studies. Still other hazards, such as those associated with nuclear power or chemical waste disposal, are sufficiently new that risk assessment must be based on complex theoretical analyses, rather than on direct experience or empirical data.

Despite an appearance of objectivity, all forms of risk assessment include a large component of subjective judgment. Someone, relying on educated intuition, must determine the structure of the risk problem, decide the consequences to be considered, and select and interpret the relevant data.

Once the analyses have been performed, they must be communicated to those who actually manage hazards, including industrialists, environmentalists, regulators, legislators, and voters. If these people do not understand or believe the data they are shown, then distrust, conflict, and ineffective hazard management are likely.

In order to aid hazard management, research on perceived risk seeks to explain people's extreme aversion to some hazards, their indifference to others, and the discrepancies between these reactions and experts' recommendations. Why, for example, do some communities react vigorously against locating a liquid natural gas terminal in their vicinity despite the assurances of experts that it is safe? Why, on the other hand, do many communities situated on earthquake faults or below great dams show little concern for experts' warnings? (Section 1.2). Why is society willing to spend so much more money to avert a fatality in some situations (e.g., radiation protection) than in others (e.g., traffic safety)? Over the past few years, researchers have been attempting to answer such questions as these by examining the options people express when they are asked, in a variety of ways, to characterize and evaluate hazardous activities and technologies (Green, 1980; Green and Brown, 1980; Slovic, Fischhoff and Lichtenstein, 1979, 1980a; Slovic, Lichtenstein and Fischhoff, 1979; Vlek and Stallen, 1979). This descriptive research aims (a) to develop a taxonomy of risk characteristics that can be used to understand and predict societal responses to hazards and (b) to develop methods for assessing public opinions about risk in a way that could be useful for policy decisions.

1.6.1. Results

A number of systematic, replicable, and potentially important results have emerged from risk perception research. Laboratory research on basic perceptions and cognitions have shown that difficulties in understanding probabilistic processes, biased media coverage, misleading personal experiences, and the anxieties generated by life's gambles cause uncertainty to be denied, risks to be misjudged (sometimes overestimated and sometimes underestimated), and judgments of fact to be made with unwarranted confidence (Slovic, Fischhoff and Lichtenstein, 1979, 1980a). Unfortunately, experts' risk judgments appear to be prone to many of the same biases as those of laypersons, particularly when experts are forced to go beyond the limits of available data and rely upon their intuitions (Fischhoff, Slovic and Lichtenstein, in press). Research further indicates that disagreements about risk should not be expected to evaporate in the presence of evidence. Strong initial views are resistant to change because they influence the way that subsequent information is interpreted. New evidence appears reliable and informative if it is consistent with one's initial beliefs, contrary evidence tends to be dismissed as unreliable, erroneous, or unrepresentative (Nisbett and Ross, 1980). When people lack strong prior opinions, the opposite situation exists--they are at the mercy of the problem formulation. Presenting the same information about risk in different ways buffets their perspectives and their actions like a ship in a storm (Slovic, Fischhoff and Lichtenstein, 1980b; Tversky and Kahneman, 1981).

Research conducted within what is called the "psychometric paradigm" yields further generalizations, among which are the following, taken from Slovic, Fischhoff and Lichtenstein (in press a):

a) Perceived risk is quantifiable and predictible. Psychometric techniques seem well suited for identifying similarities and differences among groups with regard to risk perceptions and attitudes.

b) "Risk" means different things to different people. When experts judge risk, their responses correlate highly with technical estimates of annual fatalities. Laypersons can assess annual fatalities if they are asked to (and produce estimates not unlike the technical estimates). However, their judgments of risk are sensitive to other factors as well, (e.g., catastrophic potential, threat to future generations) and, as a result, are not closely related to their own (or experts') estimates of annual fatalities.

c) Even when groups disagree about the overall riskiness of specific hazards, they show remarkable agreement when rating those hazards on characteristics of risk such as knowledge, controllability, dread, catastrophic potential, etc.

d) Many of these risk characteristics are highly correlated with each other, across a wide domain of hazards. For example, voluntary hazards tend also to be controllable and well known, hazards that threaten future generations tend also to be seen as having catastrophic potential, etc. Analysis of these interrelationships shows that they can be accounted for by two or three higher-order characteristics of factors, which seem to reflect the degree to which a risk is understood, the degree to which it evokes a feeling of dread, and the number of people exposed to the risk (see Figure 1.4.). This factor structure has been found to be similar across groups of laypersons' and experts' judgment of large and diverse sets of hazards. Making the set of hazards more specific (e.g., partitioning nuclear reactor accidents, etc.) appears to have little effect on the factor structure or its relationship to risk perceptions (Slovic, Fischhoff and Lichtenstein, in press b).

e) Many of the various characteristics, particularly those associated with the factor "Dread Risk", correlate highly with laypersons' perception of risk. The higher an activity's score on the dread factor, the higher its perceived risk, the more people want its risk reduced, and the more they want to see strict regulation employed to achieve the desired reductions in risk (see Figure 1.5). The factor labeled "Unknown Risk" tends not to correlate highly with risk perception. Factor 3, Exposure, is moderately related to lay perceptions of risk. In contrast, experts' perceptions of risk are <u>not</u> related to any of the various risk characteristics or factors

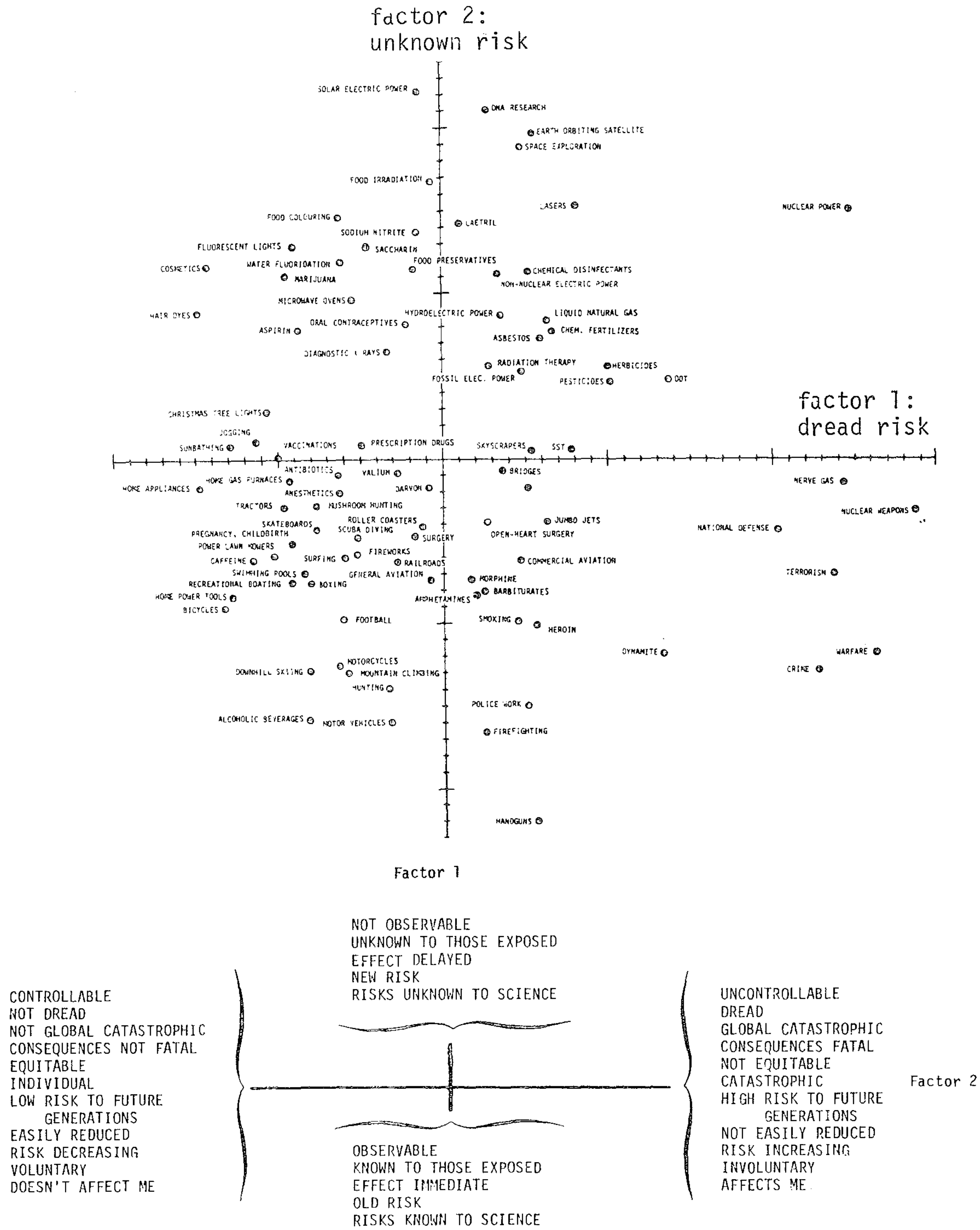

FIGURE 1.4. Hazard locations on Factors 1 and 2 of the three-dimensional structure derived from the interrelationships among 18 risk characteristics. Factor 3 (not shown) reflects the number of people exposed to the hazard and the degree of one's personal exposure. The diagram beneath the figure illustrates the characteristics that comprise the two factors.

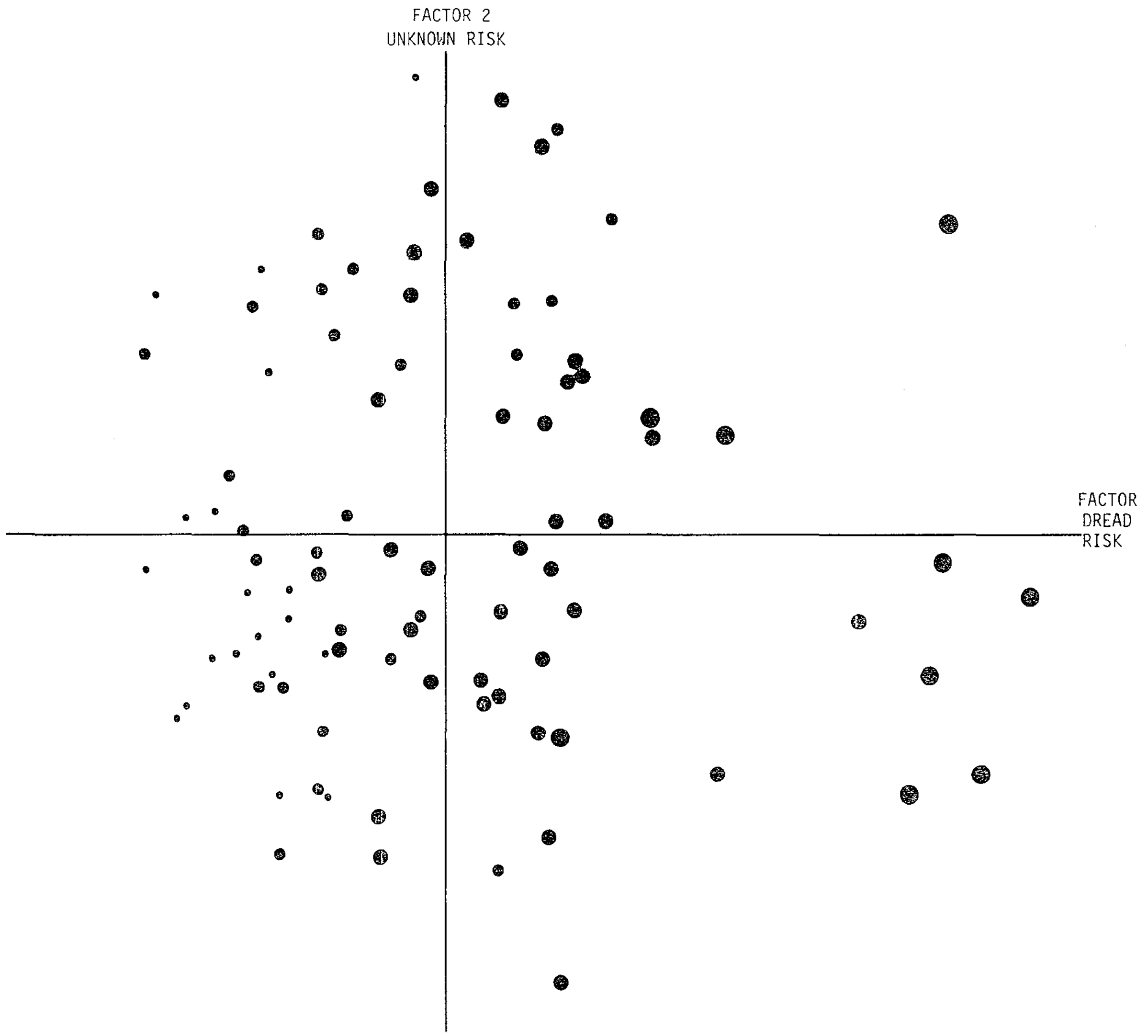

FIGURE 1.5. Attitudes towards regulation of the hazards shown in Figure 1.4. The larger the dot, the greater the desire for strict regulation to reduce risk.

derived from these characteristics.

f) In agreement with hypotheses orginally put forth by Starr (1969), people's tolerance for risk appears related to their perception of benefit. All other things being equal, the greater the perceived benefit, the greater the tolerance for risk. Morover, risk tolerance is greater for voluntary activities than for involuntary activities providing similar levels of benefit. In contrast to Starr's hypotheses, however, research indicates that risk acceptability is also influenced by other characteristics such as familiarity, control, catastrophic potential and uncertainty about the level of risk.

1.6.2. Policy Implications

Individual and societal response to hazards is multi-determined. Political, social, economic and psychological factors interact with technical feasibility in complex and, as yet, poorly understood ways. Nevertheless, risk perception research would seem to play an important role in informing hazard management policies. In particular, studies of public attitudes could be used to highlight the concerns of people at risk to forecast their responses to future hazards and management policies. For example, Slovic, Fischhoff and Lichtenstein (in press a) have described a number of policy areas in which risk perception research has produced relevant knowledge, including (a) the National Flood Insurance Program, (b) automobile seat belt legislation, (c) forecasting public acceptance of various energy technologies, and (d) performing comparative risk assessments. This last topic is particularly relevant to the present study, since comparisons of probabilities, accident magnitudes and expected losses (e.g., probabilities x magnitudes) are so heavily weighted in risk assessment and policy making (see Section 1.2). Risk perception research indicates that such comparisons may be incomplete, hence not fully satisfactory to the public. People's perceptions are determined not only by statistics, but also by a variety of other quantitative and qualitative characteristics--including a hazard's degree of controllability, the dread it evokes, its catastrophic potential, and the equity of its distribution of risks and benefits. In short, "riskiness" means more to people than "expected number of fatalities". Attempts to characterize, compare and regulate risks must be sensitive to the broader conception of risk that underlies people's concerns. However, they should not necessarily be dominated by people's perceptions for several reasons, including the following:

- there may also be no single position which can be considered representative of the people
- people's perceptions may be subject to drastic changes in relatively short periods of time

- people's perceptions may lead to policies that are clearly adverse to the best interest of the people, if these perceptions are not tempered.

1.7. Reactive versus Preventive Modes of Risk Management

At the risk of gross oversimplification, the regulation, control and management of hazard and risk can be categorized as being of a preventive or reactive mode. For example, with regard to fires, a city has codes to which certain structures should be built in order to reduce the likelihood of severe fire damage, and it has firemen to extinguish and control fires, should they occur. Smoke detectors, while they do not prevent fires, represent a preventive measure with regard to the loss of life from fires.

While society quite properly finds it appropriate and necessary to develop both preventive and reactive modes of risk management, in this study we shall focus strictly on preventive modes. Thus, we shall not deal with very important questions related to emergency preparedness. Nor shall we deal with medical measures which might be taken to remedy the adverse effects on health of exposure to contaminants or pollutants in our air or water. On the other hand, we will, in principle, be interested in measures intended to prevent hazardous wastes from contaminating our drinking water as well as in measures to reduce the concentration of hazardous contaminants which may find their way into the water.

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Chapter 2. ON CURRENT RISK MANAGEMENT PRACTICES IN LOCAL COMMUNITIES

This chapter discusses the current state of risk management practices in local communities in the U.S. and offers some alternatives to present policies, which are mainly implicit rather than explicit attempts to limit overall risks of death and injury due to technological and natural causes. The chapter discusses the concept of risk management as presently used in local government and reports results from a limited survey of local risk managers in the states of California and Oregon; in the counties of Multnomah and Lane (Oregon) and Los Angeles and Riverside (California); as well as the cities of Portland and Eugene (Oregon) and Los Angeles and Riverside (California).

While generalization is itself risky, all of our observations point toward the conclusion that local government officials have little understanding of, hence, little concern for the quantity of risk posed for citizens by various hazards. If it seems desirable to place risk management decisions in the hands of local officials, then some capacity for risk quantification, hence comparison, must be developed. The policy suggestions in Chapter 7 concern possible means through which this capacity might be augmented.

2.1. The Concept of Risk Management

This research began from the premise that risks to life and health, other than occupational risks, fall, at least in part, within the purview of the local government, and that the mitigation of these risks is, or ought to be a key concern of local decision makers. A number of assumptions flowed from this premise. One was that a generic concept of risk formed the local official's approaches to problems--policies are directed toward reducing risk as much as they are directed toward particular hazards such as air and water pollution, vehicular accidents, and the like. Another assumption was that, given an orientation toward risk, alternative management strategies based upon different risk acceptance criteria could be devised. Finally, it was also assumed that optimal mixes of these strategies could be devised for various localities so that more rational, cost-effective risk management practices could be implemented.

These assumptions were rendered suspect almost from the outset of the research. One of the first tasks undertaken was identification of risk managers in several California and Oregon localities. The procedure used was straightforward: The office of the chief executive of each locality was contacted, and knowledgeable informants, normally persons with the title of "executive assistant" or "chief administrative assistant", were asked to identify the person and agency "principally responsible for managing risks to life and health, other than occupational risk" in the locality.

This procedure followed techniques normally used to identify government agencies whose functions are of interest, but in this instance it evoked some unusual responses. One kind of response was incredulity: Informants did not understand the phrase "managing risks". At first, this kind of response was treated by suggesting specific hazards that might be managed locally, but later we refrained from doing so and instead explored whether the concept of risk was understood at all. In most instances it was not. The idea that risks of death, injury, or other adverse consequence, expressed as a probability, were to be reduced by local government action, proved elusive. Instead, reference was made to local government functions such as police, fire, and health protection rather than the outcome of these functions or their effectiveness in terms of risk to individuals. Incredulity, however, was not the model response to our initial inquiries. More often, informants designated one of two types of persons as principal risk managers. One type was civil defense or emergency preparedness coordinators, persons responsible for anticipating and managing responses to catastrophic events such as floods, earthquakes, and, of course, acts of war. The second type designated as principal risk managers was insurance administrators charged with maintaining financial protection against liability claims and property losses. (The term risk management often appears on organization charts of comptrollers' offices and finance departments to designate units responsible for insurance administration.) Civil defense officials, of course, are concerned with hazards of low probability but high consequence that comprise only a fraction of the risks to health and safety. Insurance managers are concerned exclusively with fiscal as opposed to personal risk. Personal risks to which most people are exposed but with low or delayed consequences do not fall within the purview of persons designated as risk managers by our initial informants. The reason, in retrospect, is straightforward: Whereas formal risk analysis considers risk to be the probability of exposure to hazard times the probability of its adverse effect, the concept of risk used in local government pertains mainly to infrequent but extremely risky (if not personally hazardous) events. Frequent events that pose substantial hazards such as crime, fire, and acute illness are treated as virtual certainties, not risks, hence are handled by police and fire departments, and events whose effects are uncertain, whether because their manifestation is delayed or unknown, tend not to be treated as risks by local officials.

Not only did the initial interviews show the concept of risk to be foreign to or extremely limited in local government, but they also revealed the near absence of formal risk management activities. Formal risk management normally entails the following: (1) a suspected source of risk is identified; (2) the degree of hazard posed by the source is estimated from either experimental or observational evidence and the level of exposure to the hazard is calculated so that an overall risk estimate can be made; (3) this level of risk is compared to previously established risk acceptance criteria; (4) policies are developed and implemented so that the risk does not exceed acceptable levels; and (5) a system of monitoring is set in place to insure the effectiveness of the policy. The terms identification, analysis, acceptance, policy, and monitoring describe these steps, each dependent upon the prior one. Litte resembling this rational model of risk management surfaced in our first conversations with local officials. Indeed, where we did find risk management at the local level, it was at the end rather than at the beginning of the sequence. Identification of specific hazards posing risk does not normally occur at the local level. When it does, it is sporadic and usually as the result of a highly publicized incident such as a major fire or a toxic spill. Substances or activities posing substantial hazards are not actively sought. Quantification of risk is rare at the local level, and determination of acceptable levels is all but nonexistent. There is, of course, political determination of what hazards are tolerable and what are not, but this is far different from setting quantitative standards for acceptability. Specific policies for managing risks are sometimes enacted locally, usually at the behest of state and, in turn, federal authorities and only infrequently due to local initiatives. Monitoring of hazards is, however, frequently a local function, undertaken, again, mainly at the behest of state and federal authorities.

Two key questions to be addressed then, are: (1) Why the technical concept of risk has not been understood or has been misunderstood by officials of local and state governments. And, (2) Why what appears to be a reasonable and rational sequence of steps toward formal risk management, has been altogether upended such that local government action occurs only at the end rather than at the beginning of the risk management process. In order to begin moving toward answers, we will first explore, somewhat imprecisely, the kinds of risk management activities presently undertaken by local governments. A rigorous delineation of risk management practices is not possible, partly due to time and resource constraints, but mainly because the concept of risk is so poorly understood that it encompasses potentially all local government activities. We then ask why local governments appear, for the most part, to be averse to the idea of risk management. The structure and tradition of local government in the U.S. may render local risk identification, analysis, and acceptance very risky for elected officials. A brief description of federal, state, and local government roles in the risk management process follows. This is not intended to be a complete account of risk management at all three levels of government but serves only to illustrate why the national system for dealing with various hazards has evolved as it has, and its weaknesses and strengths. Deliberately or otherwise, the present system appears to have diminished the capacity of local government to identify, analyze, and manage broad categories of risk to health and safety.

2.1.1. Types of Local Risk Management

Three types of local risk management emerged from the initial conversations with city, county, and state officials. One type we call management by reaction; the second is management by compliance; and the third is analytic or formal risk management. These three types differ somewhat from the generic approaches to risk developed by Decision Research, in part because they apply specifically to local government. In particular, what we call reactive risk management is a form of what Decision Research calls "bootstrapping" or incremental decision making. However, risk management by reaction is principally a short-term and sometimes highly political response to hazards possibly demanding more thoughtful and long-term means of mitigation.

2.1.1.1. Risk management by reaction

Risk management takes place by reaction when life-threatening situations or events causing loss of life lead to measures intended to prevent their recurrence. These measures are implemented swiftly and in most cases without careful analysis of their probable costs and benefits. Myriad instances of reactive risk management at the state and local level have come to our attention in the course of this research, including the following:

--LNG has been banned from major harbors in California. LPG, whose safety hazards are similar to and in some ways worse than LNG, was not banned, and it continues to be transported into Los Angeles harbor.

--Only after a disastrous apartment house fire was a local ordinance requiring fire doors enacted.

--Another apartment house fire triggered enactment of an ordinance requiring smoke detectors in all dwelling units.

--Discovery of trace amounts of TCE in drinking water caused closure of waterwells in a wide area.

--The use of an extremely effective nematode killer, DBCP, was effectively banned when a high incidence of sterility was detected among workers in a plant manufacturing the substance.

Several elements are common to situations where reaction governs risk management. One is a highly publicized event. Normally, government temporizes. A speedy response to any potential hazard occurs only when substantial attention is given by the media. Thus, for example, an unnoticed tenement fire would be much less likely to result in a smoke detector ordinance than a fire in a luxury high-rise. A second element is conversion of scientific questions concerning risk into political issues of public safety and protection. Generally, this requires that someone in a visible elected or appointed office adopts the issue as his or her own. The smoke detector ordinance is again illustrative. The public investigation of the high-rise fire that culminated in the ordinance was undertaken, in part, to draw attention to a municipal fire commission that had always been overshadowed by its counterpart local police commission. A third characteristic of reactive risk management is its short time frame. Problems arise swiftly and vanish from public view once some action has been taken, regardless of the effectiveness of the measures enacted.

A somewhat different and less dramatic form of risk management by reaction occurs when last year's disaster triggers this year's emergency planning. Southern California, in particular, experiences this cycle of drought, brush-fire, rain, flood and mudslide. Only in the aftermath of the "fire season", which strips foliage (and dwellings) from hillsides, can the potential for floods and slides be ascertained and preventive measures taken, which comprise mainly the deployment of personnel and equipment. This type of risk management is labeled reactive because it operates on a year-to-year basis, and no analysis of long-term risk and benefits is conducted. None of the larger issues--should fire zones and flood and slide plains be evacuated permanently?--are permitted to surface. Planning for emergency response to catastrophic events that have not occurred, such as major earthquakes and acts of war is anticipatory rather than reactive, but is nonetheless principally concerned with maintaining essential services rather than mitigating potential losses.

2.1.1.2. Risk management by compliance

Risk management occurs by compliance when rules, codes, standards, and statutes govern decisions affecting life and health. Compliance is distinguished from reaction in that it is orderly rather than ad hoc. The same standards, more or less, apply to all similar cases. Compliance is also distinguished from more analytic approaches in that the standards themselves rather than independent risk assessment and risk acceptance criteria inform choices. Myriad examples of risk management by compliance can be given:

--The amounts and types of wastes discharged into public waterways, the disposal of hazardous wastes, and the levels of contaminants in public drinking water are limited by federal regulations promulgated by the EPA.

--Seismic design for buildings, transportation and storage of hazardous materials, and highway safety are regulated by state and local statutes.

--The design of electrical generation and transmission networks, waterworks facilities, and dams and bridges is governed by professional engineering standards.

Risk management by compliance sometimes entails what Decision Research calls "bootstrapping" whereby precedent and political and economic realities shape standards, and it sometimes entails "professional management", whereby judgements of experts are relied upon. However, no matter what the process from which standards are derived and no matter where their source, risk management is by such compliance so long as decisions makers rely upon standards and codes set by others without attention to a guiding concept of risk or explicit risk acceptance criteria.

2.1.1.3. Risk management by analysis

Analytical methods for dealing with risk combine most of the elements of the formal risk management model discussed above. Specifically, there is an effort to confine overall levels of risk within the bounds of what is believed acceptable, however the latter is determined. The analytic approach is distinguished from reactive risk management in that it involves quantification and estimation of risk prior to decisions. Analysis is distinguished from compliance in that it does not automatically accept standards set elsewhere that determine allowable levels of hazards if not acceptable levels of risk. Examples of the analytic approach to risk management in state and local government include the following:

--The final physical plan for major harbor facilities in a large port was made contingent upon detailed analysis of risks under alternative scenarios. Planning studies for a proposed LNG terminal at another port were also contingent upon risk analysis.

--The design--but not the siting--of a regional hazardous waste disposal facility was based upon engineering criteria that included explicit estimation of risk.

--Most epidemiological studies conducted by local health authorities are, by implication, studies of risk.

Analytic studies of risk are often undertaken to satisfy federal funding requirements; this is the case, for example, for port facilities. In other instances, risk analysis consists of the application of engineering and statistical principles to well-delineated problems such as the design of a disposal facility and estimation of morbidity and mortality rates. Analytic approaches to risk, then, tend not to be used to frame policy decisions at the local level, but they may accompany their implementation.

2.1.1.4. The balance of the three types in local government

Overall, local government entities tend very much toward risk management by reaction and by compliance,and relatively little toward analytical techniques. Indeed, what is most striking in examining federal government is the extent of specialization of its functions and the absence of an overriding quantitative conception of risk acceptance or mitigation, or, in the argot of local administration, public protection. The bulk of local, and to a lesser extent state, expenditures are for public protection, emergency response services--police, fire, acute medical care--and planning for emergency response. Expenditures for risk mitigation generally support enforcement of codes and regulations applying to very specific kinds of hazards such as storage of flammable materials, contaminants in drinking water, and the like--but not analytical studies aimed at identifying, quantifying, and comparing risks. There are many reasons why analytical approaches to risk, which are aimed explicitly at maximizing public protection consistent with values and resources, have not displaced other approaches. These reasons will be explored in some detail in the next section.

2.1.2. The Perils of Risk Management

Money forces divert public officials from thinking and directing policy in terms of a quantitative conception of risk. One impediment to quantification, which is implicit in analytic approaches to risk, is at the cognitive level. People tend to overestimate some risks and underestimate or ignore others. Another limitation is historical. Traditionally, the functions of local governments have been limited to service delivery, and localities have not had a mandate to protect their citizens from all conceivable risks to life and health. There are also political limitations affecting management of risks of low visibility or salience since short-run benefits from analytic approaches to risk are likely to be invisible, and the costs will be substantial.

2.1.2.1. Cognitive limitations

It is well documented that the public misperceives the relative riskiness of different kinds of hazards. Generally, risks associated with hazards that are sensationalized in the press, such as earthquakes, tornadoes, and major fires and crime, tend to be overestimated as are risks of death due to causes that are statistically rare but dramatic such as botulism and rabies. By contrast, the riskiness of chronic hazards affecting many people tends to be underestimated. Most people, for example, think that they have a better-than-average chance of living past eighty and that they are better-than-average drivers. Most people, furthermore, underestimate substantially deaths caused by accidents, cancer, and cardiovascular disease.

This cognitive aspect of risk cannot be overlooked in asking why analytic risk management is infrequent in local government. Absent public perception that a hazard poses substantial risk, local action is difficult if not impossible. Absent local action when public perception of a risk is high, discontent will ensue. This perception of magnitudes of risk, however, is but one element of the problem, and perhaps the minor element. To the extent that the public's understanding of risk is conditioned by the media, considerable volatility will exist in what is perceived hazardous and what is not, hence where action is demanded and where there is indifference. The disposal of toxic wastes, for example, was not a principle concern of local officials in California until the Love Canal achieved national notoriety. Major seepages from hazardous wastedumps were discovered shortly thereafter in both Los Angeles and Riverside Counties, California. Generally, local officials are not surprised and do not express dismay when rapid shifts of public opinion compel them to address problems which had earlier been ignored. Quite the opposite, tumultuousness in public life is expected. As one policy analyst, not a civil defense official, expressed the situation, "It's like living in a bombshelter-- you never know when you are going to be hit or what you will be hit with". But under such conditions of volatility, objective analysis that requires quantification and calculation gives way to demands for immediate action. Analytic approaches to risk rarely prove helpful when the vicissitudes of public opinion demand decisions in a short time frame.

2.1.2.2. Historical limitations

Historically, local government has had limited functions, principally delivery of direct government services to citizens. These services include primary and secondary education, police and fire protection, streets, sanitation, and public parks and recreation. Over time, functions have tended to accrue at the local level, and older cities provide more and more varied services than newer ones. The newer services include welfare, which was added to local government in the 1930's and health, which was added through the 1950's and 1960's. Certain analytic functions have also been added in some cities in the last ten to twenty years, including revenue and expenditure forecasting activities. It should be noted however, that forecasting activities utilize rudimentary economic models that are easily understood, and that they may be vital to the financial survival of city government if not the personal survival of citizens. The primacy of service delivery has had several effects on the texture of local government that limit capacity for analytic approaches to risk.

First, service delivery operates on short-time horizons. Most, but not all, that local government does demands relatively rapid responses to citizen input: minutes for emergency services, days, but not years, for maintenance of physical plant, and somewhat longer for land use decisions. The service orientation also renders analytic capacity weak and not highly valued as performance is preferred to prognostication. Since most hazards that are potentially the subject of formal risk analysis are not imminent, concern for them is displaced by more pressing demands.

Second, the primacy of service delivery renders constituencies issue-specific and therefore short-lived and inchoate at the local level. Local political parties are often weak or irrelevant, although this is much less the case at the state level. Specific kinds of hazards, especially those most recently publicized, may draw attention, but the larger concept of risk analysis and management lacks sufficient specificity to attract sustained interest.

Third, risk management may detract from the delivery of essential services. Supplies of public drinking water, sewage systems, and refuse disposal will be maintained so long as they pose no immediate and substantial threat to health and safety. Few local officials will state explicitly that comprehensive risk management intentionally poses obstacles rather than advantages to them, but such a view is implicit in a political calculus that leads to indifference to analytical approaches to risk since the outcomes of such exercises will never be utilized.

2.1.2.3. Political and financial limitations

Ultimately, the unwillingness or inability of localities to approach issues of risk analytically stems from political and fiscal weaknesses. Stated simply, the mandates and resources available to local and even to state governments with which to formulate and execute long-term policies of any kind are modest compared to the federal government. Such incapacities stem from a variety of sources in the institutional structure of local government.

First, cities, and to a lesser extent counties, are creatures of the state and therefore have limited power. These limitations vary from time to time and from place to place, but local government codes, "home rule" charters and the like rarely make explicit provision for the management of unspecified and often unknown hazards.

Second, local government in the U.S. is a patchwork of cities, counties, states, as well as special districts and regional authorities. The more one thinks in terms of risk management as opposed to specific types of public service and protection, the less likely it is that problems are confined to a single jurisdiction. Coordination across units of government is difficult and normally occurs only when forced. The siting of hazardous waste disposal facilities in Southern California is again illustrative: Only when the state threatened to preempt local zoning codes in order to maintain a Class A disposal facility did local authorities begin exploring a cooperative solution.

Third, individual mobility and the mobility of industrial firms in and out of local communities and even states is extremely high in the U.S., resulting in insensitivity if not indifference to long-term consequences of short-run decisions. This pattern is much more evident in financial management than in risk management: Short-term borrowing initiated during the Depression and used thereafter to cover revenue shortfalls resulted in the collapse if not formal bankruptcy of several Eastern cities in the 1970's. Similarly, generous pension benefits offered municipal workers in the 1960's threaten to bankrupt a number of other cities in the 1980's. The outcomes of these questionable fiscal practices could have been anticipated with much greater certainty than the results of risk mismanagement. Since most decisions concerning risk involve substantial uncertainty, the capacity of localities to formulate and implement long-term risk management policies must be questioned.

Fourth, local government budgets allow for little slack with which to undertake studies leading to risk identification, acceptance and policy. State agencies are somewhat advantaged in this respect as their budgets are not so closely tied to property tax rates.

In sum, misperception of risks, or, better, unpredictable changes in their salience as local issues, the service orientation of local government, and institutional as well as fiscal constraints limit the possibility for formal, analytic approaches to risk management, especially in cities and counties. This does not mean that no possibility exists for more effective management of risks at the local level, but it does suggest that, one way or the other, the federal role in risk management will be crucial.

2.2. A Survey of Risk Managers

In order to document somewhat systematically the impressions formed in the initial interviews, a limited survey of local and state risk managers was undertaken. Since concepts of risk analysis and management are at best poorly understood by local officials and encompass potentially all local government activities, it was decided to limit the survey to managers responsible for risks associated with the drinking water and the disposal of hazardous wastes. A procedure similar to that followed in our initial inquiries was used to locate informants at the state level. A knowledgeable informant in the governor's office was asked to give the title and name of the persons principally responsible for management of risks arising due to contamination of drinking water as well as disposal of hazardous chemical wastes. These two persons, or in some instances their immediate subordinates, were interviewed. Before the interviews with state officials were terminated, informants were asked for the titles of persons at the county (or regional) and municipal levels who had similar risk management responsibilities. The names of such persons in selected counties and municipalities were also sought. In each of two counties as well as of two cities in a state, interviews were then conducted with the persons designated by their state-level counterparts. In each state, then, it was intended to interview two officials at the state level and two officials in each of two counties and two cities.

Our interviews combined both open- and closed-ended questions. Informants were asked a variety of specific questions, for example: "Do you monitor hazardous activities to insure compliance with standards?" Following each closed-ended question, however, the informant was asked for comments or elaboration. For example, if it was indicated that hazardous activities were monitored, we would ask the informant to specify which activities were monitored and with what intensity. The interviews were conducted by both mail and telephone. Copies of the interview form were mailed several weeks in advance to prospective informants. Informants were asked to complete the questionnaire but not return it to Decision Research. Instead, it was indicated that a representative of Decision Research would call to discuss the answers on the telephone. This procedure allowed informants both to gather necessary information well in advance of direct interviews and to comment thoughtfully upon the individual questions. As will be noted below, the open-ended comments made by informants changed substantially the way one might have interpreted the closed-ended responses if they were considered alone.

The two states chosen for this limited survey were Oregon and California. The localities were Multnomah and Lane Counties as well as the cities of Portland and Eugene, Oregon, and Los Angeles and Riverside Counties as well as the cities of Los Angeles and Riverside, California. Four officials at the state level, eight from counties or regional authorities, and eight from cities, then, were to have been interviewed. Not all of the assigned informants could be reached, however, so that a total of nineteen interviews were completed. Overall, five state officials, seven at the county or regional level, and seven in cities cooperated in the survey. (An extra interview was obtained at the state level because the California Water Resources Board shares with the Department of Health responsibility for drinking water contamination.) No claim is made for the representativeness of this small sample of risk management officials. Indeed, it is unlikely that the representatives of any sample could be determined as there is no clearly defined population of risk managers who are potentially the subjects of study. However, the survey does provide direct information on the beliefs and perceptions of selected risk managers and thereby complements some of the observations made above.

Several broad issues arise out of the survey. One is the extent to which the full spectrum of risk management activities are carried out in local government. Another is the adequacy of existing scientific and technological information, manpower, and legal authority with which to manage hazards effectively. A third topic is the adequacy of current organizational arrangements among federal, state, and local authorities concerned with risks, as well as the desirability of a centralized risk management office in each locality.

2.2.1. Local Risk Management Practices

Given that risk is associated with almost all activities of government and the limited scope of this research, a compendium delineating local risk management procedures would not be feasible even if it were desirable. We can, however, draw some observations about how local officials conceive of risk, which elements of the overall risk management process outlined above tend to be present in local administration and which tend not to be, and the relative importance of analytic as opposed to more traditional incremental approaches to decisions concerning risk.

The first and perhaps most important observation to be drawn from the interviews is that local risk managers tend not to think of risk quantitatively, although this is somewhat less the case for the state as opposed to city, county, or regional officials. The interviews did not ask directly how risk is conceived of, as this would have yielded only perfunctory answers. We did inquire, however, whether priorities for which hazards receive the most attention has been established, and, if so, "How has it been done?" Almost all informants said that priorities had been established, but few indicated that they were based upon quantitative assessments of risk. Some of the local officials' responses to the probe concerning how priorities were established include the following:

--"Things on a complaint basis..."

--"[Everything gets] about the same priority. We're a three-man department."

--"...based on loss experience."

--"...past history."

--"Primarily subjective based on injuries."

--"State is responsible. Don't have analytic capabilities."

One local official denied that her agency set any priorities--"We believe in state and county preemptions"--and five were unable to respond to the probe about how priorities were set. By contrast, one official stated that his agency's priorities were determined by an assessment of the impact of various hazards upon public health, while another stated that priorities were the result of "determination of the difference between ambient standards and maximum concentrations and the relative ability to achieve the standards." In short, only two of fourteen local informants suggested that their efforts were directed toward mitigating hazards either posing the greatest risks or most easily reduced within constraints of current resources.

Informants in state agencies generally gave much richer responses to questions concerning priorities for hazards receiving the most attention. One (of five) could not indicate how priorities were set, but the other four indicated the following as determining which activities take precedence over others:

--"Priorities have been shifted from acute to carcinogenic and toxic--concern at the Federal level has prompted this."

--"Generally respond to toxics. In most cases, priorities are site, not hazard relative."

--"Public health is first major priority, environmental damage second."

--"Ignitability, corrosivity, radioactivity, and toxicity [above specified levels]."

The last two state officials had at least an implicit if not explicit quantitative conception of risk.

A similar pattern of responses emerged when officials were asked directly about their role in formulating and executing risk management policies. Informants were asked, for example, whether their agencies were responsible for identification of new hazards. Three of fourteen local officials claimed that their agencies did do this, but they were unable to elaborate further. Four others gave highly qualified positive responses:

--"Yes, but it is not sophisticated."

--"Not consistently."

--"Bacteriological only--other [organics] are done by the EPA."

--"On an incidental basis."

The remaining seven local officials indicated that they did not direct effort toward identification of new hazards or that they did not understand the question. A typical reply indicating non-comprehension was, "We identify pollutants exceeding established limits."

Responses of state officials to the item concerning identification of new hazards did not differ greatly from those of their local counterparts. One gave an unqualified "Yes", which was not elaborated , and another indicated that unique conditions in his state compelled his agency to search for new hazards. One state informant gave a flat negative response--"We do not define new dangers."--while two indicated incomprehension as follows:

--"Yes, we do routine inspections."

--"Monitoring and enforcing pollution laws."

Informants were also asked whether "Estimating risks associated with hazards" was undertaken by their agencies. Four of the fourteen local officials responded affirmatively, but without elaboration or comment. (Three of these four had also responded affirmatively to the question concerning identification of new hazards, also without elaboration, suggesting there to be a predisposition toward positive responses or what has been called the "yes effect" among survey practitioners.) Two more local officials gave qualified affirmative responses as follows:

--"Embryonic."

--"Very partially, i.e., aluminum in water."

Six local informants gave outright negative responses to the questions concerning estimation of risk associated with hazards, and the answers of two others indicated non-comprehension:

--"We certify contaminants by EPA or regional standards."

--"Review 1977 regulations under the Clean Water Act."

Responses of state-level informants as to whether they attempt quantitative estimation of risk differed somewhat from those of local informants. One stated "yes" without elaboration, the same informant who gave an unqualified affirmative response to the earlier item about risk identification. (This suggests the "yes effect.") Two responded affirmatively, stating that their toxicology laboratories made risk assessments. A fourth informant stated that risk estimates were not made for the following reason:

--"They are not worth the safety savings."

While the fifth informant responded incomprehendingly:

--"Monitoring water quality."

A generalization that might be drawn from these responses is that quantification of risk occurs only when technical expertise is available within an agency.

A further question asked informants whether they were responsible for setting safety standards. Almost all local risk management officials indicated little or no involvement in setting standards or policies; those who did indicated only marginal involvement--for example, in formulating building codes or "working practices" aimed at achieving federal or state standards. One local informant stated unequivocally that he had standard-setting responsibility, but he answered every question "yes".

State officials' responses were not dramatically different. Three of the five whom we contacted indicated that they rely basically upon the EPA and other federal agencies in setting acceptable limits for risk; one indicated that his agency was wholly responsible for water standards, overlooking EPA rules; and another state official indicated, without elaboration, that he had standard-setting authority, but he too answered every question "yes". We had expected to find more state involvement in determining acceptable levels of water pollution and chemical contamination in this limited survey, given that the states are permitted to fix rules more stringent than those promulgated by the federal government, and especially since California was one of the two states covered. It may be, however, that the possibility of preemption by federal agencies renders their state counterparts, even those with adequate scientific capacity, reluctant to move from evidence concerning the riskiness of a hazard to policies setting maximum allowable levels.

Several broader questions were asked to elicit comments concerning risk management policies. The one yielding some of the most interesting responses asked risk managers to describe their "general policy with respect to risk management decision making." Informants were asked to rank three options, which were as follows:

(a). Laissez-faire: Risk decisions are normally left to the private sector except when public health and safety are clearly threatened.

(b). Incremental: Risk management decisions are made by government, consistent with political, economic, and scientific realities.

(c). Formal: Problems are anticipated and decisions are made on the basis of a scientific analysis of risks.

All five state officials and all but two local officials ranked the "incremental" option first. (The two local officials indicating preferences for formal methods gave very terse responses throughout the interviews, which provided little indication as to whether or not they understood the meaning of formalization.) One state official commented on the "incremental" option as follows: "This is where we are." With regard to formal methods, he stated, "This is where we would like to be." Another state official indicated bluntly that, "I don't have time and resources" for formal risk analysis. Local officials, by contrast, had remarkably few comments when probed about general risk management decision making procedures. Two perceived a trend in the direction of increased formalization, even though they retained incremental practices. And one official stated most graphically his agency's policy, which was classified as incremental; "If it's in the sewer, we're there."

Just as there is near unanimity that local risk management policy is determined for the most part incrementally rather than through formal means, there is also near unanimity that local and state risk managers have responsibility for monitoring hazards and intervening when standards are violated. All five state officials said they had monitoring and enforcement responsibilities as did all but two of the fourteen local officials contacted. One of the two local officials not having these responsibilities was principally a planner, and the other held a policy making position in the mayor's office. It should be noted that the meaning of monitoring may be somewhat different for state and local agencies. State agencies are generally responsible for receiving information generated by their local counterparts but not for direct supervision of hazardous activities. Local agencies, by contrast, operate in the field and directly with sources or carriers of contamination. Even though the monitoring functions may be quite different at state and local agencies, officials at both levels indicated that substantial portions of their agencies' efforts are devoted to monitoring and enforcement activities. Of the ten informants who were able to estimate the proportion of their time devoted toward monitoring and intervention when standards are violated, five stated that seventy-five percent or more of their work fell into these categories, four estimated that fifty or seventy-four percent of their time was directed toward monitoring enforcement, and one said that forty percent of the effort of his agency was monitoring and enforcement. These results confirm the pattern suggested in our exploratory interviews, mainly that the principal risk management activities of local government are directed toward compliance with standards set elsewhere, and that the identification of new hazards and estimation of risks associated with these hazards, indeed any quantitative conception of risk, are largely absent from local and to some extent state levels of government.

2.2.2. The Adequacy of Resources

The interviews also included a battery of items concerning the adequacy of fiscal, scientific, and technical resources available to local risk managers. None of these questions, save for one, indicated any important unmet need of risk managers. Some of the comments given in response to probes accompanying the forced-choice questions indicated why this is so.

Informants were asked whether they strongly agreed, agreed, disagreed, or strongly disagreed with the statement, "There is adequate coordination between local, state, and Federal agencies to manage the hazards under my jurisdiction." Among state officials, two agreed, two disagreed, and one disagreed strongly. A similar pattern characterized local officials' responses: Two agreed strongly, five agreed, four disagreed, and three disagreed strongly. The following open-ended probe elicited relatively few comments, but those that addressed the substance of the resource issue suggested why the closed-ended responses were so scattered:

--"Do not have adequate resources for water programs--others just barely adequate. Not keeping up with technical improvements."

--"[Agree] for major hazards such as heavy metals... enough for mundane hazards."

--"We have a six-person office for monitoring 20,000 hazardous waste generators."

--"..to the extent that some hazards, though identified, may not be highly prioritized."

One informant clearly lacked sufficient staff, but the others perceived that greater funding would permit them to maintain surveillance over a greater array of hazards, some possibly posing substantial risks. These comments together with the responses to the agree-disagree question suggest considerable uncertainty in the risk manager's role: While there are generally sufficient resources to monitor hazards that now receive attention, all of the risks that should be monitored are not known and should be pursued. Risk managers perceiving large numbers of unregulated hazards, then, perceive resources to be inadequate, while those not sharing this belief do not.

Informants were also asked for their agreement or disagreement with a statement that scientific and technical information about risk "is easily accessible to decision makers." As before, no clear pattern emerged from the closed-ended responses. Two state officials agreeed, and three disagreed. Of the twelve local risk managers who answered the question, seven agreed, four disagreed, and one disagreed strongly. Few discursive comments were elicited from those who agreed with the statement, but some of those who disagreed observed the following:

--"Little staff time is available to locate technical information."

--"Lots of loopholes in research."

--"Very little meaningful and particularly accessible information."

--"It is not. It takes money to get and must be updated along the way, which takes more money."

Again, these scattered comments do not form the basis for any strong inferences, but the near absence of elaboration from those agreeing that scientific and technical information is available together with the problems noted by those disagreeing suggest that at least some officials feel the need for more and more readily available risk information.

This information is suggested by responses to a third open-ended item, "There is need for additional quantification of hazards to assist decision making." Four of five state officials strongly agreed with this statement, and one disagreed. Four of thirteen local officials responding to this item expressed strong agreement, and seven more agreed. Two local officials disagreed. There was greater consensus on this item than on any other opinion question in the survey, and the comments elicited by our open-ended probes were among the most forceful encountered:

--"Lack of resources for us to do [quantification]. I would like to know what part per million chlorine kills giardia (a protozoan)."

--"Toxicity of many existing chemicals not well defined."

--"Feds have to do it. State doesn't have the research resources."

--"Toxics are a new field."

--"Haven't quantified 'large dose.' What does that mean? Scare tactics used."

--"We based most decisions on experience. Having quantitative analysis would be helpful."

--"Always a need and very expensive to obtain materials in print."

--"[Should be] coupled with definition of <u>who</u> or <u>what</u> is to be protected."

There is, of course, the possibility that the near-unanimous support for additional quantification reflects one more "yes effect", but this seems unlikely in light of the discursive responses elicited in open-ended probes. Furthermore, as shown above, local risk managers do not themselves engage in quantification of risk, and they tend not to think of the risks presently managed in quantitative terms. On the other hand, the question concerning the need for quantification of hazards elicited some of the most consistent and strongest responses of any item in the survey, and the comments accompanying individual answers also suggest felt needs. It may be that the thinking of risk managers is, in fact, little different from ours. They perceive, correctly, that there has been little quantification of hazards and that a quantitative conception of risk is absent from current practices. They may perceive also, again correctly, that they have little capacity to undertake quantification of risks with their own resources and probably will not have in the future sufficient resources with which to do this. Nonetheless, they may still believe strongly that augmented quantitative data are needed if they are to function as effectively as they might in their positions as risk managers.

In sum, there is no clear consensus among local risk managers concerning the adequacy of fiscal resources available to their agencies or the adequacy of scientific and technical information that is available to decision makers. There is strong consensus, however, that additional quantification of hazards is needed to aid decision making. Some of the comments made in response to probes concerning the need for additional quantification as well as other statements indicating inexperience if not unwillingness to quantify risks locally suggest, however, that quantitative estimation of riskiness ought to be developed by federal rather than state and local agencies.

2.2.3. The Adequacy of Existing Organization for Risk Management

Several items aimed at assessing the adequacy of current organizational forms for managing risks were also incorporated into our interviews. One question asked local managers to agree or disagree as to whether, "The legal authority I have in managing risks is adequate." There was near consensus on this issue: Four state officials agreed and one disagreed; of the nine local officials who responded, three agreed strongly and six expressed agreement. Much less consensus was exhibited as to whether "adequate coordination" exists among local, state, and federal agencies charged with managing hazards. Four state officials agreed and one disagreed--the latter observing, however, that, "It's beginning to happen." Local officials, however, were of much more mixed views concerning the adequacy of coordination. One agreed strongly that coordination was adequate and six expressed agreement, while five disagreed, and one expressed strong disagreement. (One official did not respond.) Their comments are instructive, as they indicate even less satisfaction with existing arrangements than the closed-ended question would suggest:

--"Locals must respond directly to the feds, and feds don't keep on top of things."

--"Direct link between locals and feds--everyone is floating around."

--"Disputes over Hazardous Waste Control Law over local authority."

--"[Agree] overall--not for radioactive and other exotic wastes."

--"Very little coordination."

--"Agencies still fighting for authority."

--"Regulatory agencies are understaffed--poor coordination."

There is not sure explanation for the discrepant views concerning the adequacy of coordination help by state and local officials, but in all likelihood this reflects their different functions. The states make policy by accepting federal standards or exercising primacy, whereas local entities implement policy subject to federal and state controls that pose numerous questions of intent and jurisdiction. Because localities' latitude is so much more constrained than states', the former may be much more sensitive to difficulties of coordination as well as more uncertain as to where risk management policies are in fact set and to whom they are ultimately responsible.

Informants were also asked to agree or disagree as to whether a "centralized risk management office" would be useful. The question was in all likelihood worded improperly as "centralized risk management office" was not defined, and for this reason several informants declined to respond. Those who did respond were not particularly supportive of the idea: One state official agreed strongly, two agreed, and two disagreed, while four local officials agreed strongly, two agreed, and four disagreed. Four local officials declined to answer. Very few discursive comments were given in reaction to our probes concerning the desirability of a centralized risk management office, but two, which were completely spontaneous, should be reproduced:

--"[Should be done] at the Federal level! Need for a network or a simple telephone number that we can call for a history of cleanups and effects of particular chemicals."

--"Need for standardization across hazards."

Some informants, then, but by no means all, perceive a need for orderly and organized information than presently exists concerning risks to life and health.

Overall, the interview responses suggest that local officials, although not their state-level counterparts, feel somewhat put-upon by an inter-governmental system that holds them responsible for executing risk management policies without defining authorities and jurisdictions of the various state and federal agencies that participate in the policy making process. There is no perceived lack of legal authority with which to manage risks, nor is there overwhelming sentiment favoring centralization of risk management. Rather there is a perceived absence of coordination, which is probably the result of a system that separates policy formation from its implementation, and in which there are multiple policy making bodies at both the state and federal levels of government who are sometimes in disagreement as to procedures as well as the substance of what they are doing.

2.3. Summary

Firm conclusions cannot be drawn from a survey of nineteen informants as their representativeness of all risk managers cannot be guaranteed. Nonetheless, some of the more striking results do give pause; identification of new hazards and quantification of risk are not features of local government, except incidentally. Priorities in dealing with risks are not based on assessments of riskiness. Almost all policy making is incremental, based on past practice, rather than formal, based on quantitative analysis of risks. The resources available to local agencies to do what they are now doing may or may not be adequate; the pattern is ambiguous. The adequacy of information provided to decision makers also may or may not be adequate. There is overwhelming agreement, however, that additional quantification of hazards would be of assistance in local decision making. At the same time, at least from the perspective of city, county, and regional agencies, coordination among the various bodies charged with risk management is inadequate. There are frequent complaints about both substantive and jurisdictional issues arising due to combined state and federal supervision of local risk management practices. A straightforward suggestion arising from these data, then, is that local communities might be given more and more timely scientific data concerning risk while, at the same time, they might be freed somewhat from federal, and to a much lesser extent state, policies mandating levels of acceptable risk. This suggestion entails a fairly basic shift in the present apparatus for formulating and implementing risk management policies, and it will be discussed as one of several options in Chapter 7 of this report.

Part II: Case Studies of Two Very Different Risks

Chapter 3. A Case Study: Drinking Water and Hazardous Waste Disposal (Solomon and Meyer)

Chapter 4. A Social Decision Analysis of the Earthquake Safety Problem (Sarin)

Chapter 3. A CASE STUDY: DRINKING WATER

3.1. Summary

In this chapter, we discuss the role of local and state agencies in managing the risk to life and health associated with drinking water. Our conclusions are not promising for local government risk management. We argue that the management of risks associated with drinking water has not been and should not be expected to take place at the local level, and that the role of the states in this activity, while important and requiring augmentation, is limited. We base our conclusions on the following points: First, considerable risk is associated with organic contaminants in water, and substantial technical expertise is needed to estimate risks associated with each known contaminant. Further, the uncertainty or confidence bands around these estimates is substantial. Second, local government does not possess now or prospectively the resources needed to identify hazards and quantify risks, and state government possesses these resources only to a limited extent. Third, political and practical necessities divert attention of local agencies from long-run risk to problems requiring immediate attention. And, fourth, the same political and practical necessities do not operate with the same force at the federal level; hence, it is desirable to encourage risk assessment and policy at the apex of the intergovernmental system and leave only its implementation to local officials for this risk.

3.2. Scope of Study

In the remainder of this section, we provide motivation for this study by showing not only that the risk associated with drinking water is real, but by demonstrating that knowledge about the extent of this risk is highly uncertain. We do this by reviewing the results of an EPA survey and other surveys.

In Section 3.3, Risks of Risk Analysis, we demonstrate that the risk analyst does not even have a good handle on all of the contaminants present in water. We examine three sets of studies--animal tests, epidemiologic, and ecologic--and find that animal studies show chloroform to be the most prevalent carcinogen in drinking water. We also discuss additional problems in estimating the risk--most prominently due to (a) the synergistic interactions between carcinogens and (b) the ten to fifteen year latent period of cancer.

In Section 3.4, the Role of Local Government, we show that the role in managing drinking water risks is quite limited.

Our policy implications are discussed in Section 3.5. We offer some risk management alternatives.

3.2.1. The EPA Survey for Suspected Carcinogens

On April 18, 1975, the EPA announced the preliminary results of a nationwide survey for organics in drinking water [EPA, 1977].

This National Organics Reconnaissance Survey (NORS) is one of several efforts underway to investigate the possible problem of suspected carcinogens in drinking water. This survey had three major objectives. One was to determine the extent of the presence of the four trihalomethanes: chloroform, bromodichloromethane, dibromochloromethane, and bromoform in finished water, and to determine whether or not these compounds are formed by chlorination. The second objective was to determine the effects raw water source and water treatment practices other than chlorination have on the formation of these compounds. The third objective was to characterize the organic content of eleven finished drinking water supplies representing five major categories of raw water sources in use in the United States today.

Eighty water supplies in eleven cities were surveyed to determine the presence of the above mentioned four organics, and 1, 2 dichloromethane and carbon tetrachloride. Based on the survey finds, we infer that chlorination contributes to the formation of the four trihalomethanes. Table 3.1 presents the analyses of raw water and finished water for eighty water supplies [EPA, 1975].

The eleven cities investigated and their raw water sources are: Miami, Florida and Tucson, Arizona (ground water); Seattle, Washington and New York, New York (uncontaminated upland water); Ottumwa, Iowa and Grand Forks, North Dakota (water contaminated by agricultural runoff); Philadelphia, Pennsylvania and Terrebonne, Louisiana and New Orleans, Louisiana (water contaminated by municipal waste); and Cincinnati, Ohio and Lawrence, Massachusetts (water contaminated by industrial discharges). In Table 3.2, we list the selected carcinogens and mutagens found in the eleven-city survey. Several conclusions can be drawn from their survey:

a) Chlorination process produces carcinogens which are hazardous.

b) Fifteen suspected carcinogens are identified in the water supplies. Chloroform, and carbon tetrachloride are found in most cities and trichloroethylene, dieldrin, and tetrachloroethylene are found in at least five out of the eleven cities.

c) Inconsistency can be found in all five contamination categories; one carcinogen may be found in the other city of the same category. Even if the contamination sources are known, little can be predicted as to which carcinogens will be found.

3.2.2. Risk Estimates Based on Animal and Epidemiologic Evidence

Both animal and epidemiologic studies have limitations for use in human risk estimates. Animal tests yield varying results and are beset by uncertainty in converting to human risk estimates. Epidemiologic studies cannot control for all possibly confounding factors

Table 3.1 Analyses of Raw Water and Finished Water

Compound	Number of Locations Detected Where Organic Compounds are Found		Range of Concentration, μg/l	
	Raw Water	Finished Water	Raw Water	Finished Water
*Chloroform	45	79	0.1-0.9	0.1-311
*Carbon Tetrachloride	4	10	2-4	2-3
**Bromodichloromethane	6	76	0.2-0.8	1.8-116
**Dibromochloromethane	0	70	---	0.4-100
***1,2 Dichloromethane	11	26	0.2-3	0.2-6
Bromoform	0	25	---	1.0-92
No. Organic Compounds Found	30	0	---	---

*Animal Carcinogen

**Mutagen

***Carcinogen, but carcinogenicity not known

Data from Tables 3 and 4 of "Preliminary Report on Suspected Carcinogens Found in Drinking Water [EPA, 1975].

Table 3.2 Selected Carcinogens and Mutagens Found in 11-City Survey

Compound	New Orleans	Miami	Seattle	Ottumwa, Iowa	Philadelphia	Cincinnatti	Tucson	N.Y.C.	Lawrence, MA	Grand Forks	Terr., La.
*Benzene	x			x	x	x					x
*Carbon Tetrachloride	x	x		x	x	x		x	x	x	x
*Bis (2-chloro-ethyl) ether	x				x						
*Chloroform	x	x	x	x	x	x	x	x	x	x	
*1,2 Dichloro-ethane	x	x			x	x					
*Dieldrin	x	x	x	x		x					
*DDT, DDE	x										
*Heptachlor	x										
*Hexachloro-benzene	x										
*Hexachloro-cyclohexane						x					
*Lindane						x			x		
*PCB						x					
*Tetrachloro-ethylene	x	x		x		x	x	x	x		
*Trichloro-ethylene	x	x		x	x	x		x			
*Vinyl Chloride		x			x						
**Bromodichloro-methane	x	x	x	x	x	x		x	x	x	x
**Chlorobenzene	x	x	x	x	x	x		x	x	x	x
**Methylene Chloride	x	x	x	x	x		x	x	x	x	x
**Dibromochloromethane	x	x	x		x	x	x	x	x	x	x

*Indicated carcinogenic
**Indicated mutagenic

and suffer from the absence of exposure data several decades ago.

Estimating risk based on animal studies is constrained by the paucity of data on the carcinogenicity of chemicals identified in drinking water; less than ten percent of the chemicals found in drinking water have been tested for their potential carcinogenicity.

Based on available data, we performed two risk estimates for those few carcinogens in Miami and New Orleans drinking water for which animal data and monitoring data were available. The total risk estimation for New Orleans (Table 3.3) is 23 cancers per million population per year; for Miami (Table 3.4) is nineteen cancers per million population year.

Our risk estimates are both incomplete and possibly misleading; the concentration of each carcinogen listed in Tables 3.3 and 3.4 is based on limited sampling data and there were present in both waters several additional carcinogens for which either the exposure or carcinogenicity data were not available. Two ecological studies (whole population) involving 88 Ohio and 64 Louisiana counties suggest that contaminated surface water was responsible for approximately eight percent and fifteen percent, respectively, of the total cancer mortality rate [NAS, 1977]. Given the total United States annual cancer mortality rate of about 1,673 per million, these studies imply that contaminated surface water similar to that of these two states may be responsible for between 135 and 250 cancer deaths per million annually. Although there is insufficient data on the quality of the water included in these studies to determine the average exposure to the community involved, it appears that the risk estimates suggested by these studies are not unreasonable for drinking water with 250 ppb of trihalomethanes as well as synthetic organic chemicals of industrial origin.

3.2.3. The New York Study

A 1977 case control study of cancer rates in seven New York counties [Rai and Ryzin, 1979] indicated that urban areas served by chlorinated water supplies have combined GI and UT cancer rates 2.7 times higher than urban areas with non-chlorinated supplies; in rural areas, the cancer rate is 1.8 times higher for chlorinated supplies. It is not known to what extent these higher rates are associated with the level of chlorination by-products or other drinking water contaminants. Using the nationwide combined GI and UT cancer rate of 536 per million as an estimate of the rate for areas served by chlorinated water supplies, the above finding suggested that 233-355 excess deaths per million population annually are associated with chlorinated drinking water. These estimates, together with the estimates derived above are summarized in Table 3.5.

Table 3.3 Cancer Risk Estimation for New Orleans Drinking Water for Those Carcinogens Identified in the 80-City Survey.*

Carcinogen	Animal Test Results*				Concentration in drinking water* (ppb)	Our Risk Estimates (Cancers/ 10^6 years)
	Species	Dose (mg/kg/d)	Exposure (weeks)	Tumor Incidence (Percent)		
1,2-Dichloroethane	Rats	34	78	30	8	0.3
Hexachloroethane	Mice	421	73	38	4.3	0.0
Tetrachloroethelane	Mice	382	78	55	0.2	0.0
Dieldrin	Rats	0.005	104	36	0.07	13.2
Chloroform	Mice	51	96	22	200	9.7
1,1,2-Trichloro-ethane	Mice	279	78	89	8.5	0.2
DDE	Mice	15	78	43	0.05	0.0
Bis(2-Chloroethyl)-ether	Mice	33	78	72	0.16	0.0
				Total Risk Estimations		23.4

mg ≡ milligram
kg ≡ kilogram
d ≡ day
ppb ≡ part per billion

*Data from Table 3, "Removal of Carcinogens from Drinking Water" [Page et al., 1979]

Table 3.4 Cancer Risk Estimation for Miami Drinking Water for Those Carcinogens Identified in the 80-City Survey.

Carcinogens	Animal Test Results*				Concentration in Drinking Water* (ppb)	Our Risk Estimates (Cancers/ 10^6 years)
	Species	Dose (mg/kg/d)	Exposure (weeks)	Tumor Incidence (Percent)		
Vinyl Chloride	Rats	5.4	104	15	5.6	0.6
Vinylidene Chloride	Rats	1.2	82	18	0.1	0.1
Hexachloroethane	Mice	421	78	32	0.5	0.0
Tetrachloroethylene	Mice	382	78	55	0.1	0.0
Trichloroethylene	Mice	1169	78	47	0.2	0.0
Dieldrin	Rats	0.005	104	36	0.002	0.4
Chloroform	Mice	51	96	22	366	17.8
					Total Risk Estimation	18.9

*Data from Table 4, "Removal of Carcinogens from Drinking Water" [Page et al., 1979]

Table 3.5 Summary of Risk Estimates from Animal and Epidemiologic Studies

Animal Tests	Cancers/Million Population/Year
New Orleans	10-23
Miami	18-19
Epidemiologic Studies	Cancer Deaths/Million Population/Year
Ohio counties (Surface vs Ground Water)	140
Louisiana counties (Miss. River vs Ground Water)	250
80-Cities Survey (250 ppb Chloroform)	45-110
New York counties (Chlorinated vs Non-chlorinated)	240-340

The lifetime cancer risk for New Orleans drinking water, as shown on Table 3.5, is ten to twenty-three cancers per million population per year. The number ten is derived by using our risk assessment model where we use the dose-response data of Table 3.3. These dose-response data are the statistical results of many animal experiments, while the number twenty-three is from Table 3.4, where the result is calculated from one single experiment. The ten cancers per million population per year should be the better estimate.

3.3. Risks of Risk Analysis

The analysis of carcinogenic risks--by epidemiologic studies or animal studies or otherwise--associated with drinking water is but a single illustration of the complexity and uncertainty of analyzing all risks due to organic contamination for water supplies. Considerable uncertainty exists as to the levels of these contaminants, their sources, and their effects as well.

3.3.1. Unidentified Organics and Unknown Effects of Known Organics

Recent research has demonstrated that organic contaminants potentially harmful to human health are ubiquitous in America's drinking water. Over 700 such contaminants have been identified, yet they represent only about fifteen percent-by-weight of the total organic matter in drinking water [NAS, 1979]. Many contaminants cannot be identified and/or quantified given present analytical methodologies. Primary sources of these contaminants are solid waste disposal facilities.

Only a small fraction (less than ten percent) of the known contaminants have been adequately tested for adverse health effects. Twenty-three chemicals have been identified as known or suspected carcinogens, while a few others are known or suspected as either mutagens or tumor promoters [NAS, 1977].

Although observed concentrations of specific contaminants are very small, concentration levels are meaningless without knowledge of potency. Most of our knowledge about relative potency comes from animal studies. It is worth noting that animal studies have shown that chloroform, the most prevalent carcinogen in drinking water, is only moderately potent in rodents, and many of the chemicals present in much lower concentrations are far more potent. For example, Dieldrin is 1,500 times more potent than chloroform in mice.

3.3.2. Interaction Effects

The total risk associated with exposure to multiple carcinogens may be far greater than the sum of the risks posed by each chemical individually, due to synergistic interactions between carcinogens. In addition, a single promoter has been shown to intensify the effects of a particular carcinogen by a factor of 1,000 [EPA, 1979].

3.3.3. Lags Between Exposure and Effects

The time elapsing between exposure and clinical symptoms of the disease is often as much as twenty to forty years. Thus, organic contaminants pose a potential threat to health today and in the future.

3.3.4. Imprecise Methods of Estimating Carcinogenic Risk

The extent to which cancer is caused by organic contaminants in drinking water is extremely difficult to determine [NAS, 1977; EPA, 1979; NCHS, 1977]. The currently developed means of assessing cancer risks all have considerable limitations. We discuss three major means: animal cancer tests, epidemiologic studies and short-term tests, in the following paragraphs.

3.3.4.1. Animal cancer tests

To estimate human cancer risk from animal cancer tests, suspect carcinogens are administered to animals over a period of two to three years. Estimates of human risk can be made by correlating dose levels and the number of resulting tumors. Most mathematical methods that have been developed to estimate the risk from long-term exposure to a potential carcinogen are concerned only with the problem of low-dose extrapolation. That is, animal data from experiments conducted at dose levels high enough to produce tumors in an appreciable percentage of the test animals are applied to human population. Estimations of lifetime cancer risk are made on the assumptions that extrapolations from the animal experiments are valid. Computer codes have been developed for the extrapolation purpose [Rai and Ryzin, 1979]. One general consideration given to the problems with animal-to-human extrapolation is to express the data on the basis of dose per unit of surface area. Generally, animal tests yield much smaller estimates of risks than epidemiologic studies, possibly because of the relatively short lags between exposures and observed effects.

3.3.4.2. Epidemiologic studies

Epidemiologic studies relate the incidence of human disease to known or suspected causal factors. There are two types of studies. Analytic (case control) studies compare a group of individuals with the disease being studied to a group of similar individuals without the disease, matching individuals with similar characteristics on a case-by-case basis. Ecologic (whole population) studies compare population groups without matching on an individual basis.

Ecologic studies are primarily used for the generation of hypotheses concerning the association of drinking water contaminants and cancer. Although relevant factors such as occupation, age, sex and ethnic group can be entered into the calculus, these determinations are not made at the individual level, and quantification of the excess risk due to drinking water remains imprecise. Quantifying excess cancer rates on the basis of ecologic studies is generally not an accepted practice. In the absence of more precise data, however, such calculations have some utility.

Excess cancer risks can be quantified from analytic studies, since individual determinations of relevant factors are made. Even these types of studies, however, cannot control for all the potentially relevant factors and must be interpreted with caution. It is difficult to know from epidemiologic studies whether the observed excess cancer is solely attributable to drinking water contaminants, or whether the effects of these contaminants are potentiated by other types of exposures; e.g., from food, air pollution, or smoking. Even if other exposures do not have influence, it may still be the case that removing carcinogens from water will also eliminate the excess cancer risk.

Generally, epidemiologic studies yield much higher risk estimates than animal studies. This may occur for a variety of reasons, but the most important of them may be the inability of such studies to eliminate or control for confounding factors. A careful review of the quality of such studies, paying particular attention to the extent to which confounding factors have been removed or statistically controlled, may be necessary.

3.3.4.3. Short term tests

Efforts to develop rapid assays for mutagenesis and carcinogenesis have been greatly expanded. Methods that show promise include tests for mutagenicity that make use of bacterial, cell transformation, and organ culture systems. The utility of these rapid methods will depend on experimental demonstration that their results are well correlated with those obtained from conventional long-term studies of carcinogenicity with well designed animal systems. However, it offers reasonable probability of success in a relatively short time and at lower cost than long-term testing, and it would be very useful for a primary screen for selecting compounds for long-term assay. Although the potency exhibited in both animal tests and short-term tests appears to be positively related, short-term tests are presently used for qualitative purposes only.

3.3.5. Unreliable Measurement

Measurement of organic contaminants in public drinking water may be highly unreliable or reflect rapidly fluctuating levels of such contaminants. The controversy surrounding the level of TCE contamination in well water in the San Gabriel Valley illustrates this problem. The TCE concentration of a few selected wells are shown in Table 3.6. It is noted that the TCE concentration does not always remain at a stable level, rather, it changes largely in a short period of time.

Table 3.6 Time Variation of TCE Concentration (CA, 1981)

Location	Date Measured	Concentration (μg/l)
Azusa, CA	12/27/79	250
Well #5	1/05/80	64
	1/09/80	3.3
	1/18/80	9.8
Glendale, CA	1/26/80	4.2
	1/07/80	3.2
Well #7	1/10/80	1.3
	1/14/80	22
Valley County, CA	12/26/79	560
	12/27/79	540
Marada St. , #3	1/03/80	560
	1/03/80	600
	1/05/80	520

3.3.6. Multiple Sources of Contamination

If the sources of the contaminants in the drinking water can be determined, the quality of the water can be improved by eliminating the contamination sources. However, this is not easily done even if it were possible. Generally, organic chemicals in drinking water can be divided by sources and types under the following headings:

(1) Chemicals derived from natural sources (e.g., human).

(2) Contaminants introduced as a result of treatment technology (e.g., industry trihalomethanes).

(3) Synthetic chemicals from point sources (e.g., industry and hazardous waste disposal facilities).

(4) Chemicals from non-point sources (e.g., pesticides or aromatics).

Nothing much can be done about the category (1) above. The contamination from category (4) can be reduced by limiting the use of the specific pesticide or aromatic. The contamination from the category (2) can be reduced by improving the chlorination process, that is, reduce the organic chemicals concentration before the chlorination and reduce the amount of chloride used. The problems of reducing the contamination from category (3) are not simple. Little information about the pollutant concentrations in the industrial waste effluent are available.

We contend that the following concerns about eliminating the contamination sources in category (3) need to be addressed:

(1) Measuring the concentrations of pollutants is not simple. The problem involved is the very large number of pollutants, for example, over 500,000 potential chemical products in waste water, very gross classifications, and the high cost investment of identifying and analyzing the contaminants.

(2) The variety of chemical pollutants is wide. Often the sources of these compounds found in water are not thoroughly understood, although their origin is certainly from nature, domestic, and industrial activities.

(3) Potential contaminants will have some antagonistic or synergistic effects, which may occur when combinations of these chemicals interact.

3.4. The Role of Local Government

3.4.1. Three Regulatory Systems at the Federal Level

We now turn to the role of local government in risk analysis and policy. Three systems exist, at the federal level, for regulating contamination of drinking water. One is the National Pollutant Discharge Elimination System, for which authority is provided in the 1977 Clean Water Act [92nd Congress, 1972].

Prior to 1965, regulatory water quality standards were enforced only after a violation was discovered. The first federal regulatory law which mandated regulation of point sources based on a prediction of their effect on the quality of water, was passed in 1965.

One of the number of problems in the Act was that the federal government could initiate enforcement procedures only when pollution in one state endangered people of another state.

To correct some of the inherent problems in the 1965 Act, the 1972 legislation was drafted. The statutory approach of the 1972 Act is quite different from that of the 1965 Act. Rather than basing controls on aggregate water quality, the 1972 Act regulates individual discharges. This approach does not rest upon a finding that the pollution is endangering the health and welfare of anyone, but states that any discharge of pollutants is illegal without first obtaining a permit.

Responsibility for the implementation and enforcement of the 1972 Act is divided between the federal government (EPA), and the states, municipalities, and interstate and intermunicipal agencies.

The 1977 amendments and the 1972 Act form the 1977 Clean Water Act.

A second system is the set of regulations governing disposal of hazardous wastes promulgated by the Environmental Protection Administration as authorized by the 1976 Resource Conservation and Recovery Act [94th Congress, 1976]. A third system is direct regulation of drinking water quality by the EPA's Office of Drinking Water (Title 40, U.S. Code Div., part 1.29). The water pollution standards, for example, identify specific contaminants, maximum contaminant levels, and acceptable procedures for ascertaining levels of contamination (Title 40, U.S. Code Divisions, 1229-146). Cost benefit analysis and other forms of risk assessment were involved in formulating these regulations. The EPA's hazardous waste disposal regulations, by contrast, are much less specific, classifying wastes only by relative degree of toxicity, and were formulated without quantitative estimates of risk. EPA stated that quantitative risk analysis of hazardous wastes would, in all likelihood, be both scientifically and legally indefensible (Federal Register, 45 #98, May 19, 1980, pp. 33164-65). The EPA drinking water regulations, based on a National Academy of Sciences study of risks associated with known contaminants, sets maximum permissible levels for a large number of contaminants [NCHS, 1977].

Normally the EPA does not directly enforce regulations regarding water pollution, hazardous waste disposal, and drinking water quality. Instead, enforcement is left to the states.

As a third system, the EPA requires that states submit plans that would enable them to comply with current regulations and to report compliance by local agencies. The states, in turn, are free to set standards more stringent than those of the EPA or to set standards for contaminants which are not formally regulated, but identified in EPA advisory SNARL's--suggested no action response levels. Implementation of EPA standards remain with local water suppliers, local agencies responsible for maintaining the purity of rivers, lakes and streams (in California, the Regional Water Quality boards), and, in the case of hazardous wastes management, with a panoply of local agencies whose configuration is inchoate, hence cannot be described fully. The principal responsibility of local agencies is, then, compliance with state and, ultimately, federal standards. It is not identification or quantification of risk, and it is not comparison of extent of risk with overall level of risk deemed desirable or mandated externally.

The evolution of an intergovernmental system in which local agencies implement policies set at the federal and, to a lesser extent, state levels, cannot be described in detail here. Suffice it to say that the overall pattern has been one in which functions which local units of government have either been unable or unwilling to perform, have been preempted by the federal government.

One example of the federal government preempting the local government authorities is evident in the changes made by the 1972 Clean Water Act. By the 1965 Act, the federal government could step in and enforce the pollution regulations only when a state expressly requested it do do so. During the following period, the federal agencies realized that these provisions were ineffective, so by the 1972 Act, the ultimate responsibilities were taken over by federal agencies.

Additionally, fiscal stringencies at the local level have caused city and state governments, especially the former, to turn to the federal government for assistance; first in the form of categorical grants, later in the form of unrestricted revenue sharing. Both forms of federal aid are normally contingent upon compliance with myriad federal standards, hence reinforce the pattern whereby policy is set nationally, but implemented locally.

The capacity to assess risk associated with drinking water and, thereby, to manage it with appropriate policies, does not exist at the local level, and it is unlikely that such capacity will exist in the foreseeable future. This incapacity exists for a number of reasons, almost all of which are cited whenever the topic is broached with local water officials. The reasons include lack of expertise, lack of resources, and inadequate coordination of functions at the local level [EPA, 1973].

3.4.2. Lack of Expertise

We have already shown that risk analysis of water contamination is a risky enterprise, one requiring substantial expertise to arrive at risk estimates that have any credibility. Typically, such expertise must be drawn from diverse fields, including engineering, epidemiology, and the experimental sciences in order to determine even the approximate risks to life and health associated with known contaminants in water. Therefore, the Reorganization Plan of 1970 established the U.S. EPA [CFR Title 40, parts 0-50]. An even greater range of expertise is required when searching for unknown contaminants.

For example, in the EPA Water Quality Criteria Report of March 15, 1979, it states, "...the development of water quality criteria reflecting the latest scientific knowledge is necessarily an ongoing process. Sec. 304 of this report reflects awareness of this fact. In its requirement that criteria periodically be revised as new information becomes available, indicating that an existing criterion should be revised, or that criteria should be established for substances which haven't yet been assessed. It is expected that new or revised criteria will be developed." [Federal Register, 1979]

The water quality standards citied in the 1979 Report were based mainly on two reports prepared by two scientific commissions: the International Commission for Radiation Protection's November 23, 1975

"Report of the Task Group on Reference Man", and the National Academy of Science, National Research Council's "Drinking Water and Health", 1977.

Local governments simply do not have such experts in their employ, and most state governments have only a fraction of the personnel they would need if they were to assume full responsibility for developing and implementing water standards. By contrast, the federal government is much more easily able to amass the expertise necessary to conduct risk studies, often through contract or grant mechanisms, and because the best available talent may be involved at the federal level in risk analysis in critical areas such as water quality. The results of such studies, although highly qualified in some respects, are of high legitimacy. Local officials normally assume that studies conducted at the federal level are of high scientific merit and are not subject to dispute. Water that meets federal standards is, therefore, assumed to be "safe enough". An unacceptable risk is one not meeting federal standards. It is highly unlikely that risk studies undertaken at the local level would be of such legitimacy.

3.4.3. Lack of Resources

Local governments typically do not have adequate resources with which to undertake risk studies and often have barely sufficient resources to monitor water supplies for compliance with state and federal standards. Riverside County's Department of Water has no facilities to test contaminants, requiring them to send out to private laboratories. Within the City of Los Angeles, for example, only the Los Angeles City Department of Water and Power has testing facilities for inorganic compounds.

In some instances, the plants and technology needed to meet applicable standards cannot be built or acquired within the limits of current fiscal stringencies (e.g., Los Angeles cannot meet current EPA turbidity requirements without new filtration plants). Precisely because the results of risk studies often incur substantial costs for local authorities, disinclination to support such studies locally is pervasive.

3.4.4. Lack of Coordination

At the local government level, service delivery is fragmented, and little coordination exists between agencies.

There are several hundred local and regional water districts concerned with producing, conserving, and delivering water. Agencies in California [CA, 1980] include:

1) The Metropolitan Water District of Southern California (MWDSC) serves as a "wholesaler of water to one-half the state's population".

2) The Los Angeles City Department of Water and Power (LADWP) provides water to residents of the City of Los Angeles.

3) The East Bay Metropolitan Water District (EBMWD) delivers water to one million people in San Francisco; treats and disposes of sewage for 600,000 residents.

4) The San Francisco Water Department.

5) Among the other agencies are over 4600 special services; city and county planning departments, for example, whose major responsibility is local land use regulation, etc.

In addition, there are also many agencies managing disposal of hazardous wastes and monitoring quality of drinking water.

1) The Solid Waste Management Board (SWMB) establishes and maintains comprehensive statewide solid waste management and resources recovery program; adopts statewide standards, guidelines and policies; monitors local enforcement of county solid waste management plans, and brings proceedings to correct improper or inadequate enforcement.

2) The Resource Recovery Program (RRP) initiated a program to ensure sound management of environmental dangerous waste.

3) The Bay Area Solid Waste Management Board (BASWMB) investigates alternatives for potential utilization of Bay Area solid wastes.

4) The Department of Water Resources (DWR) is in charge of statewide plans for control, conservation, protection, enhancement and use of the states's water. It provides a basis for administration policy concerning allocation of water supplies. It studies detailed groundwater and waste water reclamation, investigates water quality, and represents the state's interests before Congress and in federal-state and interstate relations.

5) The Solid Waste Reclamation Control Board (SWRCB) enforces water pollution rules.

6) The SWRCB and 9 regional water quality control boards regulate California water resources.

7) The Division of Water Use (DWU) maintains records of water use.

8) The Division of Water Quality (DWQ) administers state and federal clean water grant programs for building and upgrading sewage treatment facilities.

9) The Regional Water Quality Board (RWQB) issues waste discharge requirements.

In addition to the local or state agencies, water retailers that maintain their own watersheds do attempt to control the use of the surrounding territory and feeder streams and lakes, but criteria of "good practice" rather than risk analysis guide their actions. Even then, "good practice" must be compromised in the face of pressures from residents and tourists using areas contiguous to watersheds, who rarely are the ultimate consumers of the water. Almost all experts acknowledge that the cheapest way to maintain water quality is to limit contamination in the first instance, rather than attempting to remove it later. But, reasons of geography and fragmentation of local government responsibilities preclude suppliers of water, as well as local agencies generally, from concentrating their efforts in a cost-effective manner toward balancing efforts to limit ground water pollution with efforts to purify drinking water supplies once contaminated.

3.5. Implications for Risk Management Policy

The nature of hazards associated with drinking water poses a set of problems not admitting of any simple administrative solution. The hazards are, in all likelihood, substantial, but many organic contaminants are unknown or are undetectable, and estimates of risks associated with known organics range over as much as two orders of magnitude. Water service is provided locally, yet little of the expertise needed to assess and manage risks associated with drinking water resides at the local level. In the concluding section, then, we will review the respective roles of local, state, and federal levels of government in insuring the safety of water supplies, considering alternatives to present risk management practices. We will also discuss whether other kinds of risks potentially falling under the purview of governments ought to be managed like risks associated with drinking water.

3.5.1. Risk Management Alternatives

We will discuss risk management alternatives for local, state and federal levels of government. There is substantially greater potential for policy initiatives and innovation at the state level than at the local level, but the federal role nonetheless remains paramount.

3.5.1.1. Alternatives for local government

A wide range of potential risk management options exists in principle for local government, but as a practical matter local agencies may be able to move little beyond current capacities and practices. The present role of local government is monitoring and reporting of compliance with state and local government contamination of domestic water supplies. Risk identification, analysis, and policy are made elsewhere. Local government is hampered in managing risk associated with water because of lack of resources and expertise, and, in some instances, lack of jurisdiction. Additionally, the service delivery ethos of local government preempts activities aimed at long-term mitigation.

Any proposal to delegate the management of risk associated with carcinogens in drinking water wholly to local government agencies would be costly because duplication of effort would result, and ineffective because service delivery would take precedence over hazard mitigation or both. This does not mean that there is no room for improvement in local risk management practices, but it does mean that improvements will be confined to facilitating concrete activities. Hazard monitoring or identification capacities of local governments might be enhanced somewhat through pooling or sharing of information about previously unknown or unsuspected contaminants. At present, most local agencies monitor water for EPA- or state-identified organics. It could be relatively easy and inexpensive to monitor, at the same time, contaminants suspected in other localities to pose significant hazards but not yet on EPA or state "hit" lists where information about these contaminants is easily available. The capacity of local governments to prevent contamination might also be improved somewhat, as preventive measures are many times cheaper than purification in most instances. Prevention requires long-term cooperation of water "retailers" with agencies supervising discharges in the water supplies as well as agencies overseeing disposal of hazardous wastes. The processes through which such cooperation is to be achieved cannot be specified here, but such efforts necessarily extend beyond the jurisdiction of any single unit of local government.

3.5.1.2. Alternatives for state government

The states play a unique role in risk management, one that is potentially far more important that the passive "banker" role portrayed in much of the literature on the intergovernmental system. The states, to begin with, do not suffer the same resource constraints as local entities. Although they have far fewer resources than the federal government, their health and environmental agencies are capable of risk analyses and policy formation to a limited extent. Jurisdictional issues do not arise as frequently at the state level as between local governments. Indeed, precisely because states have the power to preempt local ordinances, especially land use regulations, state governments can compel cooperation among local entities when disputes arise concerning protection of watersheds and siting hazardous waste dumps. State-level agencies can potentially regulate most of the stages to their use and disposal. The same powers are rarely vested in any single local entity because enforcement of construction and fire codes, highway and traffic laws, and disposal regulations are vested in different jurisdictions. States also have power over occupational health and safety as well as public health and welfare. Because the effects of many hazardous chemicals appear in occupational settings--chemicals contaminations in work places are many times higher than the levels to which the public may be exposed--previously unknown or undetected substances posing substantial hazards are likely to come to the attention of state authorities long before local authorities hear of them.

A strengthening of the state role in management of hazards associated with water contamination is thus indicated. Such a strengthening would entail two elements of key importance: (1) Improving state capacity to track known hazardous substances from "cradle" to "grave" through coordinated action of state agencies, and (2) facilitating and augmenting communication between agencies concerned with occupational health and safety and public health and safety officials.

3.5.1.3. Alternatives at the federal level

The entire range of alternatives for management of carcinogens in drinking water available to federal agencies cannot be reviewed here. Our concern is limited to federal actions and initiatives that might support state and local governments in their risk management activities. No direct federal supervision or subsidization of these risk management activities at the local level appears warranted at this time. Through the states, existing federal programs might be modified to encourage greater sharing of information and cooperation among officials in different jurisdictions, but it is unlikely that such cooperative efforts can be mandated effectively by federal action. A somewhat enlarged state role in management of risks associated with drinking water might be encouraged by at least four federal actions. First, greater responsibility for surveillance and identification of hazardous substances should be given the states. Second, the states should be permitted greater voice in federal policy to insure greater consistency and feasibility in EPA regulations governing disposal of hazardous wastes, discharges of pollutants into rivers and streams, and contamination of drinking water supplies. Operational experience at the state level should inform policy formation at the federal level. Third, somewhat greater support might be provided for coordination of state agencies whose actions affect, directly or indirectly, contamination of drinking water, and for encouragement of cooperation among local units of government. And, fourth, exchange of information concerning potential contaminants and the levels of risk associated with them among local, state and federal agencies should be supported and encouraged. These suggestions notwithstanding, it remains probable that most risk analysis and policy formulation will take place at the federal level. Policy formation and policy implementation can be improved by more effective state input, but the ultimate scientific and policy determinations must be made federally.

3.5.2. Comparison of Risks

We turn finally to the generalizability of our findings: Ought all risks be managed similarly by state and local governments, or do risks differ in significant ways that render no single management scheme applicable to all of them? Our impression is that significant differences exist across different types of risk, hence the suggestions made here apply mainly to risks associated with chemical contamination.

The following are characteristic of the problem of organic contaminants in drinking water:

1) The hazard is chronic, not catastrophic.
2) The hazard is widespread, not localized, although levels and types of contaminants vary across localities.

3) The hazard is in some instances unknown or undetectable, not known and visible.

4) Substantial rather than moderate uncertainty is associated with risk estimates.

5) Management of the hazard conflicts with rather than augments the traditional service delivery and public protection functions of local government.

All of these characteristics would tend to diminish the local role in risk management. Chronic risks of low magnitude do not stimulate immediate demands for service delivery or protection; risks common to many localities and concentrated in none are rarely viewed as principally local problems; hazards eluding easy detection usually elude the capacity of local governments to detect them; highly uncertain risk estimates pose political perils for local officials; and risk management practices impeding or increasing the cost of service delivery may also be politically perilous. Catastrophic risks, which are localized, understood and reasonably predictable, and whose management is consistent with traditional service delivery and public protection functions of local government, might be much more amenable to effective local management.

No single pattern or plant for local government risk management activities, then, can be estimated. Indeed, it is questionable whether cities and counties ought to depart substantially from their present pattern of passive risk management--that is, monitoring risks and reporting compliance--for risks where relevant expertise is absent at the city level and where pressing local demands for hazard mitigation do not exist. Under what circumstances should the states, and particularly the federal government, actively pursue risk management policies for hazards that local governments choose not to address? These circumstances should be determined largely by technical assessments of costs and benefits anticipated from various risk management policies. However, it may also be appropriate to enter political judgments of the kind made at the local level into the final question: Do proposed risk management policies have broad public support, and are their benefits distributed equally throughout the nation?

3.6. References

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Chapter 4. A SOCIAL DECISION ANALYSIS OF THE EARTHQUAKE SAFETY PROBLEM

4.1 Introduction

A cursory look at any yearly New York Times Index under "Earthquakes" will reveal their devastating nature. The cruel impact of earthquakes on mankind was most recently dramatized when 650,000 lives were lost in Tang-Shan, China (July 28, 1976). Earthquakes occur with alarming regularity. Every few years earthquakes devastate cities with heavy loss of life and infliction of injury. In those lucky years when the impact of earthquakes is less severe, it is because these earthquakes are centered in areas of low population density and not because of their lesser number of occurrence. With the growth of population and the development of large cities the potential for great earthquake destruction increases every year.

Many cities and counties in the United States and particularly in California face a potential risk of death and injury to their residents by partial or complete collapse of buildings in the event of an earthquake. It is possible to reduce these risks by raising the standards for structural seismic resistance of the buildings. This, however, would require costly modifications by the private owners of these buildings or by the city or state government, in the cases of public buildings.

In this paper, we propose a framework for conducting a decision analysis for a societal problem such as earthquake safety. This approach is applied to the design and evaluation of alternative policies for the earthquake safety problem of the City of Los Angeles. The framework is, however, general enough to be useful to other cities and for other problems involving risks to human health and lives. Since the emphasis of this paper is on a real-world application we have omitted methodological details and have presented the ideas in a non-technical style.

In Section 4.2, a brief background of the earthquake safety problem of the City of Los Angeles is given. An overview of our approach is provided in Section 4.3. The results of a detailed social decision analysis are presented in Section 4.4. The City of Los Angeles was considering an ordinance for eathquake hazard reduction at the time this study was commenced. This ordinance was passed by the City Council on January 7, 1981. In Section 4.5, we provide our recommendations and compare these with the provisions of the city ordinance. Finally, conclusions are given in Section 4.6.

4.2. Background of the Earthquake Safety Problem of the City of Los Angeles

Los Angeles, like many other cities in the state and nation, has a large number of existing hazardous buildings. These buildings were built before earthquake standards were incorporated in the building codes. In case of a major earthquake, these buildings are most susceptible to collapse, causing death and injuries to the occupants.

This paper specifically deals with the unreinforced masonry buildings that were built before 1933--prior to code requirements designed to withstand earthquakes. We have chosen to focus on these buildings for two reasons:

1) Sufficient information on the type, use, occupancy etc. for these buildings has been compiled by the city. Similar information for the other buildings is unavailable at this time.

2) These buildings pose the greatest hazard to human life and property (see Science [1982], and U.S. Department of Commerce Report [1973]).

We now provide some factual information on these pre-1933 buildings. A detailed information is contained in Sarin [1982].

Los Angeles has approximately 7,863 old buildings made of unreinforced masonry that were built before 1933. Excluded from these figures are detached dwellings and detached apartment houses containing fewer than five units. Table 4.1 shows the distribution of these buildings and their occupancy load by council districts of the city. Approximately 10% of the buildings are residential. According to the occupancy load and the use of the buildings, all buildings are classified in four risk classes: Essential, High Risk, Medium Risk and Low Risk. A description of these risk classes is given below.

Class I: Essential Buildings

Those structures or buildings that are to be used for emergency purposes after an earthquake, in order to preserve the peace, health and safety of the general public.

Class II: High Risk Buildings

Any building other than an essential building having an occupant load of 100 occupants or more, wherein the occupancy is used for its intended purposes for more than 20 hours per week.

Class III: Medium Risk Buildings

Any building having an occupant load of 20 or more occupants that is not classified as Class I or Class II.

Class IV: Low Risk Buildings

Any building, other than Class I, having an occupant load of less than 20 occupants.

TABLE 4.1. Distribution of the Buildings by Council District

City Council District	I	II	III & IV	Occupants
1. East San Fernando Valley	-	8	26	4,015
2. Hollywood Hills	-	2	53	4,859
3. S.W. San Fernando Valley	2	2	44	5,483
4. Wilshire	7	106	882	147,630
5. West Los Angeles	1	31	282	30,323
6. Venice to Crenshaw	2	13	239	20,008
7. Central San Frando Valley	2	40	51	7,517
8. South Central Los Angeles	4	40	387	51,623
9. Central City	21	454	2,516	381,000
10. S.W. Los Angeles	4	73	818	106,029
11. Brentwood to Encino	-	-	71	9,654
12. N.W. San Fernando Valley	-	-	2	242
13. Hollywood	8	94	683	105,733
14. East Los Angeles	6	12	623	84,942
15. Watts to San Pedro	2	13	275	30,691
TOTAL	59	852	6,952	990,110

These buildings are valued at approximately $745 million, and approximately one million people live or work in them. The cost of strengthening these buildings against seismic forces is estimated to be $1 billion. While the costs for upgrading the buildings are large, the risks to property and human life are also significant, since many experts believe that a great California earthquake is imminent (e.g., see Bolt 1978). Further, these relatively large risks of deaths and injuries are faced by an identifiable segment of the population--occupants of the old buildings. After years of deliberations, the Los Angeles City Council passed an ordinance (Ordinance No. 154,807) on January 7, 1981, that will require rehabilitation of these buildings to some specified standards.

4.3. Overview of the Approach

Decision analysis has been used for a wide variety of problems during the past decade (e.g., see Keeney 1981). A social decision analysis is essentially a decision analysis of a societal problem in which the interests and preferences (often conflicting) of different members of the society must be considered in the choice of a preferred alternative. Below we discuss some important features of a social decision analysis in the context of the earthquake safety problem of the City of Los Angeles.

4.3.1. Decision Alternatives

In a social decision analysis, the full range of regulatory as well as free market decision alternatives must be considered. For the earthquake safety problem, at one extreme are the strict regulations for the design and construction of all buildings, which are based on the best available information and evaluation by the government. The other extreme is to treat safety as an economic commodity and let the free market mechanism along with professional codes of practice and existing liability laws determine the acceptable levels of standards for each type of building. The former policy option suffers from the difficulty of monitoring and enforcement; whereas, the latter presupposes that the individual members of the society can assess and evaluate possible risks (through the free market mechanisms; e.g., insurance companies or building inspection companies), and that the total cost of information dissemination will be cheaper than the cost of regulation. Besides the monetary costs, there are ethical arguments in favor and against each of these extreme positions.

Intermediate policy options include some form of government intervention in specifying seismic resistance requirements for critical facilities (school, hospitals, etc.), while providing information to the owners and the occupants about earthquake hazard and mitigation alternatives for the existing buildings. In evaluating alternative risk management policies for Los Angeles, we consider several of these policy options.

It is surprising that, in many decision situations, the full range of alternatives are not considered. For example, if we assume that the recommendations in the Los Angeles city ordinance are optimal in some sense, still the optimality is with respect to the subset of alternatives that fall within the regulatory options. A creative generation of the alternatives is the most important step in the social decision analysis.

4.3.2. Impact on the Constituents

In a social decision analysis, the consequences of a chosen alternative are felt differently by different constituents. Further, the final outcome depends on the actions of the constituents in reaction to the chosen alternative. It is therefore imperative that the impacts on different constituents should be considered explicitly in the evaluation of alternatives. We show that an interactive decision tree can be used for this purpose. The key feature of the interactive decision tree is that for each alternative the reactions of the impacted parties (such as the owners of the buildings in our case study) are treated as explicit decisions that influence the final outcome.

The earthquake safety problem decision by the city for rehabilitating the old buildings will impact several interest groups. The directly affected interest groups are the renters and the owners. Owners of the buildings will have to pay the cost of upgrading or share it with the city if some financial incentives are offered. They would, however, receive benefits in reduced property damage, a possible appreciation in the value of the building, reduced liability in case a renter gets injured or killed, and possibly higher future rents. Clearly, if the benefits to an owner were to be higher than the cost, he would have upgraded the building without any government intervention. If the owner is unaware of the benefits since much of these benefits occur in the future and are uncertain, proper information could induce him to undertake upgrading of his building. It seems that the owners are quite resistant to upgrading the buildings so it is possible that they do not perceive the benefits to be greater than the costs.

The renters of the buildings are another impacted group. Strengthening of a building clearly makes the building safer to live in but the rents might also increase. Some renters may have to leave the building temporarily or permanently during the construction phase. A majority of the renters of the old residential buildings are from the lower economic class. These people can ill-afford to pay substantially higher rents. It is therefore unclear without an explicit examination of the costs and benefits whether upgrading is attractive from the renters' viewpoint.

Policy makers and planners constitute the third group who are indirectly affected by the city's action. If the city requires costly upgrading, the sentiments of the owners run against them. The letter of an owner, Robert M. Lawson, to Councilman John Ferraro with regard to the city ordinance requiring upgrading of the buildings is representative of how a majority of the owners feel about upgrading, "...the passage of such an ordinance would destroy one of the principal remaining assets in my family. This is a poor reward for 53 years of highly productive participation in the economic growth and development of Los Angeles". If the city leaves these buildings alone and if a major earthquake does destroy them causing deaths and injuries to the occupants, then the policy makers will be held responsible for their inaction.

Finally, the public-at-large is also an affected party. Since the group that suffers the most damage in case of an earthquake is identifiable, a priori, the members of society who do not live or work in these buildings would be willing to pay some amount for the safety of the occupants of these buildings. The benevolent considerations become especially important if the public perceives that the residents of the hazardous buildings are unfairly treated because of their age, income, or other social conditions.

4.3.3. Objectives of the Decision Problem

In order to formulate and evaluate alternative policies, the objectives of the decision problem should be clearly specified. Often, there are multiple conflicting objectives. For example, one objective in earthquake safety problems is to reduce the likelihood of deaths and injuries, while the other is to reduce the cost of rehabilitating unsafe buildings. These objectives cannot simultaneously be met. Welfare of the landlords may be in conflict with the welfare of the tenants, and so on. It is, therefore, important to identify the attributes relevant to all constituents that may be affected by a policy. A discussion of a hierarchical approach for identifying attributes of a decision problem is provided in Keeney and Raiffa [1976].

4.3.4. Quantification of Consequences

The eventual consequences of a chosen alternative are uncertain in a complex societal problem such as earthquake safety. Some consequences can be predicted with reasonable accuracy using appropriate engineering estimates, past data, and experts' opinion. In general, however, the consequences must be described in the form of a probability distribution. The probability distributions over the consequences are often quantified using a combination of past data, sample scientific and engineering studies, and experts' professional judgments. Appropriate methods for quantifying probabilities (e.g., see Spetzler and Stael von Holstein [1975]) and models that simplify probability assessments are helpful in this assessment task. In most, if not all, social decision analyses, the professional estimates are the primary sources for assessing the consequences. This is done on the premise that the impacted individuals often do not have sufficient information to provide such estimates. As domonstrated by several cognitive psychologists (e.g., see Slovic et al. [1980]), an individual's estimates based on his perception may be considerably different than the so-called scientific estimates. Unfortunately, however, the acceptability of a chosen policy alternative depends crucially on perceived costs and benefits (reduced risks). If the scientific information is used in analysis, it should be compared with the public's opinion on whether these estimates are consistent. In some situations, dissemination of the information may narrow the gap between the perceived and the scientific estimates. Market research (e.g., see Green and Srinivasan [1978]) studies could also be helpful in quantifying public perception, and an analysis could be conducted based both on the scientific information and the information obtained by the market research. In some situations, a combination of the objective scientific data, experts' opinion, and the market research data may be used for analysis. A sensitivity analysis could point out the need for refining or reconciling various estimates.

4.3.5. Quantifying Preferences

In a social decision analysis the preferences of the impacted constituents must be considered in determining the tradeoffs between the attributes. In the earthquake safety problem the key tradeoff is between additional cost and safety (measured in terms of reduced injuries and deaths). We considered three approaches for quantifying the preferences in our application.

The first approach assumed that the tradeoff between cost and safety is in accordance with the empirical evidence on how much society does indeed pay for reducing similar risks. Essentially, in this approach the information from published sources (e.g. see Bailey [1980]) was used to quantify cost/safety tradeoffs.

In the second approach a small number of the occupants of the buildings were interviewed to directly determine their willingness to pay for safety. The interview data was then used to quantify cost/safety tradeoffs.

In the third approach, it was considered that the cost/safety tradeoffs should be inferred from the property value differential between earthquake-safe and earthquake-unsafe buildings. This approach, called a "hedonic price" approach, has been extensively developed in the economics literature (e.g., see Brookshire et al., [1982]).

Each of the above three approaches offers some advantages and some disadvantages. We feel that in a social decision analysis several approaches to quantify key tradeoffs should be used.

4.3.6. Evaluation and Policy Formulation

The objective of evaluation is to compare the costs and benefits of the alternative policies and select the policy that is most preferred with respect to the preferences of the impacted constituents. Unfortunately, however, the preferred policy will be different for different constituents in most social decision analysis. We consider that the first step in evaluation is to compare total costs with total benefits regardless of to whom they accrue. This analysis ignores the distributional aspects of costs and benefits, e.g., some groups may experience a relatively larger share of costs and benefits. Nevertheless, it does point out whether the total social benefits exceed the total social costs for a given alternative. The second step in the evaluation is to compare the costs and benefits from the viewpoint of various groups of impacted constituents; e.g., tenants, owners, planners and policy makers in our case study. Based on these evaluations, an acceptable policy can be formulated. The critical issue in formulating a policy is to ensure that it can be implemented, and the enforcement is possible and within the means of the concerned agency (city or state government). For example, a report by Stanley Scott [1979] points out that "a crucial weak point in seismic safety policy is the enforcement of seismic design regulations".

An acceptable policy should address several real-world institutional, socio-economic and political constraints. Public acceptability and institutional mechanisms to carry out a policy often decide the success or the failure of a risk management policy. An explicit consideration of what are all possible hurdles that could impede the implementation of a policy must be well thought out. A full ventilation of the diverse and differing opinions and a full awareness of potential problems before finally adopting a policy is a requisite for its success. Needless to say, all discontent cannot be eliminated, and all affected parties cannot be fully satisfied. An understanding of their concerns would greatly improve the design of a policy.

A word of caution is warranted here. A good policy is not the one that attempts to incorporate every single concern of the time. But a good policy recognizes what can be changed, and attempts to do so if such a change is in the greater welfare of the society; simultaneously, it recognizes the boundaries within which it must operate.

In the earthquake safety problem we show how an acceptable policy, which considers the interests of the impacted constituents and provides incentives for their cooperation can be formulated. The formulation of such a policy is based on the analysis of costs and benefits that accrue to various impacted constituents.

A technical point that may be relevant in some social decision analysis warrants some attention. In our study, all analyses assume an additive linear preference function. If the range of consequences on attributes is relatively small, this form is reasonable. Moreover, if one considers an array of policy contexts in which the same attributes (e.g., cost and safety) are impacted (e.g., fire safety, storage of chemicals, transportation of hazardous material, etc.), then for any one policy context such as earthquake safety, the range of consequences is often not large. We favor the use of additive linear form, as its informational requirements are small and it is easy to interpret. Keeney and Raiffa [1976] describe more complex forms that permit preference dependencies among attributes. Keeney [1981] shows how, by redefining attributes, additive linear form becomes appropriate even for those cases where preferences among attributes exhibit dependencies.

4.4. Analysis and Results for the Earthquake Safety Problem

In this Section, we present the analysis and results for the earthquake safety problem of the City of Los Angeles. In 4.4.1, the structure of the decision problem is described. Estimation of economic and human health consequences is given in 4.4.2. A comparison of the costs and benefits of alternative policies is made in 4.4.3.

4.4.1. Structure of the Decision Problem

4.4.1.1. Alternatives

Buildings are divided into four risk classes: Essential (Class I), High Risk (Class II), Medium Risk (Class III), and Low Risk (Class IV). In each risk class, several upgrading alternatives can be undertaken. These alternatives are: leave the buildings in their present Masonry C status; upgrade to Masonry B standard; upgrade to Masonry A standard; and upgrade to Today's Standard. Construction Qualities A, B, and C refer to the degree of earthquake resistance provided.

Construction Quality A includes good workmanship, mortar and design; reinforcement, especially lateral, bound together using steel, concrete, etc., and designed to resist lateral forces (sideways shaking).

Construction Quality B includes good workmanship and mortar; has reinforcement, but not designed to resist strong lateral forces.

Construction Quality C includes ordinary workmanship and mortar; no extreme weaknesses such as failing to tie in at corners, but not designed or reinforced to resist lateral forces.

Today's Standards refers to restoring the building to conform to current earthquake-resistant design and construction practices. The incremental hazard to these buildings in relation to recently constructed buildings is essentially negligible.

Thus, there are four upgrading alternatives for each of the four risk classes of the buildings. For the purposes of our analysis, Class III and Class IV are considered together since there is no significant difference between these two classes. Thus, we will evaluate twelve upgrading alternatives.

4.4.1.2. Attributes

The principal attributes in the decision problem are: cost of upgrading, property damage, number of deaths, and number of injuries requiring hospitalization. The first two attributes can be combined to yield a cost measure, while the last two represent a composite safety measure. Occasionally, we will use these aggregated attributes to depict cost/safety tradeoffs.

4.4.1.3. Time horizons

Any choice of a time horizon is somewhat arbitrary. We will consider ten years as a planning horizon. This planning horizon is selected because the ordinance for the earthquake hazardous buildings developed by the city, stipulates a 10-year period for a phased compliance with the code. In addition, a shorter time horizon would not reflect the earthquake damages accurately. A longer time horizon would require additional data on natural attrition of the buildings, and the possibility of more than one earthquake will have to be formally included in the analysis. It is believed that one major earthquake will result in the demolition of a large proportion of these buildings (50% to 90%), and stricter codes will be promulgated subsequent to such a disaster. Thus, at the present time, a 10-year planning horizon is realistic and relevant for evaluating policy options.

4.4.1.4. Earthquake scenarios

We examine four scenarios of eathquake in the Los Angeles Basin. There are:

- An MMI IX (7.5 Richter scale) earthquake on the Newport-Inglewood Fault (Scenario 1)
- An MMI VIII (6.5 Richter scale) earthquake on the Newport-Inglewood Fault (Scenario 2)
- An MMI X (8.3 Richter scale) earthquake on the San Andreas Fault (Scenario 3)
- No earthquake (Scenario 4).

Here MMI refers to Modified Mercalli Index, which is a measure of the intensity of an earthquake (see Wood and Neumann [1931] for a detailed description). Based on the U.S. Department of Commerce report [1973], distribution of earthquake intensity in each Los Angeles County council district is shown in Table 4.2.

In order to compute the probability of each of the four scenarios, we use the historical frequency of the occurrence of earthquakes along the two faults. Based on the historical record, a return period of 19 years is assumed for an earthquake of MMI VIII in downtown Los Angeles. If the inter-arrival time between earthquakes is assumed to be exponentially distributed, then, based on a return period of 19 years, probability of an earthquake of MMI VIII or greater in 10 years is $1 - e^{-10/19} = .41$. Based on the FEMA [1981] report, the probability of Scenario 1 is .01, and the probability of Scenario 3 is between .2 to .5. We consulted seismologist Dr. Clarence Allen of the California Institute of Technology to seek his subjective probability. He considers Scenario 2 likely to happen with .1 probability. Therefore, Scenario 3 has .3 probability of occurence. Dr. Allen's subjective probability for Scenario 3 was .25, and for Scenario 1 it was .01. We assume the probabilities of Scenarios 1 through 4 as .01, .1, .3, and .59, respectively.

TABLE 4.2. Distribution of Earthquake Intensity

	MMI Estimate		
	8.3 on San Andreas	7.5 on Newport-Inglewood	6.5 on Newport-Inglewood
1. East San Fernando Valley	VIII	IX	VIII
2. Hollywood Hills	VI	VIII	VII
3. S.W. San Fernando Valley	VIII	IX	VIII
4. Wilshire	VII	IX	VIII
5. West Los Angeles	VII	IX	VIII
6. Venice to Crenshaw	VIII	IX	VIII
7. Central San Frando Valley	VIII	IX	VIII
8. South Central Los Angeles	VIII	IX	VIII
9. Central City	VIII	IX	VIII
10. S.W. Los Angeles	VIII	IX	VIII
11. Brentwood to Encino	VI	IX	VIII
12. N.W. San Fernando Valley	VIII	IX	VIII
13. Hollywood	VII	IX	VIII
14. East Los Angeles	VII	VIII	VII
15. Watts to San Pedro	VI	IX	VIII

4.4.1.5. Interactive decision tree

The earthquake problem of the City of Los Angeles can be represented as an interactive decision tree (Fig. 4.1). For each class of the buildings, the city could take any of the four actions shows in the decision tree. The owner may comply by acting consistently with the city's chosen action, or may choose not to comply. For each class of building, the owner also has four actions available to him. It is to be noted that, under strict regulation, the owner is forced to choose the same action as the city dictates. But, for planning purposes, it is worthwhile to explore what is the owner's most preferred choice, and how this choice differs from that of the city.

The decision tree also depicts the four earthquake scenarios; only one of which will actually occur. The consequences of the four attributes for each action/scenario combination are represented at the end of each branch of the decision tree.

4.4.2. Estimation of Consequences

4.4.2.1. Cost of upgrading

Cost of upgrading the buildings from their present Masonry C standard to Masonry B, Masonry A, and Today's Standards are $5/ft^2, $10/ft^2, and $20/ft^2, respectively. These costs are based on the engineering estimates of Wheeler and Gray 1980 , who examined, in detail, some representative buildings. We took a sample of 61 residential and 60 non-residential buildings to estimate the area and the market value of these buildings. The average area of a residential building was found to be 22,471 ft^2, and for a non-residential building it was 8,783 ft^2. We also know the number of buildings in each class (Class I: 59 non-residential; Class II: 147 residential and 646 non-residential; Classes III and IV: 643 residential and 6,368 non-residential). The total cost of upgrading for each class of buildings is easily computed: (22,471 x number of residential buildings + 8,783 x number of non-residential buildings) x cost of upgrading per ft^2. This cost is given in Table 4.3. We have separated the estimates for residential and non-residential buildings because we will conduct a separate analysis for the residential buildings.

Table 4.3. Cost of Upgrading Buildings (Millions of Dollars)

	Today's Standards		Masonry A		Masonry B	
	R*	non-R**	R*	non-R**	R*	non-R**
Class I	-	10.36	-	5.18	-	2.59
Class II	66.06	113.46	33.03	56.73	16.51	28.36
Class III and IV	289	1118.6	144.5	559.3	72.25	279.65

*Residential; **Non-residential

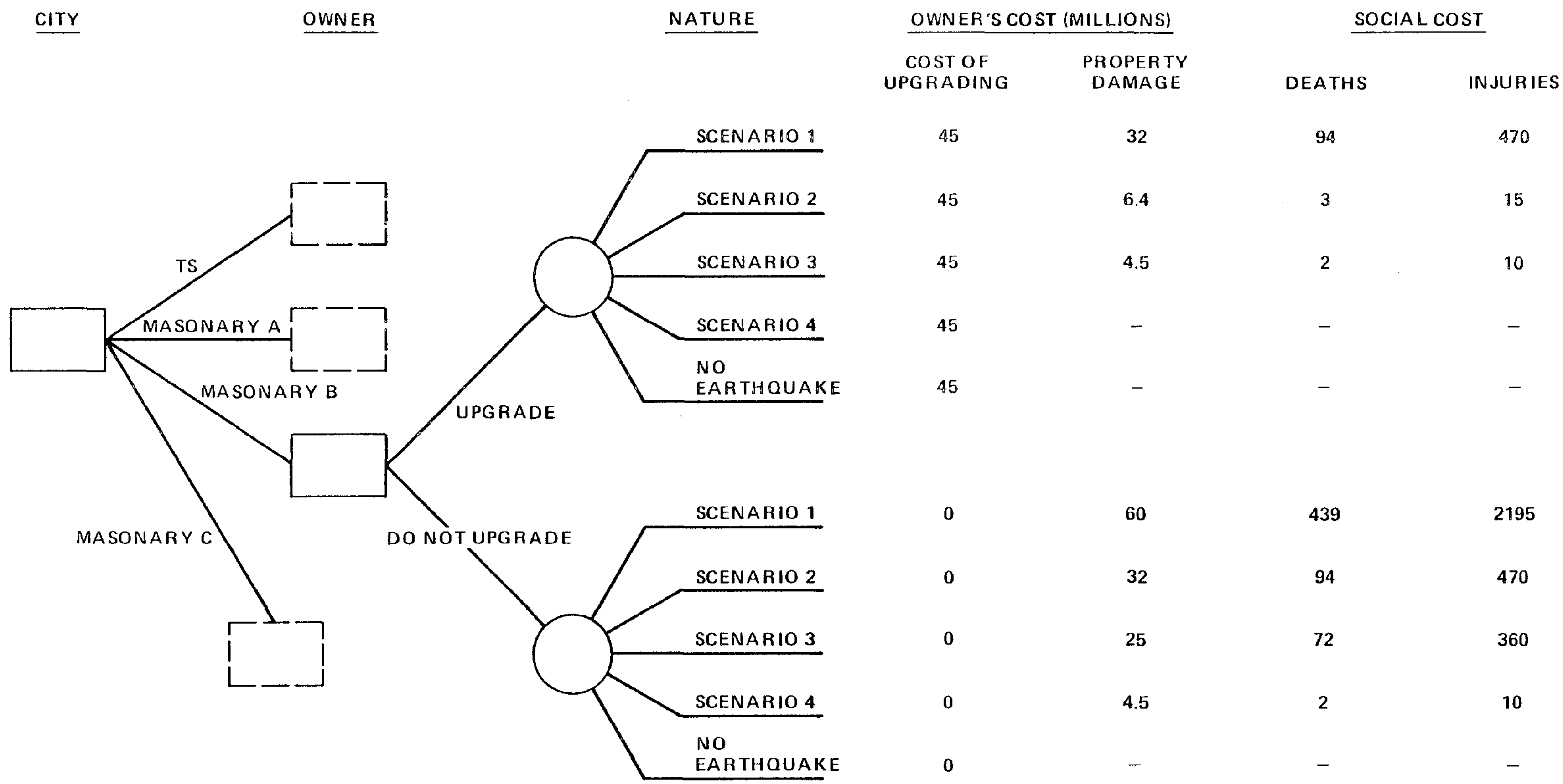

FIGURE 4.1. Analysis from the Owner's Viewpoint

4.4.2.2. Property damage

Property damage will vary for each upgrading alternative and for each scenario of the occurrence of earthquake. Based on our sample of 121 buildings, the average value of a residential building, exclusive of land, is estimated to be $34,100, and that of a non-residential building is $101,520. Property damage depends on the intensity of the earthquake and the standard of the building. Obviously, a lower standard and a higher intensity of earthquake would cause the greatest damage. In Table 4.4, the percentage of property value damaged under various intensities of earthquake, and for each of the four building standards, is given. This table is based on the definition of the MMI scale.

Table 4.4. Damage Factors (% of total value damaged)

Earthquake Intensity (MMI)	Masonry C	Masonry B	Masonry A	TS
VI	-	-	-	-
VII	10%	-	-	-
VIII	50%	10%	-	-
IX	90%	50%	10%	-

Since we know the distribution of the number of buildings in each council district, as well as the intensity of earthquake under the four scenarios, the property damage is easily computed. Based on the opinion of a real estate expert, the content value is assumed to be 25% of the value of the property. Total value damaged is, thus, 1.25 x property value damaged. These values are given in Table 4.5.

Table 4.5. Total Value of Property Damage (million dollars)

Class	Uprading Alternative	Property Damage			
		Scenario 1	Scenario 2	Scenario 3	Scenario 4
I	TS	-	-	-	-
	A	.5	-	-	-
	B	2.5	.5	.4	-
	C	4.7	2.5	2.0	-
II	TS	-	-	-	-
	A	6.4	-	-	-
	B	32	6.4	4.5	-
	C	60	32	25	-
III & IV	TS	-	-	-	-
	A	56	-	-	-
	B	277	56	40	-
	C	526	277	216	-

4.4.2.3. Number of deaths

Deaths occur because of collapse or partial collapse of buildings. The estimated number of deaths caused by an earthquake is based on the number of people exposed and the extent of the damage suffered by the buildings.

The number of people exposed to falling debris depends on the time of occurrence of the earthquake. From the occupancy data, it is seen that there are approximately an average of 125 people/building (1 million people ÷ 8,000 buildings). We will assume that, on an average, half of the occupants of each building are exposed.

Table 4.4 provides an estimate of the percentage of building damage for varying magnitudes of earthquake. We assume that 90% or more building damage will cause 5% deaths; 50% to 90% building damage will cause 2% deaths; and 30% to 50% building damage will cause .5% deaths among the occupants of the buildings. Based on these assumptions, the number of deaths under each scenario of earthquake is given in Table 4.6. For comparison, under Scenario 1, Federal Emergency Management Association [1981] estimates 4,000 to 23,000 deaths; Solomon et al. [1977] estimate 13,000 deaths; U.S. Department of Commerce Study [1973] estimates 4,000 to 20,000 deaths; and several other reported estimates in the Los Angeles Times news reports (e.g., see [1979, 1980, 1981]) are around 12,000 to 15,000 deaths. In Scenario 3, the estimates from these sources range from 3,000 to 14,000 deaths. The number of estimated deaths under Scenario 3 are lower than in the other scenarios. This is because of the larger distance between the fault and the populated areas.

4.4.2.4. Number of injuries

We have assumed the number of injuries requiring hospitalization to be five times the number of deaths. Most studies assume the number of injuries to be four to six times the number of deaths. The estimates of the number of injuries are also given in Table 4.6.

Table 4.6. Number of Deaths and Injuries

Class	Upgrading Alternative	Scenario 1 D	Scenario 1 I	Scenario 2 D	Scenario 2 I	Scenario 3 D	Scenario 3 I	Scenario 4 D	Scenario 4 I
I	TS	-	-	-	-	-	-	-	-
	A	-	-	-	-	-	-	-	-
	B	30	150	-	-	-	-	-	-
	C	145	725	30	150	20	100	-	-
II	TS	-	-	-	-	-	-	-	-
	A	5	20	-	-	-	-	-	-
	B	470	2,350	15	75	10	50	-	-
	C	2,195	10,975	470	2,350	360	1,800	-	-
III & IV	TS	-	-	-	-	-	-	-	-
	A	20	100	-	-	-	-	-	-
	B	2,040	10,200	80	400	65	325	-	-
	C	16,755	83,775	3,540	17,700	2,335	11,675	-	-

D = Deaths; I = Injuries

4.4.3. Analysis

We will first conduct the analysis from the viewpoint of the owners of the buildings who have to pay for the upgrading costs. Next, we will examine the problem from society's viewpoint. We will then do the analysis using the assumption that the occupants of these buildings are informed of the risks involved; therefore, they may pay a lower rent for higher-risk buildings. Finally, we will consider the residential buildings separately.

4.4.3.1. Owner's viewpoint

A typical owner faces the decision problem depicted in Fig. 4.1 for Class II buildings. The city could take any of the four actions. The owner also has the four alternatives available. For every scenario, the alternative of not upgrading dominates the upgrading alternative, because an owner is not liable for the deaths and injuries caused by a natural hazard. This finding is clearly supported by the owners' opposition to any ordinance that requires them to upgrade the buildings.

4.4.3.2. Society's viewpoint

In this analysis we examine the total costs and total benefits irrespective of to whom they accrue. In Table 4.7, cost of rehabilitation, expected property damage, expected deaths, and expected injuries are given for each of the 12 policies. The expected values are computed by multiplying the outcome under a given scenario (such as number of deaths) with the probability of the scenario.

Table 4.7. Social Costs and Benefits

Class	Policy	Cost of Rehabilitation (millions)	Expected Property Damage	Expected Deaths	Expected Injuries
I	TS	10.36	-	-	-
	Masonry A	5.18	.09	-	-
	Masonry B	2.59	.58	.3	1.5
	Masonry C	-	1.61	10.4	52
II	TS	179.5	-	-	-
	Masonry A	89.75	1.15	.05	.25
	Masonry B	44.9	7.45	9.2	46
	Masonry C	-	20.1	176.9	884.5
III & IV	TS	1407.6	-	-	-
	Masonry A	703.8	10.08	.2	1
	Masonry B	351.9	64.74	47.9	427.5
	Masonry C	-	175.26	1222	6110

The choice of a policy depends on society's willingness to pay in order to reduce the number of deaths and injuries. The willingness to pay, however, depends on the risk that the individuals face. In Fig. 4.2, a hypothetical curve, illustrating society's willingness to pay to prevent one expected death as a function of the probability of death, is given. This curve shows, for example, that if the individuals face a 5-in-1000 chance of dying, then society is willing to pay $1 million to prevent one expected death. But, if individuals face only a 5-in-10,000 chance of dying, then society will pay only $500,000 to prevent one expected death. The probability of death that an individual faces under alternative policies is given in Table 4.8.

From Table 4.7, and using the approximate figures from the willingness-to-pay curve, the incremental costs and benefits are computed in Table 4.9. For precise computation, the willingness-to-pay curve should be analytically expressed, and the
one policy to another (e.g., Masonry C to Masonry B) should be computed using integration. Our calculations are based on simple approximations. For example, in Classes III and IV, to go from Masonry C to Masonry B, the individual probability of death improves from 4.5×10^{-3} to 4.5×10^{-4}. We then take the willingness to pay to be (1 + 5)/2 = $.75 million per expected death. Total willingness to pay is (1222 - 47.9) x .75 = $880.5 million.

FIGURE 4.2. Willingness-to-Pay Curve

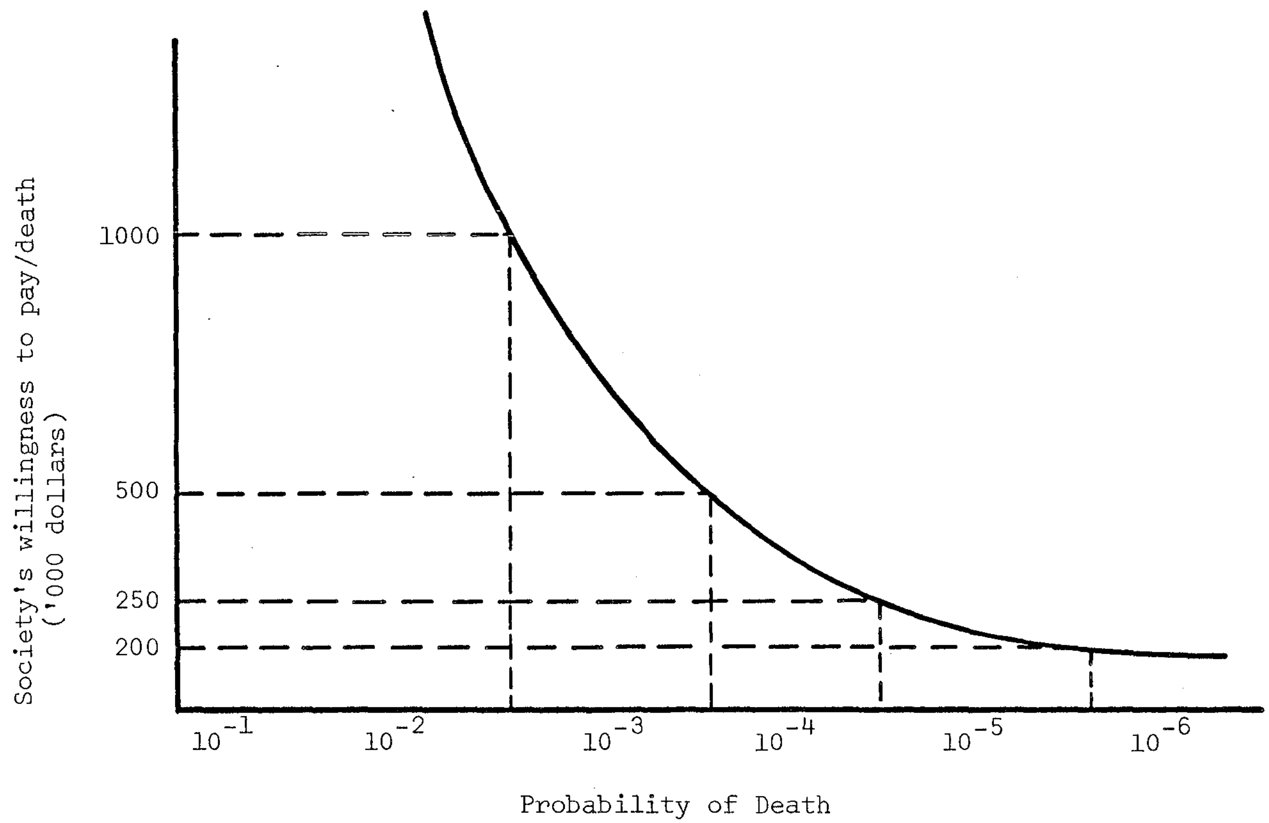

Table 4.8. Individual Probability of Death

Class	Alternative	Individual Probability
I	TS	-
	Masonry A	-
	Masonry B	7.2×10^{-4}
	Masonry C	4.53×10^{-3}
II	TS	-
	Masonry A	8×10^{-6}
	Masonry B	8.16×10^{-4}
	Masonry C	4.83×10^{-3}
III & IV	TS	-
	Masonry A	4×10^{-6}
	Masonry B	4.44×10^{-4}
	Masonry C	4.45×10^{-3}

Table 4.9. Incremental Social Costs and Benefits (million dollars)

		Cost	Benefits			
Class	Policy	Additional Cost of Upgrading	Property Damage	Value of Deaths	Value Value of Injuries	Benefit-Cost
I	A to TS	5.18	.09	-	-	-5.09
	B to A	2.59	.49	.15	.037	-1.9
	C to B	2.59	.73	7.9	1.3	7.34
II	A to TS	89.74	1.15	-	-	-88.60
	B to A	44.9	6.30	4.57	1.15	-32.88
	C to B	44.9	12.65	125.7	22.1	115.55
III & IV	A to TS	703.8	10.08	.02	.025	-693.67
	B to A	351.9	54.66	23.85	10.68	-262.71
	C to B	351.9	110.52	880.5	152.75	791.87

A similar curve can be estimated for injuries. For simplicity, we will assume that society is willing to pay $25,000 per injury prevented. The following conclusions can be drawn from this analysis:

- o For Class II and Class III and IV buildings, upgrading to Masonry B standard deserves consideration. For the other two alternatives (Masonry A and Today's Standards), additional costs outweigh the additional benefits.
- o For Class I buildings, although the net benefit is negative for Today's Standards upgrading policy, the magnitude of the negative benefit is relatively small. Other qualitative considerations (e.g., Class I buildings provide essential service to the community in case of an eathquake), may dictate that these buildings be upgraded to Today's Standards.
- o It should be noted that even though net benefit in going from Masonry C standard to Masonry A standard is positive for Class II and Class III and IV buildings, it is not cost-effective to upgrade to Masonry A. This is because most of the benefits of upgrading are reaped in going to Masonry B standard, and the additional benefit of further improvement to Masonry A does not justify the additional cost.

4.4.3.3. Empirical estimation of willingness to pay for safety

In this section, we will discuss two approaches that we used in estimating the willingness of the occupants of the hazardous buildings to pay for safety. In one approach, a questionnaire was used to directly elicit how much an occupant is willing to pay for a decrease in probability of death and injury due to earthquake. In the other approach, market-determined price of the earthquake-unsafe buildings was compared with the price for similar earthquake-safe buildings. The difference in the market price, when adjusted for the quality of the buildings, provided an estimate on how much premium the market is attaching to the safer buildings.

4.4.3.4. Direct estimation of willingness to pay for safety

In this approach, twelve residents were individually interviewed to obtain their willingness to pay additional monthly rent if the buildings were strengthened. Each resident was asked for background information on age, income, monthly rent, number of years in the building, and his general comments on the earthquake safety issue. To estimate willingness to pay, the following question was asked:

> "Your building is known to be unsafe with regard to earthquakes. There are 10,000 people living in such buildings in your neighborhood. If nothing is done to strengthen the buildings, 10 of these residents

are going to die in the next 10 years when the earthquake will strike. You or your family members could also become fatalities. Are you prepared to pay an increased rent to help strengthen the buildings so that 9 out of the 10 residents would be saved?_______ How much?_______How much are you prepared to pay so that none of your 10,000 neighbors will get killed?"

The above scenario estimates the willingness to pay for decreasing the probability of death from 1 in 1,000 to 1 in 10,000. Alternative scenarios were presented to estimate willingness to pay for different levels of decreases in the probability of death.

The results of this survey were as follows:

- The willingness to pay increased monthly rents varied from \$0 to \$25/month.
- The willingness to pay did not depend on the initial probability of death. Respondents took the position that the amount paid is the same whether 1 of 10,000 people are killed or 10 or 100 of 10,000 people are killed.
- Older residents (above age 70) were willing to pay little or nothing for the improved safety.

4.4.3.5. Property value differential approach for willingness to pay for safety

In this approach, the market prices of pre-1933 buildings were compared with those of post-1933 buildings by choosing a sample of matched pairs. Both buildings in a pair were located adjacent or at least on the same block to control for neighborhood, environmental, and social service quality levels. Thus, the buildings in a pair differed on building quality, size, and seismic resistance. Field work by project staff was undertaken to compile subjective ratings on the "differences in quality" between all matched pairs. The resulting "rating" variable became the independent variable (x) in the regression analysis. Size differences were taken care of by normalization: the dependent variable (y) of the regression became value per square foot of building space. The building value data came from Los Angeles County Assessor's records.

The regression of value-per-square-foot (y) on differences in quality rating (x) was carried out with a transformation on the dependent variable. The intercept term can be interpreted as property value differences that exist for the case of no difference in quality. Assuming an annualized yield of 10%, the average difference between earthquake-safe and earthquake-unsafe buildings was found to be \$.41/square foot. Thus, an 800 square-foot apartment would rent for \$328 per year (\$27 per month) more if it is earthquake-safe, all other things held constant.

For greater reliability, more variables measuring dwelling unit characteristics should be included in the analysis (e.g., see Brookshire et al. [1982]). If we accept the above results, it can be argued that upgrading alternatives requiring more than \$4.10 per ft^2 are cost-ineffective. Non-economic arguments, such as the willingness to pay of the unaffected residents for the safety of the residents of the hazardous buildings, may justify upgrading to Masonry B(\$5 per ft^2). The "non-economic" argements have to be substantially stronger for the higher cost upgrading schemes.

4.4.3.6. Analysis with public awareness of the earthquake hazard

In this analysis we will assume free-market conditions where there is no rent control by the city, and the tenants are aware of the earthquake hazard of their buildings. Based on our empirical study, we further assume that a tenant is willing to pay \$25/month in additional rents for an 800 ft^2 apartment if it is upgraded (and chances of a tenant's death in the next 10 years are reduced, at least from one-in-1,000 to one-in-10,000). Thus, the increased value of rental is 37.5 cents/ft^2/yr. The total area of the buildings is 83.946 million ft^2.

We also assume that property damage can occur in any of the ten years with equal probability, and the cost of upgrading is incurred in the beginning of the planning horizon. The present value of the property damage, and the increased rental income is calculated using a 10% discount rate. Present values of costs and benefits are summarized in Table 4.10.

Table 4.10. Present Values of Costs and Benefits (million dollars)

Class	Policy	Cost of Upgrading	Property Damage	Increased Rental
I	TS	10.36	-	1.5
	Masonry A	5.18	.05	1.5
	Masonry B	2.59	.35	1.5
	Masonry C	-	.95	-
II	TS	179.5	-	21
	Masonry A	89.75	1	21
	Masonry B	44.90	5	21
	Masonry C	-	12	-
III and IV	TS	1,407.6	-	171
	Masonry A	703.8	6	171
	Masonry B	351.9	40	171
	Masonry C	-	108	-

From Table 4.10 it is easily seen that upgrading to Today's Standards is clearly unattractive in spite of the increased rents. However, upgrading to Masonry B standards could be attractive for some buildings even though, in aggregate, the net benefit is negative.

4.4.3.7. Residential apartment buildings

We now examine whether it is reasonable to have a separate policy for the residential buildings. Based on the Environmental Impact Report [1979] of the Los Angeles City Planning Department, there are 137,000 apartment dwellers who live in 45,622 earthquake-unsafe units. We assume that, on an average, two-thirds of the residential buildings are exposed to earthquake. This exposure estimate may be high for a normal population, but is reasonable in this case because a majority of the residents of these buildings are old and retired. Based on the exposure, we can now calculate the expected deaths and injuries as discussed earlier. We have already provided the cost of upgrading for residental buildings in Table 4.3. Since we know the distribution of these buildings amoung council districts, the expected property damage can be calculated. The costs and benefits of the residential buildings are given in Table 4.11.

Table 4.11. Costs and Benefits of Residential Buildings

Policy	Cost of upgrading (million dollars)	Expected Property Damage (million dollars)	Expected Deaths	Expected Injuries
TS	355.06	-	-	-
Masonry A	177.53	3.28	.04	.2
Masonry B	88.76	21.1	10.7	53.5
Masonry C	-	57.12	262.1	1,310.5

It is seen from this table that, if society is willing to pay $200,000 per life saved and $10,000 per injury prevented, then upgrading to Masonry B standard is cost-effective. Further, the additional cost of upgrading, net of property damage, for upgrading to Masonry B standard is $52.74 million. This cost is easily recouped in 10 years even if the rents are raised for each dwelling unit by $20/month. The break-even rental increase, at a discount rate of 10% for 10 years, is approximately $16/month. In our survey, the residents were willing to pay this amount for increased safety.

4.5. Recommendations

Our study shows that the risks to the occupants of the unreinforced masonry buildings are significant. If no upgrading of these buildings is undertaken, an individual occupant faces approximately a five-in-1,000 chance of death, and a 25-in-1,000 chance of serious injury due to earthquake in the next 10 years. This risk is about ten times the risk due to fire and flames, and about 40 times the risk due to electricity current in the home during the same time period. Moreover, this risk could be ten times higher if we assume that a 90% collapse of the building would cause deaths to 25% of its occupants.

Our estimated total cost of upgrading to Masonry B standard is approximately $400 million. Of course, upgrading these buildings will result in a lower property damage to the owners of these buildings ($125 million savings), but this gain clearly does not offset the costs involved. A policy that does not account for the owners' interests has low likelihood of success. Besides, the cost of implementing a policy that disregards the owners' interests would be tremendous. This is because the unwilling owners will find all sorts of ways (legal, political, unethical) for not complying with the policy.

Past experience suggests that the owners have ignored the upgrading of the buildings because of the high cost of rehabilitation. There is also evidence that the city has been unable to enforce seismic design regulations because of financial problems and trained manpower shortage. Therefore, a seismic safety policy should provide an incentive for the owners to cooperate. Keeping in view the interests of both the owners and the occupants of the buildings we provide the following recommendations:

- Class I buildings constitute essential buildings such as schools, hospitals, fire stations, etc. These buildings should be upgraded to Today's Standards. A negative net benefit of upgrading reported in our analysis does not include the benefits to the general public due to uninterrupted operation of these emergency facilities in the event of an earthquake.
- Residential buildings should be upgraded to Masonry B standard. The net benefit of this policy is positive if an individual occupant is willing to pay $16/month for the reduced risk.

  We recommend that the owner be allowed to increase rents to partially offset the cost of upgrading.

We feel that approximately $10/month/dwelling increase in rent is a fair cost sharing by the owners and the tenants. This is because the owner receives other benefits, e.g. tax advantage, increase in the life of the building, increased property value, protection against lawsuits, insurance benefits, etc., that were not included in our calculations. The city should also ensure that adequate financing through conventional channels is made available to the owners for undertaking the upgrading.

We do not recommend that the city should simply post signs to make the residents aware of the hazard on the belief that the market mechanism will determine the optimal action. This is because, for an average resident, it is relatively difficult to assess the risks involved. Besides, because of the housing shortage in Los Angeles, in the short run, the residents may not have a real choice of paying a higher rent for a safer building. An ordinance based on a cost sharing scheme between the tenants and the owners and would reduce the resistance of the owners to upgrading. Such a scheme would therefore be beneficial to both the owners and the tenants.

- Buildings other than Class I and residentials should not be regulated. For these buildings we recommend that occupants be made aware of the hazard. The final course of action should be allowed to be decided by the market mechanism. A scheme to inform the public about the seismic hazard of a building has been opposed by the owners of the buildings. It is our belief that the risks involved are substantial and therefore it is the responsibility of the city to inform the public about the risks involved. We conjecture that some owners will decide to upgrade the buildings to avoid adverse public reaction and pressure from the occupants once earthquake hazard information is made public.

The city ordinance requires all buildings to be upgraded to specified design standards that in our terminology amount to an upgrading to somewhere between Masonry A and Today's Standards. The owners are given two options. In Option 1 they must meet the standards within 3 years from the date they are notified to upgrade the buildings. The actual notification date varies depending on the building classification. In Option 2, the owners could undertake a reduced upgrading, (wall anchoring) that corresponds to somewhere between Masonry C and Masonry B standards, within a year of the notification. Once this reduced upgrading is undertaken, an additional three to nine years are permitted for full compliance.

It is not possible to compare the relative success of implementation of our recommendations with the provisions of the city ordinance. It can, however, be said that the ordinance provides little, if any, incentives to the owners. As reported in the Los Angeles Times [1981], the owners oppose the ordinance. The owners' lack of cooperation will undoubtedly make the enforcement tedious.

The city ordinance does not distinguish between residential and commercial/industrial buildings. Our recommendations would provide adequate safety to the residents while allowing the market mechanism, public opinion, occupant/owner negotiations to determine the acceptable course of action for the non-residential buildings. One possible result may be that some buildings are upgraded while some others are put to alternate use with low people exposure, e.g., warehouse, etc.

Finally, our recommendations are based on an analysis of costs and benefits of each alternative. It is to be admitted that all costs and all benefits were not quantified in the formal analysis. Nevertheless, the results of a social decision analysis could be quite useful in formulating a policy.

The question can be raised that a local government often lacks resources to conduct a detailed social analysis. It may, therefore, be more appropriate for a state or a federal level agency to conduct an analysis as we have proposed. This reservation has merit. We recommend that an extensive effort must only be undertaken for problems having significant impacts on the constituents, and where choice of a policy is not clear. In many situations a quick and aggregate analysis along the lines of the approach discussed here may reveal a dominating policy. In some situations, available data can be used to establish whether a problem needs urgent action or simply occasional monitoring.

In conclusion, we recommend that even if a local government lacks resources to conduct social decision analyses, the steps of our approach provide a guideline for a discussion of various aspects of the problem.

4.6. Conclusions

In this paper we provided a social decision analysis for the seismic safety problem faced by the City of Los Angeles with regard to its old masonry buildings. Costs and benefits of alternative policies were compared for the society as a whole and for the impacted constituents. Both regulatory and free-market alternatives were evaluated. The tradeoffs between additional cost and safety were determined by using a direct willingness to pay approach and an economic approach based on property value differential.

We conclude that the solutions for a societal problem that impacts a large number of citizens should not be left solely to the intuitive determination of bureaucrats and politicians. For formal analysis, while it cannot resolve the complex value questions completely, goes a long way in pointing out socially desirable policies. A social decision analysis integrates scientific facts and the value tradeoffs of the impacted constituents. Thus, it provides a useful insight into various dimensions of the decision problem and hopefully has potential to aid the decision makers as well as various impacted constituents in the process of reaching an acceptable solution.

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Part III: Five Separate Perspectives on Risk Management at the State and Local Level

Chapter 5. Classification of Risks (Solomon and Meyer)

Chapter 6. The Office of Risk Assessor (Apostolakis)

Chapter 7. Policy Alternatives (Meyer and Solomon)

Chapter 8. Some General Policy Recommendations for Improved State and Local Risk Management (Bordas)

Chapter 9. An Incentive Approach in Risk Management (Gordon)

Chapter 5. CLASSIFICATION OF RISKS

5.1. Summary

Society is becoming increasingly aware of many hazards heretofore unknown or ignored. The abundance and severity of these hazards dictates the need for a structured plan to mitigate risks. An organized body of information concerning risk--if available to public officials at all levels--would support this plan. We address this chapter to public officials at all levels of government to stimulate discussion and as a prolegomenon to the national risk management information system.

We offer nine alternative classifications whose function is to array the hazards to which society might be exposed. We examine by example nine alternative hazard classifications because no single classification could spectrum either uniquely or completely all hazards. In fact, we believe that even our nine alternatives do not comprehend all possible hazards. The nine alternative taxonomies categorize risk by the following:

--situation in which hazard or risk is encountered

--cause of the hazard or risk

--hazard or risk itself

--manner in which hazard or risk is perceived

--magnitude of the hazard or risk

--geographic division of hazard or risk management responsibility

--dollars expended to manage the hazard or risk

--ratio of dollar damage to dollar benefit

--the way the hazard or risk is already managed

Our approach consists principally of defining under each of the above nine categories, increasingly detailed subsets which quantitatively describe specific hazards or risks.* The danger from industry--a rather general category--is in a first level or the first digit category. More specifically, we could quantify the hazards from manufacturing explosives--a specific industry--in the second digit category; manufacturing TNT in the third level, and so on. To create a profile for a sample taxonomy, we quantified some of these risks from existing vital statistics for the United States as a whole, California, and the counties of Riverside and Los Angeles for ease of comparison.

The taxonomy of classifications and profiles that we provide here are likely to be valuable in at least three ways. First, the taxonomies and profiles would provide a basis or framework for rational decision making by identifying a more complete array of risks and by

*Although we recognize there is a technical difference between the definition of hazard and risk, we use the words interchangeably in this study.

profiling these risks across several geographic regions. These taxonomies will at least acquaint the risk manager with how his or her community's riskiness will compare to that of other communities. If a Riverside risk manager (policy maker) sees that Los Angeles has a lower rate of highway accidents, he or she may recommend road improvement in Riverside. Next, he or she will study the cost/benefit taxonomy for further reinforcement of his recommendation. This recommendation would, of course, depend on a number of other cost/benefit considerations. The risk manager might be able to determine whether some risks are overmanaged (managed in conflicting ways by different agencies) or undermanaged.

Second, the taxonomy and profile may introduce the risk manager to a new way to quantitatively represent risk.

And third, the risk manager might learn to think in a broader domain-situation of risk, ratio of dollar damage to dollar expended to reduce risk, source of risk and so on. Addressing risk management in a broader domain might offer a more comprehensive management structure.

The taxonomy and profile approach we use here has major shortcomings, however, and the extent to which these shortcomings could be mitigated by providing finer and finer detail to our tables is quite uncertain. But, we assert that an array of taxonomies and profiles more complete than what we offer here might, in fact, prove useful by both providing a framework for a followup development and by providing the perspective on risk needed for effective decision making.

We have found nine taxonomies which could be used separately or together, depending on what the risk manager wishes to know. He or she can use the table, in whatever way is most helpful, to form a global picture of a particular hazard. By comparing relative magnitudes of risk, he or she will see--on paper--how the various aspects of the hazard more clearly fit together.

The tables we have brainstormed consider some of the issues which may be important to a risk manager (i.e., determining largest risk, or highest probability of risk, or highest consequence), but, of course, there are other ways to structure the taxonomies, and other classifications certainly exist which may prove to be more helpful in a specific region.

Now, we will describe our nine tables and show some ways a risk manager would be able to use them to facilitate his or her decision making capabilities.

5.2. Background

Many and diverse are the risks facing us, and even more diverse are the ways of avoiding them. For a long time our society, specifically, our decision makers, have been dealing with the problems on a reactive basis; namely, reacting only to the aftermath and cleanup, or at best preparing for emergencies and not planning ahead to try to avoid the risk. That explains in part why, for instance, the ordinance requiring smoke detectors in residential apartments in the Los Angeles area was passed only after a fire caused death and injuries at the Bunker Towers apartment complex. Some Los Angeles City Fire Department officials claim that they have been campaigning for this ordinance for years. In contrast, however, since policy makers have been long aware of earthquake hazards in California, they have been continually updating building standards and emergency response procedures for earthquakes.

Still another risk management approach--one in the process of changing from a reactive mode to a preventative mode--is the management of hazardous drinking water. Until recently, society, by its apparent lack of action, often gave little concern to the quality of the water we drink. Local government often reacted to sewage and chemicals dumped into the water supply by cleaning them out after they were dumped; little was done to prevent the initial contamination; mitigation of consequence rather than prevention was the rule. However, recently, events like Love Canal have inspired concern to the extent of causing the legislators to take preventative measures prior to the spill. The issue of managing drinking water is discussed in depth in an accompanying study.

So, we see that society often reacts after the occurrence of a hazardous situation and only prepares for one if enough controversy about it surfaces.

5.2.1. Basic Definitions

First, we need to describe what we mean by societal risk management. We can do this by describing some vague person or group of people with very overlapping functions who somehow manage risk; that is to say, identify the risk, quantify it perhaps, take action to reduce its probability of occurrence, and should it occur, mitigate the consequences. The risk manager is truly a vague person, because no single city or county government we examined has such a person with this single role. Rather, many people having overlapping roles tend to manage diverse menus of risks. However, for the purposes of this study, we refer to this collective array of managers as the risk manager.

The risk manager is a product of a relatively new philosophy which prefers a long lasting and well planned effort to minimize or avoid future risks, as opposed to the previously described reactive approach.

The "risk manager"--already described functionally--is some catchall term referring to a hypothetical person in city or county government whose primary function is to manage risk; that is to say, to perhaps assess risk, to budget dollars that will be used to reduce or eliminate risk and/or mitigate consequences of the risk, to monitor risky situations, and so on. In reality, no city or county government has any single person whose function is solely what we just described. The management of risk--the subject of an accompanying study--is done by many and with varying degrees of formality and precision. But, for the purpose of our study, we will define this vague group as a single "risk manager".

A taxonomy, in simple terms, is an ordered array of hierarchy of hazards, while a profile is a taxonomy which assigns a quantitative probability and consequence to this array. Profiles are constructed within a particular geographic division since they consist of statistics on consequences of hazards present in a certain location. Yet, our profiles are not merely lists of statistics, since that would mimic the past reactive approach to cleaning up after a disaster. Instead, these profiles include many of the answers to questions which are sure to arise when determining a method to approach mitigating risk. How grave is this hazard? What is its probability of occurrence? How many dollars would be expended in order to return a noticeable benefit? Since the questions could continue forever, it's time for answers. Taxonomies and profiles are described more thoroughly in Sections 5.3 and 5.4.

5.2.2. Prior Work

While the taxonomy and the profile have been recognized by some as rather important ingredients in the risk management process, few risk taxonomies have yet been published. One such taxonomy, currently under way by Clark University and Decision Research in a study funded by the National Science Foundation, is developed primarily on the basis of how risks and benefits are perceived. Although we recognize that such an approach would prove quite useful, we further contend that a multifaceted taxonomy--one that is based on a variety of alternative characteristics--might prove even more useful.

The Clark/Decision Research Taxonomy--discussed below--is extracted and paraphrased from "Risks in the Technological Society," edited by C. Hohenemser and J.X. Kasperson for the AAAS Selected Symposium #65.

The Clark/Decision Research Study intends to classify hazards in a logical way--allowing the use of similar managerial tools for all hazards of a given class. They intend to address such questions as what do saccharin, skateboards, and the collapse of the Grand Teton Dam have in common?

5.2.2.1. Dimensions of Causal Structure

Recently they have used the causal model described in their study to construct a taxonomy of technological hazards. On the basis of information derived from the scientific literature, they have coded 93 technological hazards on 16 dimensions. Each stage of the causal structure of hazard is characterized by one or more dimensions, as indicated in Figure 5.1. Wherever possible, they used numerical scales of logarithmic character: scale increments of unity were defined to correspond to multiplicative factors of 10 or 100. In this sense their scales are similar to other sociophysical scales in which physical events of human interest cover many orders of magnitude in physical "intensity". In the field of hazard analysis,

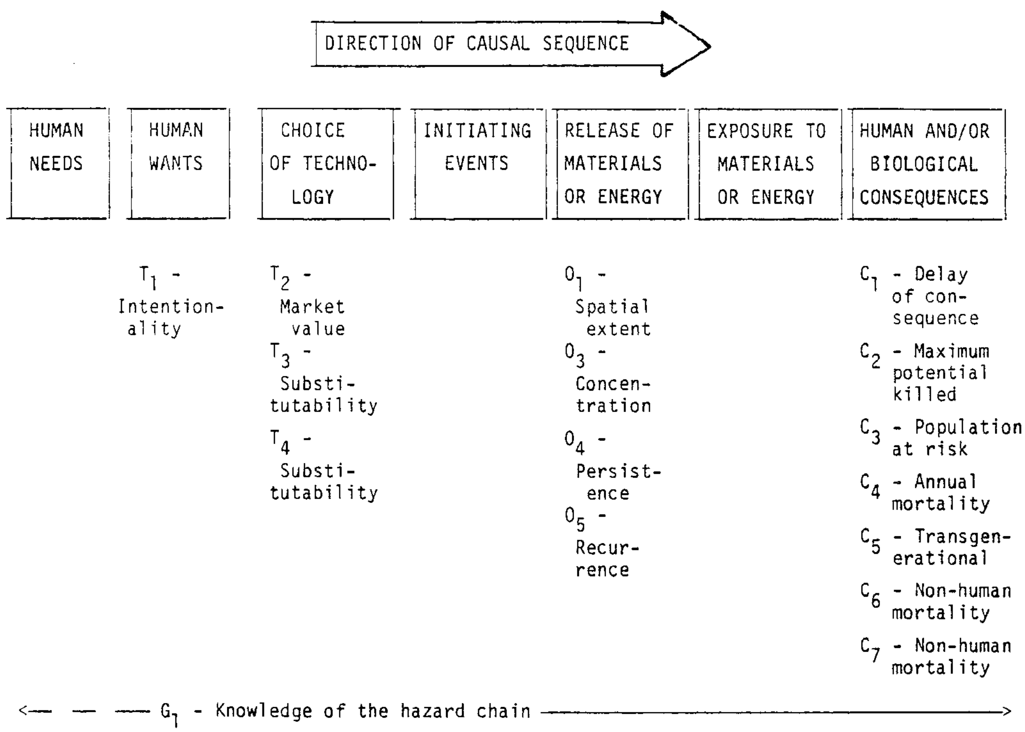


Figure 9.12. Causal model of hazard, with approximate location of variables. T-variables describe human wants and choice of technology. O-variables describe outcomes or releases. C-variables describe exposure-consequence relations and consequences. G_1 describes the state of knowledge of the whole chain.

FIGURE 5.1 Stages of causal structure of a hazard.

a well-known example of such a scale is the Richter scale for earthquake magnitude, on which increments of one correspond to a factor of 10 in energy release. Beyond the wide range of the physical dimensions underlying causal structure, they chose logarithmic scales for two additional and independent reasons: (1) given the paucity of information for many hazards, it is unrealistic in general to differentiate among hazards to any greater accuracy than a factor of 10; (2) in many cases, individual events in a given hazard structure involve a range of values that may cover a factor of 10 or more. Whether such crude scaling could capture interesting differences between hazards was a question they sought to answer by trying the method. At the outset they had no a priori insight that "factor-of-10 scaling" would be successful.

5.2.2.2. Hazard Codification

Their initial selection of 66 hazards drew upon an existing library of case studies at Clark University's Center for Technology, Environment, and Development (CENTED), the caselist employed by Slovic and his collaborators, and informal discussion within their group. Their early choices, then, were not supported by a systematic selection method, but they did include a large fraction of the cases that had received public attention. After scoring the initial set of 66, they plotted their distribution on each of the scales and noted the extent of population imbalances. In selecting further hazards to round out their sample, they made a special effort to correct such imbalances. The final sample of 93 is therefore reasonably well distributed on most scales, though it can but reflect the fact that there are few hazards in the extreme regions of most scales, and many at the low end. Though their interest is technological risk and hazard, they included in their sample several "marker" cases related to smoking and alcohol use.

Most hazards were scored by two or more individuals. Many cases were discussed in order to clarify the meaning of the available literature. After all scoring was complete, one individual made a series of checks for inconsistent scoring and thereby altered 20% of the scores by one scale point and a handful by as many as 2 or 3 scale points.

5.2.2.3. Composite Dimensions

Through factor analysis they have extracted from the 12 causal structure variables that describe hazard anatomy downstream from "choice of technology" five composite, orthogonal dimensions. The composite dimensions (factors) "explain" 82% of the variance of the sample. To good approximation this means that the causal structure of each of 93 hazards, and any others to be scored in the future, may be described by values of just five composite variables.

5.2.2.4. A Taxonomy of Extremes

The factor analysis by itself is not a taxonomy of hazards, but it does offer several possible ways of constructing one. One such taxonomy may be derived from the factor analysis by identifying extreme scorers on each of the five composite scales as five hazard classes; multiple extremes as a sixth; and all others as a seventh and eighth class. The resulting grouping of hazards, Fig. 5.2, has the effect of emphasizing the extremities of hazard space, on the assumption that it is these cases that merit special societal attention. In this sense, the present taxonomy defines in a systematic manner a partial list of society's "worry beads". Assuming that our methodology is found workable, this should remove some of the ad hoc character from much of the discussion of hazard identification, evaluation, and prioritization.

5.2.3. Scope of Study

The remainder of this chapter we divide into three primary sections. In Section 5.3 we discuss some theoretical aspects of taxonomies and profiles--their primary characteristics and shortcomings. In Section 5.4 we offer and explain nine highly abridged sample taxonomy and profile tables. Section 5.5 we reserve for observations, conclusions, and recommendations.

5.3. Theoretical Aspects of a Taxonomy and a Profile

5.3.1. Primary Characteristics

As asserted in Section 5.2, the risk manager might benefit from having risk tables--or taxonomy profiles--available which identify and logically categorize the risks. Later in this Section we will show that there is no unique way to display these tables; and as such, we classify risks on the basis of nine categories by:

- the situation in which the risk is encountered
- the cause of the risk
- the risk itself
- the manner in which the risk is perceived
- the magnitude of the risk
- the geographic division of risk management responsibility
- the hierarchy of management by the dollar expenditure to reduce the risk
- the dollar damage/benefit associated with the risk
- the way the risk is already managed in selected cities

For each of these nine categories we develop a taxonomy profile. The nine categories are further sub-categorized into more detail--or tiers of detail--in order to emphasize and pinpoint the problem with which the risk manager has to deal. For example, while source of risk represents a one-digit category, specific sources such as heavy industry, farming and public transportation represent a two-digit categorization. Under heavy industry, for example, three-digit risks include: explosives, fire, toxic chemical, etc. And under explosives,

Table 9.6. Proposed Taxonomy*

	CLASSES	EXAMPLES
1.	Multiple Extremes	Nuclear war, Recombinant DNA, Deforestation
2.	Intentional Biocides	Pesticides, Nerve gas, Antibiotics
3.	Persistent Teratogens	Uranium mining, Radioactive waste, Mercury
4.	Rare Catastrophes	Recombinant DNA, LNG, Satellites
5.	Common Killers	Automobiles, Handguns, Medical X-rays
6.	Diffuse Global Threats	Fossil fuel (CO_2), SST (NO_X), Coal burning
7.	Macro Materials, Energy	Skateboards, SST (noise), Underwater construction
8.	Micro Materials, Energy	Saccharin, Laetrile, Microwave appliances

*Extracted verbatim from "Risks in the Technological Society", C. Hohemser & J.X. Kasperson, in press.

FIGURE 5.2. Groupings of hazards.

for example, are included such four-digit risks as dynamite, gasoline, LPG, and so on. So for each of the nine different risk classifications, we determine two-digit classifications and in some instances, three- and four-digit classifications.

To generate the risk profile, we quantify some of the multi-digit coded risks on both a national and a Los Angeles and Riverside County area basis. In doing so, we distinguish between those risks more and less prevalent in specific regions. Further, we try to identify specific instances where--although the average risk may be low to moderate--there may be a very high localized risk.

5.3.2. Problems with a Taxonomy Approach

While the taxonomy of risks and the risk profiles approach provides a fundamental ingredient in developing an approach to risk management, there are some problems, specifically:

--The list of risks and risk categories generated are neither a complete list, nor are they a uniquely defined risk.

--The risks and risk categories are not ranked by magnitude of consequence or probability of occurrence; only a few are quantified

--Many of the risks are overlapping and are therefore double and triple counted; and

--Not all people would categorize risks in the same manner

--And there is inconsistency of sub-categories in the classifications.

How to and what extent can we overcome these shortcomings? One approach, and the approach we use here to at least mediate these shortcomings, is a brute force approach. That is to say, to help mediate these shortcomings, we need to describe more than one--in our case--nine taxonomies. And, hence, by highlighting the basic differences between these taxonomies, we can at least mediate these shortcomings.

5.3.3. Basic Differences Between Taxonomies

The primary difference between our nine taxonomy classification and profile lists is the manner in which the risks are categorized and then detailed. We describe these categories briefly, below:

(1) Situation in Which Risk is Encountered (Table 5.2)

Clearly a person has to be in a hazardous situation before he or she can be affected by the hazard. For example, a person involved in an occupationally related accident has to be working there (or at least visiting the place), and a motorist involved in a car accident took the risk of being injured or killed when he or she entered the car. Therefore, occupation, transportation, etc., are the situations which enabled the particular risk. They serve as the first tier of risk.

The risks can be avoided if those situations are avoided, and a risk manager has to decide if avoiding the situation is possible, and if so, is it cost-effective. For instance, "allowing pedestrians on freeways" is a situation of risk which can be avoided and it is beneficial to do so, therefore, no pedestrians are allowed on a freeway. On the other hand, air transportation is a situation of risk which can be avoided, but it is not because society has ruled in in favor of air transportation; the benefit associated with air transportation seems to outweigh its risk. And there are situations that cannot be avoided at all. A person at age 70 has a much greater chance of heart attack than a person at age 20, but there is little we can do to change these relative risks.

(2) Cause of Risk (Table 5.3)

A second characteristic of a risk for which we develop a taxonomy is the source or cause of risk. For example, the risk of developing cancer from water pollution is *caused* by the carcinogens in the water, the risk of electrocution is *caused* by an electric current. So, carcinogens, bacteria, electric current, etc., are the sources of risk. Again, at this level, the risk manager has to decide not only if the cause of risk is avoidable, but also to combine it with the first characteristic--the situation. There will be situations of risk where a source can be eliminated, or at least minimized, while in other situations it cannot. For instance, hexavalent chromium (Cr^{+6}) in drinking water is considered a hazardous metal and is regulated at very low concentration levels, but the same Cr^{+6} is part of the inherent materials in the leather industry where it cannot be eliminated.

After identifying and quantifying both the situations and the sources of risk, the risk manager can combine the two characteristics and evaluate the major sources of risk in the risk situations that could not be avoided.

(3) The Hazard Itself (Table 5.4)

The third characteristic is the hazard itself, for example, cancer, car accident, electrocution, gunshot, etc. It is important to identify the risks for two reasons. First, it can help in the cases where the situation and the cause are not eliminated and avoiding the risk is the only alternative (for example, avoiding worker contact with hazardous materials in a chemical plant). Second, and more important, is the recovery stage of a hazardous event. The risk impact can be minimized by efficient medical treatment, and the risk manager may have to decide which area of medical research or medical equipment to promote.

(4) Manner in which Risk is Perceived (Fig. 5.3)

The fourth category, perception of risk, must be added to the risk management improvement recipe. The first three categories are quantified (as much as possible) but the rate at which those events occur is not the only variable the risk manager has to consider. The manner in which risk is perceived also deals with the risk management problem. At each stage of risk evaluation, the risk manager must decide how to best minimize risk. Whether he should minimize total average risk received, the risk to the most in danger, or concentrate on minimum dollar cost, can be answered after considering the fourth classification; that is, the way risk is perceived by the public.

Therefore, knowledge of the people's perception of and attitudes towards the risk involved aids the understanding of how to weight different hazardous events with equal quantitative risks. For example, the chance of death or injury from being in a car and from being exposed to a given quantity of chemicals or radiation may be the same, but because of how they are perceived, perhaps they must be assessed entirely differently. The perception of the value of an event, depending on the benefit or harm of discontinuation, rules out the possibility of ending commercial air flight, e.g., people are willing to take the risk in exchange for the benefit of quick transportation.

Even though there may be a one-in-four-thousand chance of death per year in a car accident as there is due to some hypothetical carcinogen, they may be evaluated differently.

(5) Magnitude of the Risk (Table 5.5)

We may also categorize risks by their magnitude: whether they are acute--a dam failure--or chronic--water pollution, and whether they impact a large population--an airplane crash--or a limited population--a fall off a ladder. The magnitude of the risk might reflect both the probability of the risk and the magnitude of its consequence.

(6) Geographic Division of Risk Management Responsibility (Table 5.6)

Risks may already be naturally categorized on the basis of some geographic division of responsibility. For example, police departments in adjacent cities manage crime--a risk--separately within their own jurisdictions. Flood control districts also manage risks by geographic subdivision; and so on.

(7) By Dollar Expenditure (Table 5.7)

Risk may also be categorized by the total dollars expended in their management, by the rate of expenditure, or by who makes the expenditure. Some risks are managed by direct and immediate government expenditure; for example, the cost for planting foliage on the sides of hills to minimize the impacts of floods, is borne directly by Government. Of course, indirectly, the cost is passed on to the taxpayer. The direct costs associated with reducing other risks might be shared by Government and some element of society; the dollar cost of installing a traffic light on a busy streeet may be paid by

Government (and indirectly by the taxpayer) and by the driver on that busy street who now has to wait for a traffic light. Costs may also be paid directly by the consumer; Government regulations requiring seat belts on cars forced the costs to be passed on to those who purchased the cars.

(8) By Dollar Damage/Benefit (Table 5.8)

Risks may not only be managed on the basis of how much it costs to control them, but rather on the magnitude of the damage that they may cause and the benefits that may be received from the technology that produces the risk. For example, hydroelectric facilities may potentially cause massive, known dollar damage and clearly offer large dollar benefits and, as such, should be managed quite differently than say a seldom prescribed medication which would impact a very small segment of the population and have a very unknown impact.

(9) How the Risk is Already Managed (Table 5.9)

A rather natural taxonomy would result from an expanded version of the present risk management framework already found within government. While we verify in a companion document that there is no unique, well defined risk management process within city government, the current array of risk management processes within city government might provide some foundation for a taxonomy formulation.

5.4. The Taxonomies and Profiles

In this section we summarize sets of taxonomy tables corresponding to each of the nine categories just discussed. We display the tables in varying degrees of detail--all having at least a one-digit level of detail; some with a two-digit level; and a few with three- and four-digit levels of detail. The risk profiles are then merged within only a few of these taxonomies; that is to say, these hazard classifications or taxonomies are quantified for specific geographic regions.

The taxonomies/profiles are based on the following common assumptions: population at risk used for U.S., California and Los Angeles and Riverside Counties are averaged from the 1977 through 1980 vital statistics estimates. Total populations for these regions are taken from the 1980 census. The numbers reported represent the injury and illness <mortality> rate per 100 person years of exposure for a person of average (high) risk in the U.S., California, Los Angeles County and Riverside County. A person is considered exposed to the risk if he or she encounters it on a regular basis (e.g., driving a car, swimming in a lake). Average exposure is estimated by dividing the injury or mortality numbers by the total number of people exposed. Those of high exposure (a rather subjective term) are exposed at a higher rate (e.g., a taxi driver drives 100,000 miles per year).

To better appreciate the relation between each of the nine taxonomies, it might be interesting to trace a few typical risks according to each of the tables. For example, mortality from automobile accidents are, in one way or another, a primary contributor to risk in each of the nine taxonomies, although only apparent in a few of the taxonomies. Fires and falls are also primary contributors in each taxonomy, but only visible in a few. One message learned from this, is that a fundamental difference in these taxonomies is how blatantly specific risks are identified. While the risks are the same, some taxonomies bring them to the surface more effectively.

In dealing with the profiles, people with high exposure to a specific hazard are those who are exposed to this hazard disproportionately more than the average person. For example, motorcyclists are at higher risk of death than people who don't ride motorcycles, when considering riding. However, motorcycle riders only represent a small proportion of the population. Average risk to motorcyclists is calculated by dividing motorcycle-caused injury and mortality rates by the entire population (even though the entire population may not be at risk); while high risk is calculated by dividing motorcycle-caused injury and mortality by the number of people actually exposed to motorcycles.

The sources from which the data for the tables were taken are diverse, with the data for the different geographical areas coming generally from different sources. Details on the references for the numbers of death and injuries by category of risk in the U.S. are to be found in the topical report from which this chapter was drawn (UCLA-ENG-8243).

5.4.1. Table 5.1: By Situation in Which Risk is Encountered

In Table 5.1, we display the multiple digit taxonomy categorized by situation in which the risk is encountered. By magnitude ordering, the risks due to inherited health conditions like heart or cancer precondition in the family, or natural inner conditions like age, sex, and race are by far the leading risk situations. However, they are not of much importance at the local government level, as the public medical research funds are allocated to federal or state levels. Home accidents, on the other hand, can be reduced by regulating home appliances and tools for instance, or by other kinds of regulation (like the smoke detector regulation introduced in Los Angeles). Work is a heavily regulated area, and one where statistics are plentiful and where the rate of occupational injuries and diseases is still high. Transportation and recreation are activities involving risk, but transportation is a more controllable activity.

Table 5.1 Situations in which Risk is Encountered.

		INJURY AND ILLNESS <MORTALITY> RATE PER 100 PERSON/YEARS OF EXPOSURE FOR AVERAGE AND (HIGH) RISK PEOPLE IN:			
CODE #	DESCRIPTIVE RISK	U.S.	CA	L.A. COUNTY	RIVERSIDE COUNTY
1.1	INHERITED HEALTH CONDITION (HEART CONDITION, CANCER, ETC.)	<.83>	<.71>	<.74>	<.91>
1.2	NATURAL INNER CONDITION (AGE, SEX, COLOR, ETC.)				
1.3	HOME	1.67			
1.4	WORK (OCCUPATIONAL)	1.27 (9.2)	1.5 (9.9)	1.6 (4.3)	1.34 (6.2)
1.5	TRANSPORTATION	.899 <.023>	<.026>	<.022>	<.039>
1.6	RECREATION				
1.7	UNDER ENVIRONMENTAL IMPACT	<.0006>			
1.8	UNDER NATURAL HAZARD IMPACT				
1.9	UNDER CRIME IMPACT	.44	.706	1.00	.703
1.10	UNDER UNNATURAL HAZARD IMPACT (WAR, DAM FAILURE, ETC.)				

5.4.2. Table 5.2: By The Cause of The Risk

In Table 5.2 we categorize and, to a limited extent, profile risk by the source of the risk; whether it is due to a medical reason such as bacteria or a virus; a concentrated source of energy such as electricity or explosives; or other factors such as food, medicine or water.

The quantification by causes of risk is the hardest to achieve, as statistics tend to be concentrated either on the situation of risk or on the risk itself. We used, however, a list of causes of risk which can serve as the basis for development of a more detailed classification in the future.

Table 5.2 Causes of Risk.

		INJURY AND ILLNESS <MORTALITY> RATE PER 100 PERSON/YEARS OF EXPOSURE FOR AVERAGE AND (HIGH) RISK PEOPLE IN:			
CODE #	DESCRIPTIVE RISK	U.S.	CA	L.A. COUNTY	RIVERSIDE COUNTY
2.1	GENETIC FACTORS				
2.2	BACTERIA				
2.3	VIRUS				
2.4	PERSON/PERSON				
2.5	FOOD				
2.6	WATER				
2.7	DRUGS AND MEDICINES	<.00192>			
2.8	AIR				
2.9	FLAMMABLES AND HOT SURFACES	<.00292>			
2.10	EXPLOSIVES	<.0002>			
2.11	CHEMICALS				
2.12	MECHANICAL IMPACT	<.0308>			
2.13	ELECTRICITY	<.00052>			
2.14	RADIOACTIVE MATERIALS	<0.0>			
2.15	FIREARMS	<.00095>			

5.4.3. Table 5.3: By the Risk Itself

In Table 5.3 we classify by the nature of the risk itself. We profile a lot of information on mortality rates. With respect to these profiles, we again find a significant difference across different regional areas; a useful piece of information to the risk manager.

The data for the risk or hazard classification is the easiest to obtain (mainly in the form of death rates), but as mentioned, it may not be as useful as the previous two classifications in the early risk prevention stage. However, significant differences in particular hazard rates at different locations are important indicators to a risk manager that a problem has developed and he has to trace their sources.

Diseases of the circulatory system are the biggest killers, cancer is second and all accidental deaths are third ranking. The U.S. data is from a different source, therefore some diseases may be included in a category of diseases in one source, while being excluded in the other source. As in the source of risk categorization, it is useful to investigate the different hazards that are occurring in specific situations of risk. One of them is the occupational sector where most of the hazards are accident related.

Table 5.3 Risk or Hazards.

			INJURY AND ILLNESS <MORTALITY> RATE PER 100 PERSON/YEARS OF EXPOSURE FOR AVERAGE AND (HIGH) RISK PEOPLE IN:			
CODE #	DESCRIPTIVE RISK		U.S.	CA	L.A. COUNTY	RIVERSIDE COUNTY
3.1	DISEASES OF CIRCULATORY SYSTEM		<.456>	<.382>	<.418>	<.505>
3.2	MALIGNANT NEOPLASMS		<.178>	<.170>	<.177>	<.204>
3.3	ACCIDENTS, POISONING AND VIOLENCE		<.073>	<.078>	<.078>	<.093>
3.4	DISEASES OF RESPIRATORY SYSTEM	<.035>*	<.038>	<.046>	<.039>	<.073>
3.5	DISEASES OF DIGESTIVE SYSTEM	<.029>*	<.023>	<.036>	<.037>	<.043>
3.6	ENDOCRINE-NUTRITIONAL AND METABOLIC	<.012>*	<.018>	<.014>	<.015>	<.014>
3.7	DISEASES OF GENITO-URINARY SYSTEM	<.005>*	<.007>	<.009>	<.084>	<.119>
3.8	DISEASES OF NERVOUS SYSTEM (INCLUDING SENSE ORGANS)	<.0006>*	<.0008>	<.007>	<.007>	<.010>
3.9	CAUSES OF MORTALITY IN EARLY INFANCY	<.010>*	<.013>	<.005>	<.010>	<.009>
3.10	CONGENITAL ABNORMALITIES		<.006>	<.006>	<.007>	<.006>
3.11	INFECTIVE AND PARASITIC DISEASES		<.007>	<.006>	<.006>	<.004>

*THIS IS THE CALIFORNIA DATA FOR THE GROUP OF DISEASES INCLUDED IN THE U.S. SOURCE.

5.4.4. Figure 5.3: Classification of Risk by Perception of the Risk

We take this fourth classification from the ongoing studies at Clark University/Decision Research and the paper "Perceived Risk", by P. Slovic, Proc. R. Soc. Lond. A 376, 71-34 (1981). Ninety hazards are tabulated in terms of perceived risk and perceived benefit.

Each of the 90 hazards was rated on overall riskiness and judged on all 18 characteristics of risk. In general, the risk from most of these activities were judged to be increasing, not easily reduced, and better known to science than to those people exposed to them.

As in the earlier studies, many pairs of risk characteristics were highly correlated with each other. Factor analysis showed that the 18 characteristics could be represented well by three factors, the first two of which resembled the two factors that emerged from the earlier studies. Factor 1 was associated with lack of control, fatal consequences, high catastrophic potential, reactions of dread, inequitable distribution of risks and benefits (including transfer of risks to future generations), and the belief that the risks are increasing and not easily reducible. Factor 1 thus seems to correspond closely to the factor labelled "dread risk" in the earlier study. Factor 2 was associated with risks that are unknown, unobservable, new and delayed in their manifestation. It thus corresponded closely to factor 1 ("unknown risk") of the earlier study. Factor 3 was primarily determined by the number of people exposed and the rater's personal exposure.

Scores for the individual items on factors 1 and 2 are plotted in Figure 5.3. The hazards at the extremes on each dimension give support to the factor names, which were initially determined from examination of the set of characteristics defining each factor. Items at the high end of factor 1 (nerve gas, nuclear power accidents, nuclear weapons, terrorism, warfare and crime) are all highly dreaded, in contrast to the items at the opposite end (home appliances, bicycles, Christmas tree lights, hair dyes). The locations of items on the vertical axis correspond to the degree to which their risks are perceived as known, familiar and observable. Hazards falling at the high exposure end of factor 3 (societal and personal exposure) were motor vehicle accidents, caffeine, alcoholic beverages, smoking, food preservatives, herbicides and pesticides. Hazards falling at the low end of this factor included lasers, solar electricity, space exploration, laetrile, scuba diving and open heart surgery.

They found that lay people's risk perceptions and attitudes are closely related to the position of a hazard within the factor space. Most important is dread risk. The higher an activity's score on this factor, (a) the higher its perceived risk, (b) the more people want its risk reduced, and (c) the more they want to see strict regulation employed to achieve the desired reduction in risk. The attitudes and perceptions of experts, however, appear much less closely related to the factor space.

Figure 5.3 Classification of risks by perception of the risk.

5.4.5. Table 5.4: By the Magnitude of Risk

In Table 5.4 we categorize by the magnitude (probability, consequence, etc.) of the risk. Of course, this table requires some subjective definition of what constitutes high, moderate, and low consequence and probability. For the purpose of this paper, we define the following:

- high consequence--greater than 10 immediate mortalities
- moderate consequence--less than or equal to 10 immediate mortalities but greater than three
- low consequence--less than three immediate mortalities
- high probability--greater than 0.1 chance per year
- moderate probability--greater than 0.001 chance per year but less than 0.1
- low probability--less than 0.001 chance per year

Clearly not only are the numbers quite uncertain, but so are the consequences--ours are based on immediate mortalities, but they could, of course, be based on delayed mortalities, injuries, and so on.

Table 5.4 Magnitudes of the risk.

		INJURIES AND ILLNESSES <MORTALITIES> PER 100 PERSON/YEARS OF EXPOSURE FOR AVERAGE AND (HIGH) RISK PEOPLE IN:			
CODE #	DESCRIPTIVE RISK	U.S.	CA	L.A. COUNTY	RIVERSIDE COUNTY
5.1	HIGH CONSEQUENCE/ LOW PROBABILITY				
5.2	MODERATE CONSEQUENCE/ LOW PROBABILITY				
5.3	LOW CONSEQUENCE/ LOW PROBABILITY				
5.4	HIGH CONSEQUENCE/ MODERATE PROBABILITY				
5.5	MODERATE CONSEQUENCE/ MODERATE PROBABILITY				
5.6	LOW CONSEQUENCE/ MODERATE PROBABILITY				
5.7	HIGH CONSEQUENCE/ HIGH PROBABILITY				
5.8	MODERATE CONSEQUENCE/ HIGH PROBABILITY				
5.9	LOW CONSEQUENCE/ HIGH PROBABILITY				

5.4.6. Table 5.5: By Geographic Division

Table 5.5 categorizes risk by geographic division of risk management responsibility. Again, our breakdown is quite arbitrary. Category 6.1 (Within City) means that the risk is managed within the jurisdiction of the city. Subcategories under 6.1 would include City Fire Department, City Police Department, Seismic Buildings Control, City Health Department, and so on. Many municipal water districts and land management districts would fall under category 6.2, where management responsibility would fall across city lines. County functions would fall into category 6.3, and so on.

Table 5.5 By Geographic Regions.

		INJURIES AND ILLNESSES <MORTALITIES> FOR 100 PERSON/YEARS OF EXPOSURE FOR AVERAGE AND (HIGH) RISK PEOPLE IN:			
CODE #	DESCRIPTIVE RISK	U.S.	CA	L.A. COUNTY	RIVERSIDE COUNTY
6.1	WITHIN CITY				
6.2	ACROSS CITIES				
6.3	WITHIN COUNTY				
6.4	ACROSS COUNTIES				
6.5	BY STATE				

5.4.7. Table 5.6: By Dollar Expenditure to Reduce Risk

This category is similar to the category of "by geographic division" in that both depend heavily on subjective definitions of what constitutes high, moderate, and low. Primary categories might include High, Moderate, and Low Expenditures with or without direct societal expenditures. Examples of High Expenditures with Direct Societal Costs are given in Table 5.7.

Table 5.6 Dollar Expenditure to Reduce Risk.

		INJURIES AND ILLNESSES <MORTALITIES> PER 100 PERSON/YEARS OF EXPOSURE FOR AVERAGE AND (HIGH) RISK PEOPLE IN:			
CODE #	DESCRIPTIVE RISK	U.S.	CA	L.A. COUNTY	RIVERSIDE COUNTY
7.1	HIGH EXPENDITURE/ DIRECT SOCIETAL COST				
7.2	HIGH EXPENDITURE/ INDIRECT SOCIETAL COST				
7.3	MODERATE EXPENDITURE/ DIRECT SOCIETAL COST				
7.4	MODERATE EXPENDITURE/ INDIRECT SOCIETAL COST				
7.5	LOW EXPENDITURE/ DIRECT SOCIETAL COST				
7.6	LOW EXPENDITURE/ INDIRECT SOCIETAL COST				

5.4.8. Table 5.7: By the Dollar Damage/Dollar Benefit

Risks may also be managed by the dollars of damage they might cause and the benefit that might be received from the deployment of the technology. Again we base this taxonomy on a rather subjective set of assumptions regarding what constitutes high, moderate, and low damages and benefits. One way of categorizing risks according to this scheme would be to place approximately the same number of risks in each of the nine two-digit categories. Another way might be to quantify high, moderate, and low dollar damage costs and benefits.

This taxonomy still has further problems. Not all damage and benefit could be expressed in dollars, for one. Some people equate dollar damage to number of lives lost, each life worth a dollar amount according to insurance compensation. An inherent problem in Table 5.7 is the difficulty of recording damage and benefit in dollars. If we experience a severe earthquake in the near future, we could predict dollar damages to renovate buildings depending on the extent of damage, but this is not an accurate figure to compare with dollars expended to prevent damage from a natural hazard. If we chose some dollar worth for each life lost in an earthquake hazard and added this to material damage, we could better, although still not precisely, compare dollar damage to dollar benefit of making buildings safe. Few risks would fall into the category of high dollar damage/low benefit, and many would fall into the categories of low dollar damage/low and moderate benefits.

This taxonomy profile approach could be very useful to the risk manager if it were to define a damage-to-benefit ratio with uncertainty bounds for the array of risks under the manager's jurisdiction. Presumably, Table 5.7 could be combined with Tables 5.2, 5.3 or 5.4 to provide a fairly structured taxonomy profile.

Table 5.7 By the Dollar Damage/Dollar Benefit.

		INJURIES AND ILLNESSES <MORTALITIES> PER 100 PERSON/YEARS OF EXPOSURE FOR AVERAGE AND (HIGH) RISK PEOPLE IN:			
CODE #	DESCRIPTIVE RISK	U.S.	CA	L.A. COUNTY	RIVERSIDE COUNTY
8.1	HIGH DOLLAR DAMAGE/ LOW DOLLAR BENEFIT				
8.2	MODERATE DOLLAR DAMAGE/ LOW DOLLAR BENEFIT				
8.3	LOW DOLLAR DAMAGE/ LOW DOLLAR BENEFIT				
8.4	HIGH DOLLAR DAMAGE/ MODERATE DOLLAR BENEFIT				
8.5	MODERATE DOLLAR DAMAGE/ MODERATE DOLLAR BENEFIT				
8.6	LOW DOLLAR DAMAGE/ MODERATE DOLLAR BENEFIT				
8.7	HIGH DOLLAR BENEFIT/ HIGH DOLLAR DAMAGE				
8.8	MODERATE DOLLAR BENEFIT/ HIGH DOLLAR DAMAGE				
8.9	LOW DOLLAR BENEFIT/ HIGH DOLLAR DAMAGE				

5.4.9. Table 5.8: By the Way the Risk is Already Managed

We base this classification on how local government currently handles its risk management responsibilities. Four management styles are designated: unmanaged risks, reaction, regulation, and risk analysis. Within these categories, various modes of response are noted. This categorization is incomplete, but suggestive of a way of arraying risks that possibly will aid policy making by suggesting hazards that ought to be managed more actively.

Table 5.8, it must be noted, is not so much a taxonomy of risks as it is of management styles. Some hazards will appear at many points in the table--e.g., household fires are managed by emergency response as well as by local and regional regulation. Other hazards could apply only in the "unmanaged" category. The taxonomy thus would serve to alert local officials to an immediate risk they are currently attending to, and to those they overlook, deliberately or otherwise. Furthermore, entries in the table will differ for different levels of government. For example, state regulations imposed on cities are often in response to formal risk analysis conducted at the state level, so that, from the perspective of the state, management is through analysis which, from the perspective of the city, management is by regulation. The same pattern, needless to say, is reported frequently at the federal level.

Table 5.8 Current Risk Management Practices.

		INJURIES AND ILLNESSES <MORTALITIES> PER 100 PERSON/YEARS OF EXPOSURE FOR AVERAGE AND (HIGH) RISK PEOPLE IN:			
CODE #	DESCRIPTIVE RISK	U.S.	CA	L.A. COUNTY	RIVERSIDE COUNTY
9.1	UNMANAGED RISKS (ALL THOSE NOT LISTED BELOW)				
9.2	MANAGED BY REACTION				
9.2.1	EMERGENCY RESPONSE				
9.2.2	CONTINGENCY PLANNING				
9.3	MANAGED BY REGULATION				
9.3.1	PROFESSIONAL STANDARDS AND "GOOD" PRACTICES				
9.3.2	LOCAL REGULATION				
9.3.3	STATE REGULATION				
9.3.4	REGIONAL REGULATION				
9.3.5	FEDERAL REGULATION				
9.4	MANAGED BY RISK ANALYSIS AND MITIGATION				
9.4.1	MANDATED RISK ANALYSIS				
9.4.2	VOLUNTARY RISK ANALYSIS				

5.5. Observations/Policy Conclusions/Future Work

5.5.1. Observations

What have we observed; what are the policy implications and can we define a follow-up path?

We have made five distinct observations. First, we asserted and then justified our assertion that there is no single, unique approach to defining a taxonomy. While some taxonomies are more readily justifiable, others are likely to present a more useful array of information. Some highlight specific risks more than others. Second, no two risk managers are likely to describe the same set of characteristics as desirable when describing a taxonomy. A budget-oriented risk manager might be more concerned with the marginal benefit associated with a marginal cost expenditure to reduce risks. The occupational health type risk manager would concentrate more on occupational type health hazards. A disease control type manager would concentrate more on a taxonomy that would regulate factors affecting disease; and so on. There is no such thing as a uniquely defined risk manager; each manager--a very vague title--perceives a much different set of requirements.

Third, no matter how you slice it, the risk profiles we display very clearly illustrate the often significant different magnitudes of risk to which people in geographic regions are exposed. The implications of this are quite blatant. To the extent that the cause of the specific risks can be itemized and the costs to control the risks by a specific amount be defined, then the risk manager could get a good perception of what dollar costs it might take to reduce specific risks by a predetermined amount, as well as what the "theoretical bound" of this reduction might be. For example, highway traffic deaths in Riverside County are more than 60% larger than in Los Angeles County. Why? Well, one reason is that more people from Los Angeles County die on Riverside County roads than vice versa. Another reason might be due to the number of police patrol units per traffic sector, and still another might relate to the relative speeds and the extent of two lane highways (a major contributor to highway deaths) in Los Angeles versus Riverside Counties. That is on the risk side. On the cost side, we might be able to get a handle on the dollars expended per life saved. This cost could only be estimated indirectly because we could only estimate dollars spent on traffic safety and number of deaths directly. Number of lives saved could only be estimated by using time series or regional series information to assess the sensitivity of regulation changes to lives lost. The risk manager in Los Angeles and the risk manager in Riverside Counties could--at least theoretically--be able to array a list of risks, the extent to which these risks might be reduced, and the relative costs of reducing them.

Therefore, and fourth, the taxonomy/profile provides a basis for making a rational judgment regarding the relative cost and relative value of making expenditures to reduce risk.

The extent to which these nine taxonomies are useful to the risk manager is admittedly uncertain. The entries in the tables are certainly not complete--they do not consider all risks; they are not unique--risks are often counted a multiple number of times; and they do not necessarily follow the logic or rationale of how a particular risk manager might operate. But the tables do provide some basis for rational, orderly judgment. Further, these tables provide the risk manager some quantitative basis for decision making.

And fifth, taxonomies and profiles based on a multitude of attributes--e.g., source of risk, situation in which risk is encountered, the risk itself, and so on--offer to the risk manager a more encompassing method by which to appreciate the spectrum of risks and further offer the framework for developing multiple approaches for handling risk. For example, knowing that a particular chemical is carcinogenic and may get into the water supply, is useful information to the risk manager. But knowing more than just the risk--the total number of people it might impact, the cost of eliminating it, the industrial situations in which the risk is encountered, and so on--would provide a more complete knowledge base.

5.5.2. Toward a National Risk Management Information System

Ultimately, the capacity of local government to manage risks, other than occupational risks, depends upon the availability of information. Knowledge of extant hazards, the relative degrees of risk they pose, and the effectiveness of policy interventions must be available to decision makers at the local level if their role in risk management is to be other than that of passive monitors. Three items, then, require discussion. One is the necessity of classification as the basis for a national risk management information system. The second is the role of such a system in the cumulation and dissemination of information about risk to local officials. The third item concerns the role of a risk management information system in the prediction of risks to which local governments should be attentive.

5.5.3. The Need for Classification

Information about risks can be neither accumulated, stored, nor retrieved without an appropriate system of classification. The need for systems of classification arises from the following:

(1) Absent classification, one does not even know how to think of many risks. A single example suffices: Organic contamination of water can be treated as either a water problem or a problem of ingestion of dangerous organics. Needless to say, how one thinks about this problem will affect policy judgments--whether it is treated as a water problem or problem arising at the ultimate sources of organics. No one system of classification of risks, or way of thinking about risks, can be defended as superior to any other,

a priori. However, any classification of risks is one in which the categories are mutually exclusive, but together, inclusive of all risks insures some consistency in thought; hence, policy that otherwise would be lacking could be formulated.

(2) Precise classification permits judgments in the absence of complete information. Any taxonomy of risks that is organized hierarchically allows one to view any one hazard as, on the one hand, a single instance of a more general category of hazards, and, on the other hand, composed of numerous subsidiary hazards. Because of the relational character of any scheme of classification, classification directs the inquiries of policy makers, both toward specification as well as generalization, when new hazards are encountered. Absent systems of classification, policy is controlled "fatalistically," that is, by dramatic events as represented in the news media, which may lead to both inefficiencies and inequities.

(3) Classification permits comparison of risk. Comparisons of risks are themselves risky because of differences in populations to which various categories of hazard apply. The smaller the fraction of the population subjected to a given hazard, the lower the rate of risk for the entire population. Ironically, the better specified the population, which usually means smaller, the greater the level of risk among those exposed. Explicit classification of risk makes clear these anomolies in risk data and offers a better basis for policy judgment than risk data that are not arrayed hierarchically.

(4) Risk classification insures that some categories of risk are not altogether ignored. Systematic, comprehensive risk management policy requires that the full array of risks confronting a unit of government be reviewed and understood, at least cursorily. Substantial gaps now exist in the types of hazards to which government is attentive, especially when relative degrees of risk are considered. To the degree that any risk taxonomy is exhaustive, almost all hazards present in the locality will be identified. To the extent that categories in a risk taxonomy are mutually exclusive, problems due to overlapping and conflicting jurisdictions will be identified.

All of the above is to indicate that classification of risks is not an idle exercise. It is rather a prolegomenon to systematic thinking about hazards of all sorts and their intended risks. Any set of policies or actions aimed at the entire array of risks facing citizens, as opposed to specific hazards, will rely heavily upon a scheme of classification or taxonomy as its concentric basis.

5.5.4. Cumulation of Risk Management Information

Classification of risk is also the first step in cumulation of systematic information about the impact of various natural and technological hazards that is not now available. Of critical importance is that the experiences of diverse local communities be pooled in a systematic fashion. Of concern are not only morbidity and mortality rates associated with various hazards, which are largely documented by public health authorities and the EPA, but also local physical and industrial conditions associated with the presence of various hazards. Cumulation of information requires an accepted system for classifying risks. It also requires an accepted system for identifying physical and industrial conditions of local communities, as well as relevant demographic indicators.

5.5.5. Prediction of Risk

Ultimately, a risk management information system that is both exhaustive and is comprised of mutually exclusive categories can permit prediction of risks in local communities. What is important is that various hazards be classified not only by the mortality or morbidity rates they engender, but also according to locality characteristics associated with them. The hazard itself, then, is the basic unit in a risk management information system. The array of hazards incorporated into the system is defined in one or more taxonomies; attached to each hazard is its classification relative to other hazards, its riskiness, and some description of conditions associated with its presence. Such data would enable prediction of the likelihood that given hazards are present, and would thereby direct policy makers' attention toward detection of these hazards and towards remedial action, if necessary. It is a simple matter to model the probability that a given hazard is present and the degree of risk it poses as a function of other conditions. The critical element is the definition or classification of hazards themselves, and their organization in a manner that is both comprehensible and scientifically valid.

Several comments should be added about the management and division of responsibility for a national risk management information system. The responsibility for initiating such a system falls on the federal government, for no local community or state has authority or resources with which to compel widespread participation. At the core of the system is classification--or several means of classification--of risks of several types. The system is hierarchical so that, as above, each hazard is a subcategory of a more general hazard but is, in turn, composed of several subsidiary kinds of hazards. Every locality participating in the system would be asked to develop information concerning the risks attached to every category of hazard. Complete risk profiles would be prepared for selected large metropolitan areas. Again, locality characteristics would be coded along with hazards and their attendant risks. As new risk data develops, it would replace existing data. The system would allow comparisons of risk, comparisons across localities, comparisons of cost-effectiveness of policy interventions, and comparisons of organizational responsibility for different classes of hazards. The local risk manager would be the official principally responsible for, on the one hand, maintaining an up-to-date risk profile for his community, and, on the other hand, comparing his locality's risk profile with risk profiles for other localities similarly situated. The results of such analyses would be recommendations for action which cannot now be made for lack of data.

The details of a national risk management information system cannot be developed in the abstract. They would, instead, necessarily be the result of even more thinking about classification and categorization of risk than is included in this paper as well as experimentation in the implementation of such a system. But a national basis for risk management information overcomes several of the major weaknesses of local government in dealing with hazards at the present time. It demands systematic thinking about risk, which is now weak or altogether absent. It generates risk information of much greater reliability than that now available to local officials. And it allows comparisons of risk, which permit local discretion to be governed by scientific evidence rather than only the vagaries of the political process. Indeed, it might be argued that by providing local governments with the wherewithal to make risk management decisions, rather than leaving these decisions to the federal government, the political process in states, counties and cities would be reinvigorated.

Combining two or more taxonomies offers a finer view of riskiness. For example, combining situations in which risk is encountered (Table 5.1) with cause of risk (Table 5.2) reveals some interesting insight when dealing with a situation which is an unavoidable source of risk. The code number for this hybrid classification can be formed by combining the two code numbers of situation and source. So that 1.4 (2.10) represents risks from explosion (at work) and 1.3 (2.13) means risk from electricity (at home).

While we treat, in depth, the subject of how the risk manager should "manage" risk in a companion document, we merely mention the overall management process in the present document. We introduce the management process in this document for a special reason; to put into perspective how the risk manager might utilize information about risk taxonomies and risk profiles in the process of managing risks.

To what extent should (or could) these taxonomy profiles be expanded? On the one hand, and by our initial admission, no taxonomy or set of taxonomies could ever be so complete so as to comprehend all risks, and ever be so fine tuned so as to eliminate double counting. So the near infinite extension of the taxonomies is not likely to have a high payoff. On the other hand, a systematically developed taxonomy profile might have a high payoff if it causes the risk manager to better structure his decision making. We might base a more systematic approach on a risk manager survey--asking how risks are presently managed, what sort of information is presently lacking, and how might this information be best presented.

How might the risk manager utilize the information provided in these tables? That would of course depend on the particular risk manager. Remember, by our definition, the risk manager is a rather vague person of many functions and responsibilities. At minimum, however, we would hope that the taxonomy and profile would provide an ingredient to structuring a more quantitative--perhaps even more rational--approach to managing risk.

Chapter 6. THE OFFICE OF RISK ASSESSOR

6.1 Introduction

Questions related to societal risk management have been studied extensively in the last fifteen years, especially as they relate to risks from nuclear power (Starr 1969, USNRC 1980). It is widely recognized that most decisions that society makes are the result of ad hoc methods, and that they are not necessarily the best decisions possible. It is not difficult to realize that the existing ambiguity and conflicts are manifestations of the disagreements that exist concerning the definition of a "best" decision.

Unfortunately, there is no mathematical theory that defines a "best" course of action for groups of decision makers, which is, of course, the situation in societal risk management problems. Decision theory is a tool for a single decision maker and, therefore, inapplicable to these problems. However, it is the only logical framework that does define a "best" decision and, as such, can be a valuable guide to group decision making.

The fundamental requirement of decision theory is the compliance of the decision maker with certain axioms that constitute coherent decision making (Lindley 1971). The decision maker must input into the process his knowledge about the "world" through probabilities, and his preferences through utilities. The choice of the action with the highest expected utility is, then, the well-known criterion for coherent behavior. In a community, this last step is carried out by the elected representatives of the people, e.g., the mayor and the city council, in a far less formal manner.

While the elected representatives reflect the preferences of their constituents, the first part of the decision problem, i.e., the structuring of the alternatives and the probabilities of uncertain outcomes, is largely of a technical nature and could be analyzed by a technocratic agency. It is this viewpoint that defines the charter of the Office of Risk Assessor (ORA) in this paper.

The arguments given are intended to show the decision makers the need for and the usefulness of the ORA, and to help the technocrats who will establish and run the Office define their roles and goals. The emphasis is on the quantification and presentation of risk, which is viewed as a technical problem. Social, political and economic preferences are excluded from the ORA's charter. Fundamental questions, like the use of regulations versus economic incentives, are not considered part of the ORA's responsibilities, but those of the decision makers. In any case, no matter what philosophical basis for their actions the latter choose to adopt, the ORA's role, as described here, will be equally important.

It would not be a very easy task to define the parts of a decision problem that are technical in nature and, therefore, analyzable by a group of technocrats. What are described in this paper are some inputs to the decision making process that would be deemed desirable by most "reasonable" people. For example, it is rare that a best decision can be reached by risk considerations only; therefore, the ORA, despite its name, will be required not to ignore the benefits associated with each course of action. Furthermore, the ORA will frequently have to analyze rare events, in which case precision of language and the careful display of uncertainties are very important.

Section 6.2 deals with the issue of hazard and scenario identification. The use of a logic diagram for the systematic identification of hazards is recommended and a procedure for the development of the scenarios emanating from the same hazard is discussed.

Section 6.3 discusses the issues that would be expected to be debated during the risk quantification process. The subjective nature of such quantifications (see also Section 6.1.6 on risk perception) is pointed out, and means for handling it are presented. The framework in which all of the ORA's recommendations ought to be made is described in this section. This framework essentially consists of families of risk curves and the dominant contributors to risk. The distinction between generic (community-to-community variability) and community-specific assessments is also made in this section. These curves are considered to be the most complete representation of risk. In principle, each of the taxonomies of Section 5.4 ought to be using this formulation. It is recognized, however, that it will be some time before the information and analysis required for the derivation of the risk curves become available. The taxonomies, therefore, have to rely on point values, at least for the near future.

Finally, Section 6.4 addresses some of the practical problems that the ORA would face. First, it is suggested that the Office be state-controlled with strong regional branches. This suggestion is compatible with the idea of a "network" of risk managers developed in Section 7.1.3. A second problem that is discussed is the process of deciding that a risk is significant and ought to be brought to the attention of the decision makers.

6.2. Hazards and Scenario Identification

6.2.1. Hazards

An important function of the ORA would be to identify the hazards that exist in the community and the ways (scenarios) by which they could harm people. While this function would not require the assessment of risks (probabilities and frequencies), it would still be necessary to exercise judgment as to which hazards ought to be included.

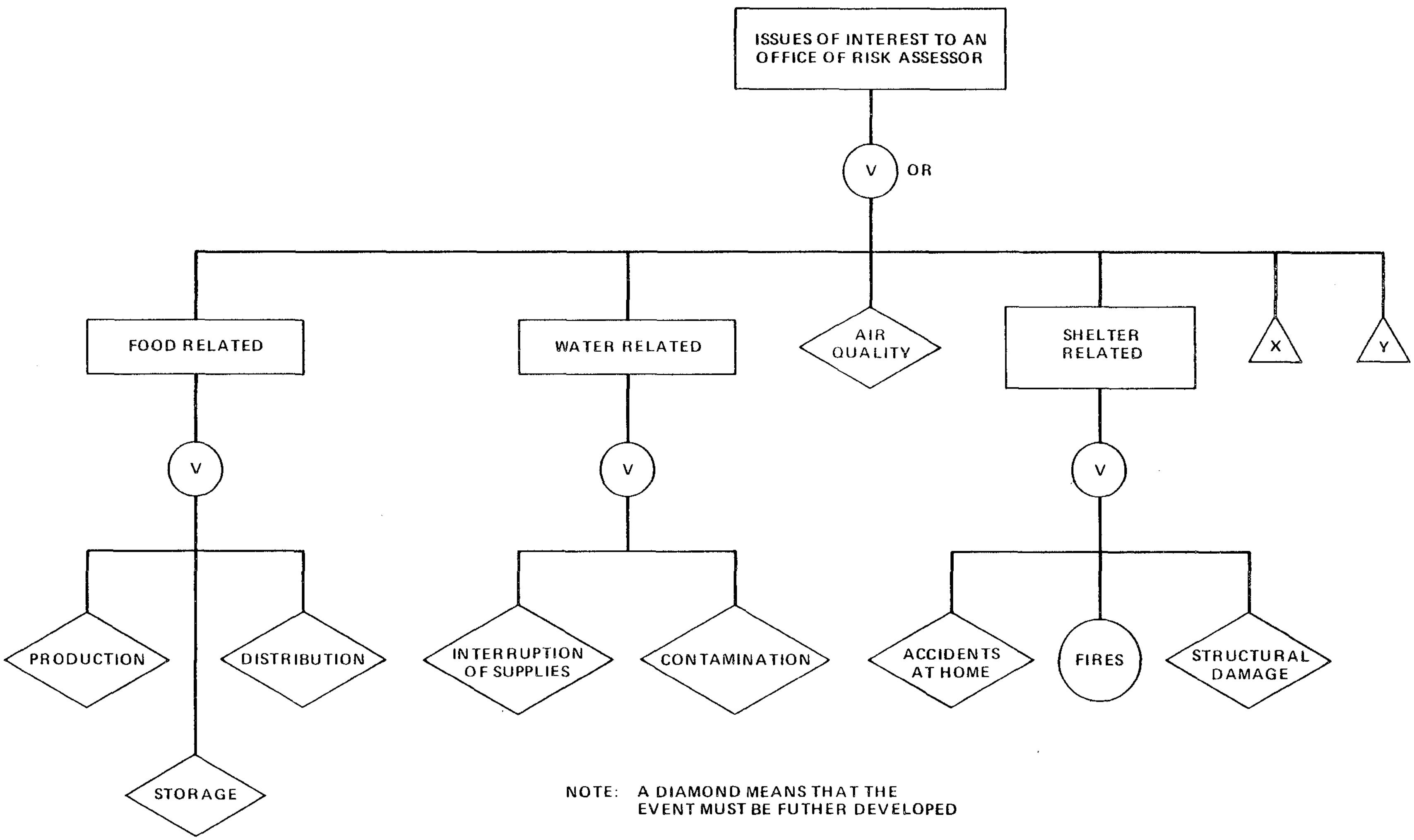
Ideally, it would be desirable for the ORA to have a complete, to the extent that is practical, picture of the risks to the residents of the community. This picture would include risks from wars, illegal drugs, firearms as well as the technological risks that come to the minds of most people when they talk about risk. It is acknowledged, however, that it would be extremely difficult, at least initially, to achieve such a goal. It would seem to be an unnecessary waste of resources to demand that the ORA assess the effects of war on the community.

We, therefore, propose that the ORA direct its resources to the identification of hazards that stem from technological endeavors or from natural phenomena. To be more specific as to which hazards ought to concern the ORA and to make their identification more systematic, we propose the use of the logic diagram of Figure 6.1. Diagrams of this type have been found very effective in risk analysis of nuclear power plants (Kaplan et al., 1981).

The first two levels of the diagram (including the diamonds) define the kinds of risks that the ORA should analyze further. Note that while this diagram resembles a fault tree, it is not. The actual scenarios that lead from a hazard to actual damage would be developed elsewhere. It should also be pointed out that the various entries to the top OR gate of the diagram would not be mutually exclusive. For example, "water contamination", "air pollution" and "concentrated large amounts of energy" would all have as a common initiator "chemical industrial facilities".

In order to maintain the simplicity of the diagram, its basic inputs should not be too detailed. For example, it would suffice to list "chemical wastes" under "water contamination".

Another function of the diagram would be to display the various federal, state and city agencies that regulate some of the hazards. It is anticipated that lines of communication would be established between the ORA and these agencies, i.e., the fire department, the EPA, etc. The ORA would be both receiving and supplying information, and the diagram would facilitate this interaction. Initially, such a diagram would help define the jurisdiction of the ORA itself.



NOTE: A DIAMOND MEANS THAT THE EVENT MUST BE FUTHER DEVELOPED

Figure 6.1. Logic Diagram for Hazard Identification.

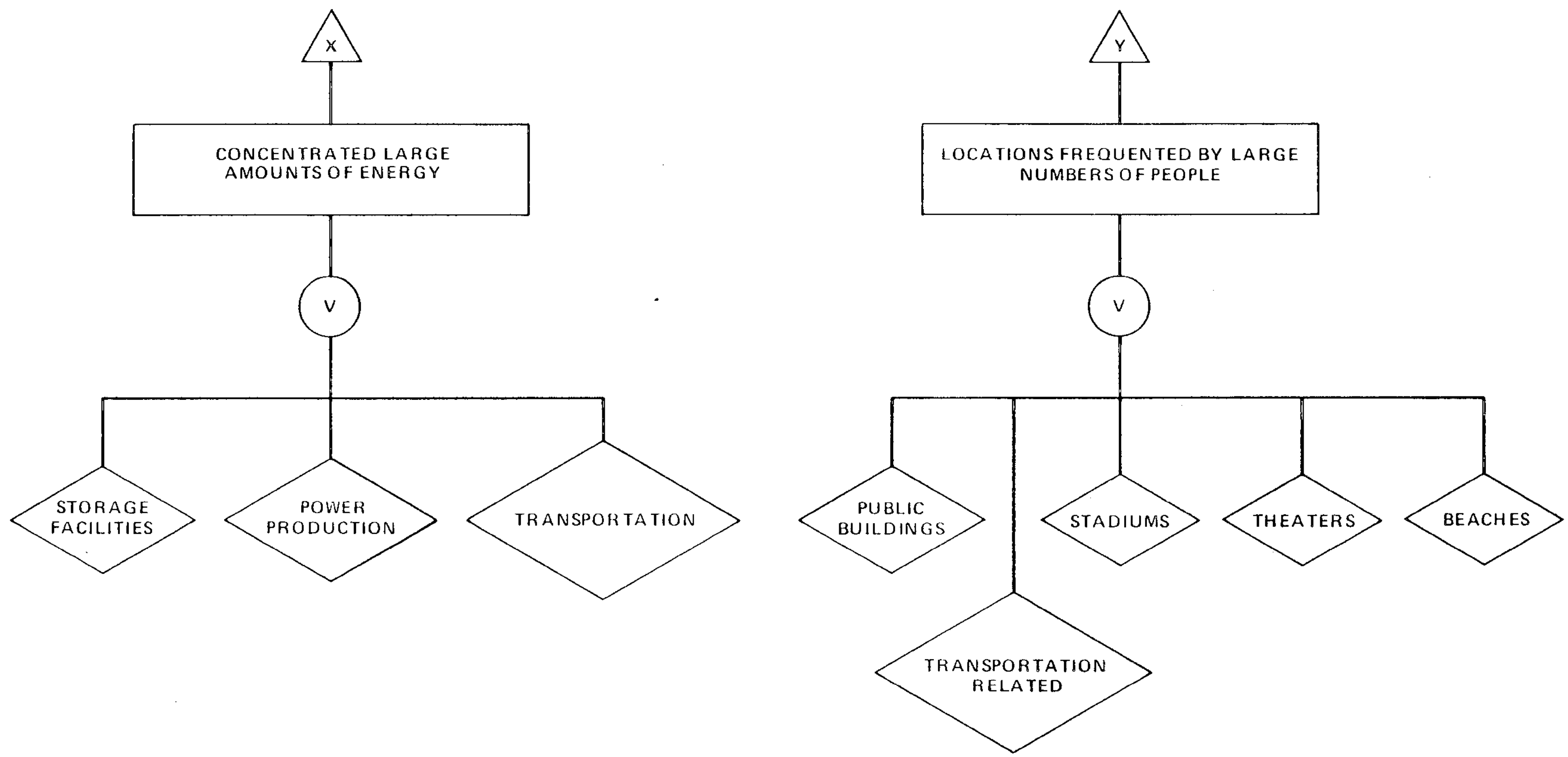


Figure 6.1. Logic Diagram for Hazard Identification (continued).

6.2.2. Scenarios

For each basic input of the logic diagram, the ORA would ask the questions:

(i) How can it occur?

(ii) If it does occur, what are the consequences?

These types of questions could, in general, be answered using fault/event trees.

This is where the specific topology of the community and, therefore, where the ORA would play a major role. To make the discussion concrete, let us consider the case of dams, which would probably be identified as a hazard under "concentrated large amounts of energy". A logical course of action for the ORA would be as follows:

(1) Identify the dams that could affect people or property within its jurisdiction.

(2) Develop fault-tree type diagrams to identify causes of dam failures. This would be done for the specific dams identified in (1) and it would include both internal and external failure causes.

(3) Develop event-tree type diagrams (USNRC 1975) to identify scenarios leading to undesirable consequences.

This general approach would force the ORA to enter into the assessment of risks from hazards that, perhaps naively, had been previously thought of as being sufficiently regulated by state or federal authorities. For example, for a particular dam to exist, some state agency must have declared it "safe". Besides the fact that such a notion is rarely quantified by these agencies, it is almost certain that the full impact on the community of this failure had not been considered, e.g., interruption of water supplies, of power, etc.

6.3. Risk Determination

6.3.1. The Subjective Nature of the Analysis

Having identified the scenarios, the ORA would be ready to estimate their frequencies. Even though this part of the analysis has nothing to do with preferences, it is highly subjective and subject to controversy. It is, therefore, essential that the ORA have a clear understanding as to what is meant by the numbers it produces.

In assessing the frequencies, the ORA would generally rely on the following sources of information:

(i) Statistical evidence from the community

(ii) Statistical evidence from other communities

(iii) Expert judgment

The "best" kind is, of course, the first one. However, due to a variety of reasons (the rarity of catastrophies, the lack of data gathering systems, etc.), the ORA will have to rely heavily on the other two sources of information, and especially on expert judgment.

An important fact that usually escapes technocrats is that it takes two (very different) kinds of expertise for a quantitative judgment to be meaningful and useful. First, the expert must, of course, be knowledgeable in the particular area of interest. Second, the expert must be trained to translate his knowledge and beliefs into numbers. It is the latter requirement that is usually absent. The problem becomes especially acute when low frequencies are assessed, in which case one may end up with numbers which are bound to lead to irrational decisions.

Some of the reasons for biases in expert opinions have been discussed by Tversky and Kahneman (1974). Peterson and Beach (1967), in their review of an experimental research project on human statistical inference, consider experiments that have investigated estimates of proportions, means, variances and correlations. It is concluded that an individual can make better statistical judgments using a set of procedures (normative inference as opposed to intuitive inference). The results also show that intuitive inferences are more conservative than the normative ones. Other findings also indicate that human beings are, in general, conservative processors of information (Edwards and Phillips 1964).

While there is no doubt that formal methods improve the estimates (we have also recommended the use of fault and event trees, where appropriate), there are still many important judgments where formal methods do not help. For example, the frequencies of errors of commission or omission by humans under stress are essentially the results of "intuitive" judgment.

The statistical evidence from other communities (or the evidence from laboratory experiments) is also subject to different interpretations. An example of a heated debate over the use of statistical evidence (actually over the assumptions behind the analysis) is that between the U.S. Nuclear Regulatory Commission (1978) and the Electric Power Research Institute (1976) in connection with the "scram" experience with Boiling Water Reactors. The two respective studies disagree about almost everything; the methods of analysis, the relevant numbers of failures, tests per year and years of experience. This is the kind of debate in which the ORA should expect to find itself, because it involves an industry (the electric power utilities, represented by EPRI), and a regulatory agency (NRC), and because some of the options considered by the NRC would be very expensive to implement.

It is situations like these that the ORA should be prepared to handle. While it would be unrealistic to expect that the ORA could adopt methodologies which would resolve such issues (because they do not exist), it would be reasonable to expect that, by placing more emphasis on uncertainty and its formal handling, some of the emotional content of the debate could be prevented. It is evident, therefore, that an approach to uncertainty which recognizes the highly subjective nature of risk analysis is required.

6.3.2. Coherence

There are quite a few misconceptions, even among technical people, concerning uncertainty. Very often, the mathematical elegance obscures the shaky assumptions upon which a theory is built. Given that the ORA's ultimate function would be to provide useful input to the decision makers, and that there is a lot of judgment involved, and conflicting views concerning many risks, the question is, how would the ORA meet its goal?

The ORA would make a good start by viewing itself as a coherent assessor of risks. Coherence has a definite technical meaning in the subjectivistic theory of probability (Lindley 1971, deFinetti 1974, Apostolakis 1981), where it means compliance with the rules of the calculus of probabilities. Probability is nothing more than a numerical measure of a state of knowledge concerning the likelihood (a notion that remains undefined) of an event. It is, in other words, a measure of degree of belief.

Although coherence, as defined above, is a very desirable property, one expects much more than that from a public agency like the ORA. In other words, given that probabilities are measures of degrees of belief, and that judgment is an integral part of any assessment, internal consistency alone is not sufficient. Tversky and Kahneman (1974) point out the necessity of the representation of the assessor's true beliefs in his probabilities, and they state: "For judged probabilities to be considered adequate, or rational, internal consistency is not enough. The judgments must be compatible with the entire web of beliefs held by the individual."

The requirement of producing probablities that reflect "true beliefs" raises the issue of whose true beliefs should be considered. This problem is, of course, the same one that arises when the usefulness of decision theory to groups of decision makers is debated. This is not surprising, because the intimate connection of decision theory and probability theory has been known for some time (Kaplan and Garrick 1981).

While the ORA cannot expect everyone to find its assessments satisfactory, it must always bear in mind that its duty is to provide useful input to the decision makers. This input must realistically reflect the state of the art and the judgments of knowledgeable people. The ultimate assessment of the validity of these judgments will, of course, be made by the ORA itself. The process of gathering these judgments will have to be formalized, and testimony from experts sought. To assure the most complete input possible, the decision making body may even consider the establishment of a permanent advisory committee which would independently provide inputs in addition to those of the ORA.

An additional way to serve the decision makers is to be very explicit about the assumptions that are behind the various probabilistic models. The presentation of risk results should also be explicit, as we discuss in the next section. We can summarize this section by stating that coherence, expanded to include the requirement of "true beliefs", is the only requirement that we impose on the ORA. We recognize that the probabilities resulting from these combined efforts will be expressions of the ORA's state of knowledge and that, in this sense, they are subjective (or personal). However, a coherent analysis deserves to be called objective. In fact, coherence and objectivity are one and the same thing when dealing with uncertainty.

6.3.3. Probabilities vs. Frequencies

A confusing aspect of risk assessments is in making the distribution between probability and frequency (Kaplan and Garrick 1981). It is important to clearly distinguish between these two concepts. Frequencies are the results of real or hypothetical experiments and can be measured, while probabilities are quantitative measures of state of knowledge and cannot be measured by experiments. Since frequencies are measurable quantities, we can talk about the probability that the frequency falls in a certain interval, while the "probability of a probability" is meaningless.

Very frequently the results of a risk analysis are presented in the form of curves that give the frequency of a level of damage x or greater. For example, Fig. 6.2 is taken from the Reactor Safety Study (USNRC 1975) and it displays the frequency of fatalities due to various man-made events.

A major criticism of this presentation of results is that it does not depict the uncertainties associated with these curves. The use of frequencies does, of course, imply uncertainty; however, the uncertainty that is not shown is the state-of-knowledge uncertainty, i.e., how well these frequencies are known.

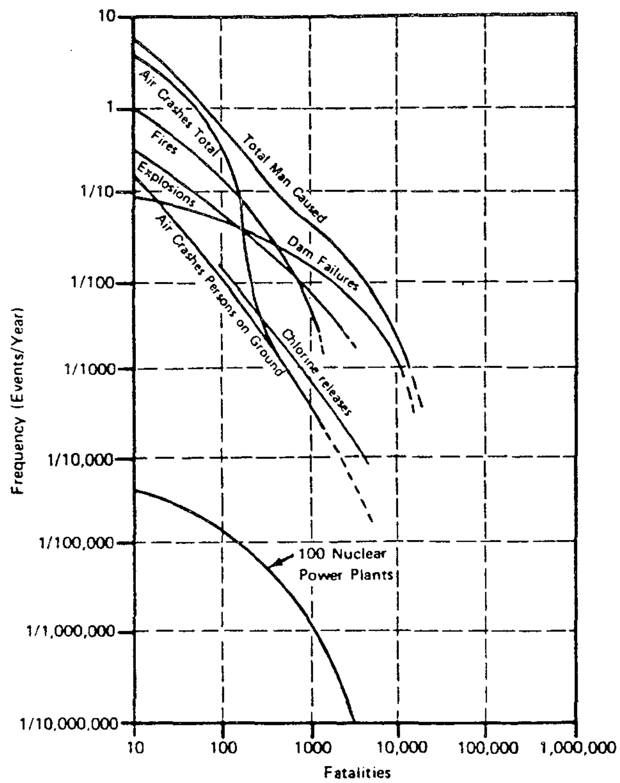


FIGURE 1-1 Frequency of Fatalities due to Man-Caused Events

Notes:
1. Fatalities due to auto accidents are not shown because data are not available. Auto accidents cause about 50,000 fatalities per year.
2. Approximate uncertainties for nuclear events are estimated to be represented by factors of 1/4 and 4 on consequence magnitudes and by factors of 1/5 and 5 on probabilities.
3. For natural and man caused occurrences the uncertainty in probability of largest recorded consequence magnitude is estimated to be represented by factors of 1/20 and 5. Smaller magnitudes have less uncertainty.

Source: WASH-1400 Reactor Safety Studies

FIGURE 6.2. Reactor Safety Study Risk Comparisons

The footnotes of the figure assign uncertainties both to frequencies and consequences. This, indeed, is an attempt to quantify state-of-knowledge uncertainty. However, it is difficult to understand how these results can be used for decision making, when the uncertainty is given on both frequency and consequences. One would expect uncertainty only on the frequency and not on the independent variable (consequences).

In the proposed context such difficulties would not arise. Rather than showing one curve for each cause of death, the ORA would display a family of curves (for each cause) (Kaplan and Garrick 1981), like the one shown in Fig. 6.3. The frequency λ^* of damage x^* or greater is the uncertain quantity (and the only one). After a very long series of observations its numerical value will be known almost exactly. Today, however, we do not know what that value is, but our analysis tells us how likely the various values are. Thus, our state of knowledge is expressed as a probability curve over this frequency. The median λ^*_{50} of that curve is the value that, according to our state of knowledge, has a fifty-fifty chance of being greater or smaller than the true value.

The above presentation applies to societal risks. An important result of the ORA's analysis would also have to be the individual risk, e.g., the frequency of death of an individual. This frequency is usually given as a function of various parameters, like the distance from the source of hazard, the time of exposure, etc. Very often, an estimate of the frequency of death of the "most exposed" individual is presented in order to convey a measure of the severity of the individual risk.

The frequency of damage to the individual is also an uncertain quantity, like λ^* of Fig. 6.3, and the same comments apply, i.e., the ORA's state of knowledge will be expressed by a probability distribution as shown in Fig. 6.4.

6.3.4. Evidence

The beliefs and judgments of the ORA will be formed by the three types of evidence that were discussed in Section 6.3.1. The statistical evidence from the community is, of course, what should be the dominant opinion-sharing factor. The other two types of evidence, i.e., statistics from other communities and expert judgment, will be major inputs, when the community-specific evidence is weak. The problem that is addressed here is how to combine the three types of evidence in a coherent way (Apostolakis et al., 1980). The fundamental tool that enables us to do this is Bayes' theorem, which we write as

$$\pi'(\lambda/E) = \frac{\pi(\lambda)L(E/\lambda)}{\int_0^\infty \pi(\lambda)L/(E/\lambda)d\lambda} \qquad (1)$$

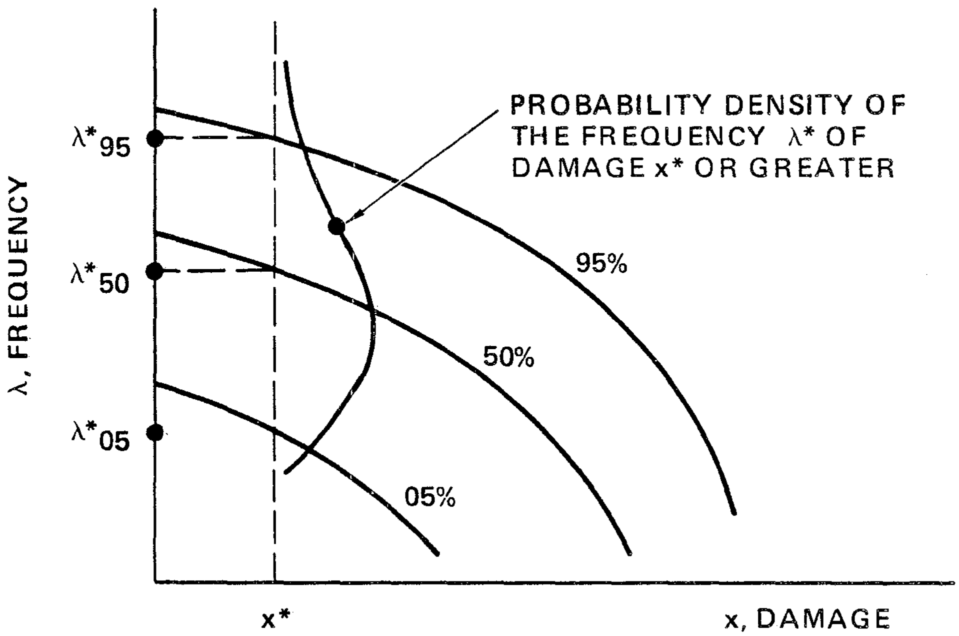


Figure 6.3. Risk Curves for Societal Damage.

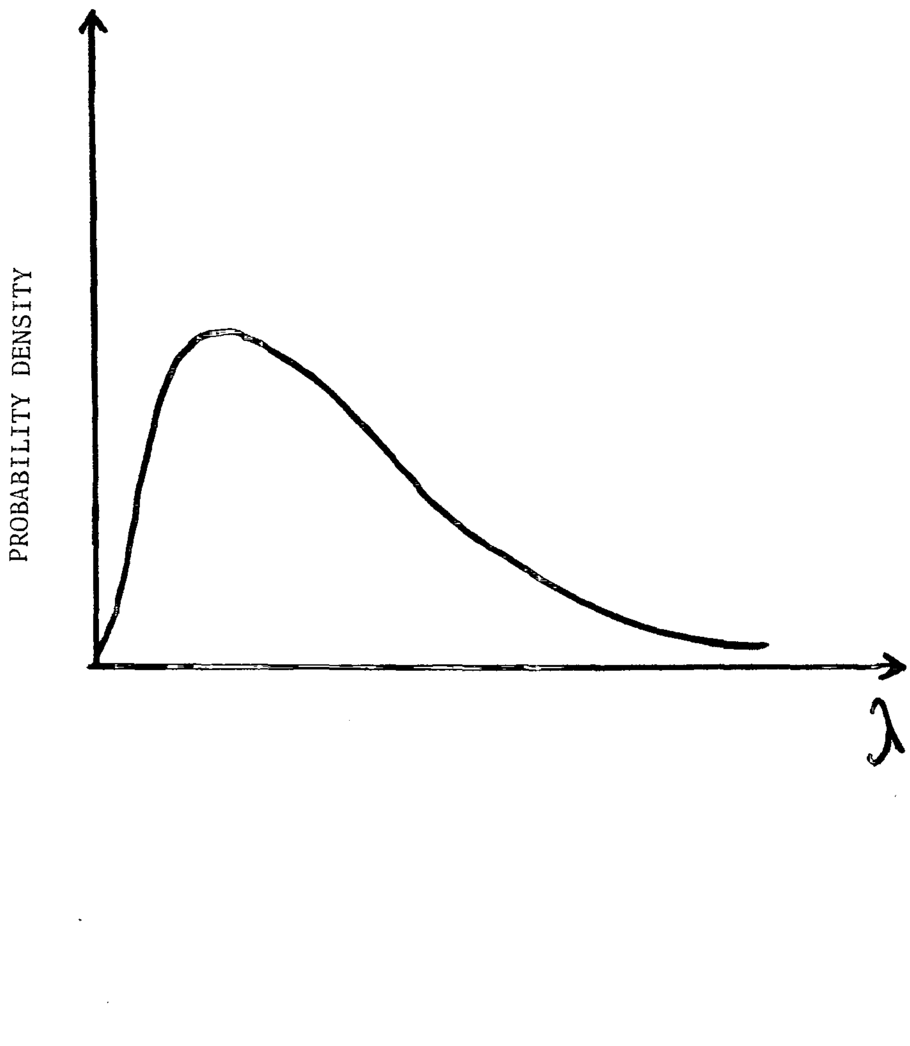


FIGURE 6.4. Probability density junction of the frequency of individual damage.

where

$\pi'(\lambda/E)$ = probability density function λ given evidence E (posterior or community specific distribution)

$\pi(\lambda)$ = the probability density prior to having evidence E (generic distribution)

$L(E/\lambda)$ = the likelihood function (probability of the evidence E given λ)

The generic distribution $\pi(\lambda)$ is expected to be very broad in a substantial number of cases. Sources of uncertainty include the applicability of evidence from other communities to the one in question, the judgment involved in using epidemiologic or laboratory studies, etc.

When the community specific evidence is statistical, the evaluation of the likelihood function is straightforward. For example, when the evidence is of the form "r events over a total time T", the likelihood is the Poisson distribution, i.e.,

$$L(E/\lambda) = \exp(-\lambda T)\frac{(\lambda T)^r}{r!}$$

under the assumption that the rate λ is constant.

6.4 Theory and Practice

The framework for the assessment of risks that we described in the preceding sections is normative. While it may satisfy one's need for rationality, it should be acknowledged that the actual implementation of what the theory demands is not easy. The approach that we take and discuss here is that the theoretical principles are a goal worth striving for. With this in mind we offer the following discussion on some issues expected to arise.

6.4.1. The Decision Makers

The issue of who should decide is of fundamental importance in shaping the Office of Risk Assessor. We have already discussed the inability of decision theory to lead groups of decision makers to reach "good" decisions. However, the structuring of a decision problem which decision theory requires is a valuable guide. Preferences among alternatives are an essential part of the problem, and society has chosen to resolve these issues through its elected representatives. Therefore, it seems reasonable to assume that the ORA will be advising an elected official body, e.g., the Governor's Office, the City Council, etc., or an appointed committee, e.g., a Risk Commission.

The comprehensive picture of the risks that we have required of the ORA (Fig. 6.1) creates problems related to jurisdictions, resources, etc. A strictly local ORA would have to significantly depart from the goals of Fig. 6.1. A strictly federal ORA would also be inappropriate, because it would have to rely on generic considerations, thus ignoring community-specific features that may be of significant importance, (an example of this in practice is the current busing controversy in Los Angeles, where distances are much greater than in other cities).

It appears, then, that the management of risk must start at the state level. The interactions and resources that Fig. 6.1 require can be much better met by the state without becoming too general. Strong regional offices should interact both with the central office and also with the local officials (e.g., mayors). The situation, therefore, calls for an organizational structure that is supported by the state and which interacts strongly with local authorities, while both receiving and supplying information.

This conclusion is also supported by the results of surveys of state and local officials concerning attitudes toward natural disasters. Wright and Rossi (1978) state that:

> "From the Federal perspective, for example, the flood problem may be serious enough to warrant large-scale, highly intrusive, even rather expensive risk-mitigation measures; at the level of local communities, these measures may appear to be capricious, inequitable, possibly even counterproductive. In some sense, then, conflict among various levels of government

over how to manage environmental hazards may well be inherent in the nature of the problem itself.

A key, if obvious, implication of this point is confirmed by data from the survey on the victimization of individuals, communities, and states by the four major natural hazards. As would be expected, states are more prone to victimization by any of these disasters than are local communities, if only because they present larger targets in the first place; further, the estimated return probabilities for another serious disaster in the next ten years are everywhere higher among state than among local respondents. Thus, states regard their hazards problems more seriously than local communities, are more likely to have been hit by a serious disaster in the recent past than are local communities, get hit by serious disasters more often given that they are hit at least once, and have higher expectations for a repeat disaster than do local communities. These results thus make it plain that hazards management is a far more pressing issue at the level of state governments than among local governments; by implication, it is more pressing at the Federal level than at the level of any particular state. One possible implication of this pattern, which tends to be confirmed in the historical record, is that policy innovations and directives will originate at higher government levels, typically the Federal level, and then be imposed upon lower levels. This pattern, we believe, does not auger well for the future of risk management policies that depend critically on the cooperation and active support of lower level governments, such as the nonstructural mitigation measures."

The following observation is also from Wright and Rossi:

"...local government seems often incapable of effectively administering virtually any human service, and there is no a priori reason why hazard risk management would be an exception."

6.4.2. Inputs to the Decision Making Process

There are several kinds of inputs to the decision process that the ORA would be expected to make. These inputs, of course, depend on the issues before the decision makers, and on the ORA's judgment of the appropriateness of bringing an issue to their attention.

The most straightforward case is when a specific issue, e.g., upgrading the seismically substandard buildings in Los Angeles, (Chapter 4) is before the decision makers. At minimum, the ORA should provide the risk curves (with uncertainties) for societal and individual risks and the dominant contributors to risk. A convenient criterion for identifying the latter is the mean frequency.

The existing dominant scenarios are now the basis for evaluating the impacts on the risk of the options that are open to the decision makers. For example, one option may be to reduce exposure to hazardous agents by a number of means (exclusion areas, "safer" industrial facilities, etc.); another option may be to provide means for mitigating the effects of accidents, and so forth. The new scenarios that these interventions would create must be probabilistically evaluated like any other scenario. In addition to the impact on the risk curves, dollar costs and other relevant attributes should be given.

The situation becomes more difficult when the ORA must take the initiative and raise an issue before the decision makers. While the decision makers would not rely solely on the ORA to raise issues that would warrant their attention, the latter would still have considerable responsibility, especially in areas where information would not be widely available so that other interested parties would intervene.

The criterion that the ORA ought to use to identify potential problem areas cannot be given by mathematical theories. Several general guidelines could be suggested, however, as a means of aiding the ORA.

A moment's reflection reveals that it would be inappropriate to base this decision only on risk considerations. Fig. 6.2 illustrates this point. Even though it does not include uncertainty (and, therefore, is incomplete), it is probably correct to claim that, as far as fatalities are concerned, nuclear power plants are safer than dams. Nevertheless, it is nuclear power that is currently under scrutiny and not dams.

A potentially useful means for identifying action items would be to compare risks that are, in some sense, "similar". Fig. 6.2 is, in part such an attempt, since it displays risk curves for fatalities due to man-caused events only. Of course, the ORA would also display the uncertainties, i.e., each curve in Fig. 6.2 would be replaced by a family of three curves, like those shown in Fig. 6.3. A "new" risk would then be evaluated against a series of such diagrams and questions like "how does it compare with all other risks?", and "how does it compare with risks from similar activities, e.g., power production?", would be addressed.

An obvious shortcoming of this approach is that it would take years for these diagrams to be developed. This is where various taxonomies could be useful. They could summarize each diagram by ranking the risks according to some point estimate, preferably the mean value. Of course, one might argue that, to get the mean value, one would have to quantify the uncertainties. At this point, however, the ORA would probably be willing to accept "point estimates", a usually ill-defined notion, and rank the risks according to them. For an initial evaluation of risks and their importance, such an approach would not be unacceptable. It would be one of the ORA's goals, however, to produce the risk curves as soon as possible.

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Chapter 7. POLICY ALTERNATIVES

7.1. Summary

In this chapter we define and, to a limited extent, evaluate five policy alternatives for managing risk at the city and county level. We assess the "Present System"--dominated by the federal government--and compare its advantages and disadvantages with a "Weak Risk Manager" characterized by strengthening local capabilities over the present system; a "Network Management Scheme" described as interconnected modes of various risk managers in a variety of locales via computer; a "Strong Risk Manager" where this risk manager is involved in both risk identification and management; and a "Decentralized Risk Manager" characterized by management on a situation basis.

While no one management scheme is clearly superior to all others, our cautious recommendations suggest that the network scheme has potential promise.

7.2. Introduction

Just as the subject of local risk management is diffuse and complex, so are judgments to overall risk management processes and their implementation. Not only are values involved--some people in some localities prefer certain kinds of risk and levels of risk than others--but there are also technical questions; for example, costs due to externalities in information versus costs incurred by highly centralized administration. For this reason, the alternatives developed here are in all likelihood incomplete and in some respects impractical. One should never underestimate the importance of trial and error in shaping any existing system.

The following constraints have guided the formulation of alternative risk management systems that are intended to deal with risk as such rather than with specific hazards facing localities:

(1) Risk judgments are comparative. Most risks are not susceptible to simple means of mitigation that have not already been found, and for this reason further risk reduction involves the trade of risks for dollars or of one risk for another. These tradeoffs in the past have been somewhat more implicit than explicit, but explicit comparison, often in the form of cost-benefit analysis, is likely to be required in the future. Comparison entails quantification. At some point in an overall system of risk management, although not necessarily at the local level, explicit quantification of risks and of costs of mitigation must take place. A critical issue, then, is at what level or levels of the intergovernmental system in the U.S. the technical capacity to make quantitative risk judgments should be located, and how much capacity should exist for interpreting these data at each level. At present, this capacity lies almost entirely at the federal level and only slightly in city, county, or regional authorities.

(2) Risk judgments may vary across localities. There are two sources of likely variation in risk judgments across localities, one physical and one political. Localities vary greatly in geography, climate, and industrial mix such that the presence of a particular hazard or a particular level of a hazard may be acceptable in one locality but unacceptable in another. Additionally, citizen preferences may vary substantially across localities such that an overall level of risk that is acceptable in one is not acceptable in another, or, alternatively, costs of hazard mitigation that are acceptable in one are not acceptable in the other. Uniform federal regulations governing risk, then, can incur substantial suboptimalities.

(3) Risk judgments need legitimacy. Because risk analysis deals with probabilities rather than certainties, any judgment is subject to challenge on scientific grounds. Such challenges can undermine the entire risk analysis enterprise unless there is consensus that the best available evidence and expertise have been used in formulating standards. Needless to say, such consensus is difficult to achieve when localities are making independent assessments of risks associated with the same hazards.

(4) Risk judgments may need revision in light of information concerning new hazards and new information concerning the riskiness of known hazards. The probabilistic character of risk judgments also renders the data on which they are based subject to continual revision. These revisions have two sources, the detection of previously unknown hazardous substances or of substances previously thought benign and now considered hazardous, and new experimental or epidemiological evidence modifying existing risk estimates. Risk judgments, then, must be based on the cumulated experience of both researchers and localities and must therefore be open to modification.

(5) The burden of making risk judgments should be distributed equitably. Information concerning risks to life and health is not only probabilistic but it is also costly. This leaves little incentive for a single locality to invest substantial sums in replicating analyses done elsewhere, and there is substantial incentive to appropriate, without compensation, analyses constructed elsewhere. Some means of equitably distributing costs of risk analysis, particularly the identification of previously unknown hazards and the quantification of risks associated with them, is needed to insure that it is undertaken at all. In the past, the principal means of insuring equity in the distribution of costs has been reliance upon the federal government.

The constraints of comparability of risk judgments, variability across localities, legitimacy, openness to revision in face of new information, and equitable distribution of costs are inconsistent with one another in some respects. For example, comparability of risk judgments requires a level of scientific and technical expertise whose costs are not easily distributed equitably among units of local government; variability in risk judgments across localities and change in them over time contribute little to their legitimacy; and the values underlying comparability, which, again, demands scientific technical expertise, may be totally at odds with differences in subjective preferences that give risk to variations in risk judgments across localities. No single optimal pattern of risk management activities, then, will emerge out of these constraints. Indeed, a number of possible management models are suggested, the choice between them depending upon the relative importance attributed to the various constraints but, importantly, also upon the capacity of localities and the federal government to pursue innovative forms of administration.

7.3. Models of Risk Management

Five models of local risk management are proposed. One is the present system, largely dominated by the federal government, whose fit with the five constraints outlined above is outlined briefly. The second model buttresses the present system by strengthening local capacities to utilize competent professional judgment in managing diverse risks. This model is called the "weak" risk manager, or "weak" office of risk management. The third alternative ties risk managers, who occupy relatively weak offices at local, state, and federal levels, into a network that facilitates sharing of data on hazards, risks associated with them, and risk acceptance criteria as well as policy. The fourth alternative is the "strong" risk manager who is charged with the full spectrum of risk management activities, from risk identification to policy making and implementation. This "strong" risk manager, importantly, is a local rather than a federal official. The fifth model is one of radical decentralization of risk management, whereby prima facie evidence of riskiness above a low threshold compels the source of risk, whether an agency of local government, or owner of property or of means of transport, to obtain appropriate risk studies showing the safety of proposed activities before proceeding with them.

7.3.1. The existing system

The present system of local risk management combines a number of weaknesses but some strengths. The greatest strength is equity. Costs are distributed more or less evenly across localities, and substantially similar levels of hazard mitigation result, save for instances where states or localities apply standards more stringent than those of the federal government. Legitimacy is fairly high as standards are authoritative if accepted grudgingly. Quantification of risk is undertaken in the formulation of risk management criteria, but not in their implementation. There is no provision for trading hazards and their attendant risks against one another. Revision and updating of standards occur somewhat haphazardly, as there is no systematic means of cumulating the experiences of diverse localities. Not only is there little coordination between local and state agencies, but various federal offices charged with enforcement of environmental and safety laws often do not communicate with one another. Finally, little allowance is made for variation in risk management policies across localities, whether due to physical conditions or citizen preferences, as uniform standards are applied in most instances.

7.3.2. The "weak" risk manager

A modification of the existing system buttresses capabilities of local and state governments by introducing an office specifically charged with managing risks, but with limited powers. A distinctive feature of this office would be expertise: Its incumbent would understand the scientific basis, or lack of same, for regulations and professional standards governing local practices. The incumbent would seek, in selected instances, flexibility in the application of regulations and professional standards because of unique local circumstances. Additionally, under the "weak" risk management model, the reactive style of risk management would give way to a more anticipatory mode. Questions concerning the likelihood of flood, fire, tornado, and the like would be raised, and local responses would be keyed to probabilities rather than perceived certainties induced by panic. The "weak" risk manager would not be charged with identification of new hazards, quantification of risks, or formulation of risk acceptance criteria, as he would not have resources with which to accomplish these. He would hold, however, general authority over implementation of various policies directed at reducing risk. The role of the "weak" risk manager, then, is a means of augmenting professional competence among local officials whose basic job is to administer federal and to a lesser extent state regulations governing hazardous activities.

The model of the "weak" risk manager has many of the equity advantages of the present system. The legitimacy of risk judgments would probably be somewhat greater under this alternative than the extant system. Risk comparisons and quantifications might be slightly augmented by the "weak" model of the risk manager, but lacking the wherewithal for original investigation, these advantages would be slight. The "weak" risk manager might also provide slight advantages in the revision and updating of standards, but his effect would be minimal as no formal means is provided whereby his judgments can serve to inform the federal policy making apparatus. The "weak" risk manager might also be able to take slight cognizance of local preferences in his judgments, but, as before, his latitude is limited as he has at best an advisory role in the formation of policy.

The "weak" risk manager may be among the least costly and controversial of alternatives to the present system, for it requires only training or upgrading of present local employees or, possibly, creating a small number of additional positions in the largest jurisdictions. It is a matter of imparting competence, and not of constructing new bureaus with broad responsibilities.

7.3.3. The "network" of risk managers

Network approaches to administration are not widely understood because they are at odds with a conception of command hierarchy that permeates most thinking about organizations, especially governmental agencies. Structurally, networks consist of totally or almost totally interconnected nodes such that any person has access to any other. There is no hierarchy of intermediate offices. Operationally, coordination of action in networks is secondary to the capacity of individuals to draw information and expertise from other members of the system. Network approaches to administration become feasible only where reliable and cheap technologies for storing and transferring information are available. Such is the case with large commercial data banks that are accessible by telephone from anywhere in the U.S.

There are a number of alternative designs for a network approach to local risk management, but the basic elements in any network approach might be as follows: First, information about risks is stored centrally. Any risk management information system presupposes at least one and probably several schemes for ordering and classifying hazards that satisfy criteria of overall inclusivity as well as exclusivity of categories. (Several such schemes are suggested in the report by Solomon et al. on risk taxonomies.) Estimates of riskiness both for the general population as well as for high exposure groups are provided for each hazard, but these estimates are subject to change as experience is accumulated. Second, information about localities is also maintained. Not only are risk profiles prepared and continually updated for a number of representative localities, but so are geographic, demographic, climatological, and economic data describing them. Of particular importance is information describing the type and location of industrial, transportation, and waste disposal facilities. Third, information entering the system, which originates from a variety of sources including local community, state, and federal agencies, as well as universities and research laboratories, is filtered through a national (although not necessarily federal government) body responsible for maintaining the risk management system. Fourth, local representatives, perhaps called "risk managers", would be trained in utilization of the system so that they can determine for local policy makers (1) the riskiness of specific hazards, (2) the overall level of risk due to known technological and natural hazards affecting their citizens, and, (3) hazards likely to be present based on the experience of other cities, counties, and states but not yet detected locally.

The network approach to local risk management appears, on the surface, to offer the possibility of equitable distribution of costs. Presumably, although not necessarily, federal dollars would cover the cost of the risk management information system, while utilization of the system would be funded locally. Externalities in information costs are largely avoided. The legitimacy of risk judgments arising from this approach would, in all likelihood, be high since the estimates of risk associated with particular hazards would be based upon the best available evidence and expertise while, at the same time, risk acceptance and policy would be left to local determination. Quantification of risks at the local level, which allows for comparative risk assessment, is enhanced substantially compared to the existing system and the "weak" model of risk management discussed above. The network approach also provides explicitly for revision and updating of risk information, which is not possible under the previous models. Finally, the network model also accomodates variations in risk judgments across localities. It is to be anticipated, however, that divergences in risk acceptance standards across localities might not be dramatic since quantitative comparisons would force explicit policy judgments which, if substantially different from the norm, could prove to be political liabilities.

The feasibility of the network approach to risk management cannot be determined at the present. There is little experience in non-hierarchical forms of administration, especially in the public sector, at present, and, additionally, it is not clear how objective risk data can be organized so that they are maximally useful to local officials. Both of these considerations need further exploration and will be discussed in the concluding section of this report.

7.3.4. The "strong" risk manager

The "strong" risk manager is charged with a full range of responsibilities, from risk identification to risk acceptance and implementation of policy. His is a self-contained unit of local government that does not rely heavily upon the scientific capabilities or expertise of other governmental units, although it may make use of scientific and engineering expertise drawn from a variety of sources.

The consequences of the "strong" risk management model for the constraints outlined above are fairly obvious. To begin, substantial inequities are created. Localities either duplicate one another's risk management activities, incurring substantial costs, or behave opportunistically by relying upon analyses done by others, thereby creating substantial externalities in information in that a small number of localities bear the brunt of expenditures without compensation. The legitimacy of risk management judgments would also be problematic, as adjacent localities could, in principle, arrive at widely varying risk estimates for the same hazards. Quantification and comparative risk judgments would be undertaken under the "strong" risk management model, but the capacity of the local officials to draw effectively upon other localities' experiences and to revise and update risk estimates would be limited. Variations in risk acceptance and policy across localities would, of course, be substantial. The "strong" risk management model is inherently unstable because it offers little incentive for any single locality to invest adequately in risk identification, quantification of risk, and even risk acceptance.

7.3.5. Radically decentralized risk management

It is possible to imagine, if not implement, a scheme that moves the locus of much of the risk management process to units even smaller and less aggregated than local governments, namely to the sources of risk themselves. Under radically decentralized risk management, public officials, not necessarily at the local level, would determine activities that are presumptively risky--for example, certain types of construction, transportation, storage and disposal of hazardous materials, and the like. In order to be licensed for any presumptively risky activity, a formal risk analysis, i.e., quantitative estimation of risks, would have to be undertaken or commissioned by the person, company, or agency planning the activity and the results of the analysis would have to fit within an overall risk acceptance framework developed locally. Radical decentralization, then, removes the public sector from risk identification and quantification, save for projects that are initated by public bodies themselves.

The radically decentralized model has heuristic value, even if it is not realistic, because it compels sources of potential risk to bear the costs of determining actual risk, allows for comparative risk judgments based on quantification, and allows for variation in risk acceptance due to local preferences. However, radical decentralization, to even a greater extent than the "strong" model of risk management, either is extremely costly and inequitable due to duplication of effort and imposition of roughly the same costs on units of extremely different sizes and resources, or is fraught with externalities and "free-riders" such that, as before, risk analyses done for one individual or agency are appropriated by others without compensation. Neither is a satisfactory state of affairs; hence, radically decentralized risk management would, under most circumstances, be even less stable than the "strong" risk management model discussed above.

7.3.6. Comment

Constraints of comparability, which entails quantification, legitimacy, and equity tend toward centralization of an overall risk management system whereas constraints posted by incomplete knowledge of hazards and the risks they pose, which require continual revision of risk estimates, and by variations in local preferences concerning risk acceptance tend toward decentralization. A mixed system for managing the entire range of risks affecting local entities appears, therefore, to be suggested. Such a mixed system emphasizes cooperation among local, state, and federal authorities rather than, on the one hand, regulation and mandated compliance, and, on the other hand, inattention to significant differences in preferences for risk acceptance across local jurisdictions. A mixed system that emphasizes cooperation also minimizes needless duplication of effort and externalities in information costs that would characterize any decentralized system, and it maximizes the possibility for cumulation and sharing of risk management experiences of localities. The "network" model outlined above is closest to a mixed system. A summary of the five models, Table 7.1, follows.

7.4. Implementing the Network Model

The network model may function most effectively within the constraints bounding an overall system for local government risk

TABLE 7.1. A Summary of Five Policy Alternatives

POLICY ALTERNATIVE	CHARACTERISTICS	ADVANTAGES	DISADVANTAGES
Present System	•Dominated by federal government •Risks quantified only for management criteria--not for implementation	•Equitable; costs are distributed more or less evenly, across localities •Similar levels of hazard mitigation result within specified localities	•No procedure for "tracking" hazards •Revisions and updating of standards occur somewhat haphazardly •No systematic means of cumulating experience of diverse localities •Little agency coordination •Little allowance for variation in risk management policies across localities
Weak Risk Manager	•Strengthens local capacities over present systems •Utilizes professional judgment within a predefined office •Basic job to administer federal and, to a lesser extent, state regulations •Manager has more or less an advisory role	•Office would understand scientific basis •Flexibility in application of regulations because of unique circumstances •Might include anticipatory mode •Limited to quantitative justification •Would implement policy •Legitimacy of risk judgments •Relatively low cost to implement; would require minor modification of present structure	•Would not formulate risk criteria •Risk manager would lack formal means to notify other agencies

TABLE 7.1. A Summary of Five Policy Alternatives (cont'd.)

POLICY ALTERNATIVE	CHARACTERISTICS	ADVANTAGES	DISADVANTAGES
Network Management	•Implements a network that facilitates data sharing °Interconnected nodes of people--via computer •Individuals would add to and draw from information on data bank	•Requires inexpensive storage and retrieval of data systems which are now available •All information about risk is real time accessible •Would likely distribute costs equitably •Would reduce duplicative efforts and hence be cost efficient •Easy to update data bank •Members would add to data bank that which was in their limit	•Violates concept of "command hierarchy"--may be difficult to implement •May be more costly to implement •Most valuable when there is full participation--not likely to take place quickly •Would require an agreed-to taxonomy •Would require a mechanism for checking data integrity
Strong Risk Manager	•Involved in risk identification as well as risk management •A local official charged with full range of administrative and enforcement responsibilities •A self-contained unit of government	•Each locality would likely have a strong management team (if it could afford to)	•Inequities are inherent •Adjacent localities would duplicate service •A limitied number of localities might bear almost entire cost--others would ride free •Local experience might be too limited to cover all aspects of risk •Unstable

TABLE 7.1. A Summary of Five Policy Alternatives (cont'd.)

POLICY ALTERNATIVE	CHARACTERISTICS	ADVANTAGES	DISADVANTAGES
Decentralized Manager	•Manages risk on a situation basis	•Simple •Equitable--source of risk bears the cost	•Costly--likely to have extensive duplication of effort

management, but because the concept is novel and relies upon information technologies not heretofore utilized by city, county, and state governments, some developmental work will be needed before its implementation could begin. Three kinds of developmental work are indicated. One is a policy study that would identify changes in federal regulations and authorities needed for effective networking. The second is construction of alternative models of information systems that would be the core of the cooperative risk management network. A third study would be experimental, aimed at determining the likely utilization and effectiveness of a risk management information network.

7.4.1. Policy study

As has been shown above, almost all local government risk management policy is an extension of federal policy, save for traditional public safety functions. The federal strategy has, in the past, been one of management through regulation based on the best available evidence. A shift away from the regulatory mode and toward the dissemination of reliable information ought therefore to be explored as a possible means of beginning implementation of the network concept. The details of such a study cannot be outlined here. Suffice it to say that possible statutory as well as organizational changes aimed at shifting activities from rule making to the gathering and dissemination of reliable risk data need to be reviewed.

7.4.2. Information study

How risk data are to be organized, classified, updated, and disseminated most effectively requires careful exploration. To begin, classification or taxonomy of risk, following the report of Solomon et al., is the first step in the development of a risk management information system. What kinds of classification or taxonomy best fit the capabilities of local governments needs to be determined. How risk estimates are to be updated is also problematic and requires the development of decision criteria. Additionally, substantial differences in exposure to hazards means that discrepancies between risk estimates applying to high exposure groups and those applying to the public at large will depend upon how one defines high exposure groups. How newly discovered hazards are to be added to the categorization or taxonomy of risks needs also to be explored as do possible procedures for removing sources no longer believed hazardous. Additionally, certain physical characteristics of the system--for example, where the data files can be located and how they are to be assessed and updated--need to be designed.

7.4.3. Utilization study

Perhaps the most important question is whether, given appropriate shifts in federal policy as well as the availability of "state-of-the art" risk data, local policy makers would in fact utilize this information, thereby anticipating risks and making quantitative risk judgments. Perhaps the only means of approaching this problem is through controlled experimentation. Two matched groups of localities would have to be selected, one group provided with detailed data concerning at least one significant type of hazard, (e.g., organics in ground water or hazardous chemical wastes), and one not. The experimental group would be observed to determine if they utilize the data, whether the data enter into actual risk decisions, whether risk experience across localities is cumulated and risk estimates thereby revised, and whether the quality of overall risk management is improved as gauged by conventional criteria of efficiency or cost-effectiveness, and equity. Several years would be needed to undertake such an experiment and evaluate the results; indeed, a substantial period of time would be needed even to design such an experiment. Such an experimental approach is needed, however, to determine whether viable alternatives exist to the present pattern of risk management, which from the federal perspective operates largely through regulation but is executed, at the local level, largely through compliance.

Chapter 8. SOME GENERAL POLICY RECOMMENDATIONS FOR IMPROVED STATE AND LOCAL RISK MANAGEMENT

8.1. Some Observations on Risk Management

Improved risk management decision making at the state and local level will depend upon overcoming numerous, interrelated technical, institutional, and cognitive obstacles. Practically speaking, these are inseparable in a policy context. Debates over technical issues, for example, often become a vehicle for introducing wider social concerns about policy. A local demand for banning the transport of nuclear waste through a municipality can simultaneously be a technical, political, and cognitive issue.

The complexity of the problems facing state and local decision makers does not mean that remedial efforts cannot be made to upgrade risk management policy. There must be, however, a broad recognition as to the nature of extant policy, and the way state and local activities fit into the overall framework of risk management.

Risk management should be regarded as a comprehensive process that includes identification, assessment, acceptance, monitoring and intervention. These are interdependent tasks. They are also tasks that have been distributed in such a way that authoritative decisions are becoming increasingly centralized. The major functions within the risk management process carried on by state and local authorities are generally restricted to monitoring and intervention, although in certain cases state agencies have engaged in more comprehensive policy making.

The process of centralization, unfortunately, is proceeding without a full recognition as to the effects which this shift can produce. For instance, burdening local decision makers with new hazards sanctioned as "safe" by higher authorities produces institutional needs for additional resources at the local level; it enhances the technical challenges in monitoring risk, e.g., potential synergistic effects of new hazards; it also challenges the cognitive skills of decision makers who must deal with unfamiliar and difficult problems for which they have had no training. Adequate risk management demands that all such changes be accounted for in any systematic approach. At this point, however, state and local authorities find themselves with risk management problems that have been thrust upon them through a process that has not fully anticipated the technical, institutional, and cognitive ramifications of the decisions that must be made.

Technically, many of the hazards now confronting state and local officials are characterized by complexity and uncertainty of effect. An example is the diffusion of large numbers of new chemical compounds. Although federal standards may accompany new hazards, more local authorities must contend with the specific ways in which hazards become manifest in their communities. Acceptable risk decisions made at one level of government may only address limited aspects of the decision problem, leaving other entities to "fine-tune" the analysis. An example is that ambient air and water quality standards make no distinction between tradeoffs of societal risk, and risk to the most exposed or vulnerable groups (such as old people). State and local authorities must try and do their best to find an equitable distribution of costs and benefits in the face of incomplete information. Another problem is that standards derived at one governmental level can only consider a restricted set of potential difficulties. Exposure to any one particular source of a hazard, say radiation, may fall within allowable limits. But what of the aggregate effects upon a population group of different sources of exposure to the same hazard? Health officials, for example, in North Carolina are currently investigating formaldehyde exposure in the general population. As a result of a unique combination of occupational and living patterns there, residents may be vulnerable to a cumulative exposure in excess of what has been established as safe.

An important component of risk management, therefore, is the ability to define hazards. But this exercise is not self-evident owing to the uncertainty attendant with many societal hazards. State and local officials may be very much on their own when it comes to identifying an activity in their locale as hazardous. The particular problem definition they choose will very much influence whether a hazard is viewed as something of little significance or a major societal concern.

Inherent technical problems with regard to hazards, therefore, present decision makers with difficulties in locating risk-bearing activity as well as specifying consequences and potential action alternatives. The present overall set-up of the risk management process finds the technical aspects of risk overwhelming the capacity of state and local authorities to manage their responsibilities more systematically.

Institutionally, decision makers must deal with risk problems mediated by the following:

- the press of special interest groups trying to impose their own agenda on risk management. This influences the mandate and resources for risk management agencies.

- poor coordination between federal, state and local authorities. Mandates for risk management often either overlap, leading to jurisdictional conflict, or are discontinuous leading to serious gaps in overseeing management of the risk "cycle".

- changing legal definitions of hazards which do not conform to management responsibilities. Officials are often forbidden from going over the "picket fence" to manage problems which technically should come under their supervision. Also, regulations are constantly being revised and amended to accord with new technical information as well as the realities of political bargaining.

- o resource constraints that limit the time, personnel, and equipment that are necessary. State and local authorities, in particular, are extremely vulnerable to the vagaries of their local economies. Unlike federal agencies, state and local officials find that they cannot be assured of consistent appropriations to deal with problems. A decrease in revenues finds its correlate in curtailed budgets.

At this point, the institutional capacity of both state and local government to mobilize the technical, informational, economic and administrative resources needed to meet their responsibilities in the risk management process is seriously deficient.

Cognitively, state and local officials must deal with many risk management situations that place a premium on formal modes of reasoning. Yet interviews with state and local officials indicate that they tend to rely on more inferential rules of judgment. This is not surprising. A wide range of both experimental and non-experimental research on human decision making demonstrates that individuals construct simplified models of the world they deal with owing to cognitive limitations. Faced with complexity, decision makers impose a "bounded rationality" on problems that allows them to, on the one hand, respond to situations that jeopardize goal attainment, without, on the other hand, having to take on the difficult task of systematically accounting for all the important factors that enter into a decision.

The heuristic devices relied upon by decision makers may be valid in some circumstances, but in others may lead to large and persistent biases with severe implications for risk assessment. Much of the psychological literature, for instance, shows that in the absence of statistical evidence, intuitive judgments on probabilities often yield large and systematic biases. Interviews with state and local officials suggested that perceptions of risk were influenced by intuitive judgments, particularly on the part of elected officials who lacked technical familiarity with problems.

As a consequence of these technical, institutional, and cognitive problems, the character of state and local risk management policy tends to be reactive, piecemeal, episodic, and dependent on the prevailing issues of the day. Solving the overall problems in this area may well require more fundamental revisions of the policy process.

8.2. General Recommendations

Some general policy recommendations that are believed to be feasible within the context of extant policy processes follow below:

(1) Workshops on societal risk management should be held for state and local officials. Interviews with state and local risk managers indicated a basic unfamiliarity with concepts associated with societal risk. Workshops could provide individuals with information about societal risk as well as assistance in how to think more systematically about the problems they face. Risk problems are decision

problems, and require a choice between alternatives. Because many risks involve uncertain effects, they also require the ability to think probabilistically. And because the issues are so complex, and must, inevitably, incorporate a wide range of technical and non-technical considerations, risk management problems assume an ability to think clearly and systematically about structuring decisions. The purpose of the workshops would not be to advocate any one particular approach to risk management, but rather to encourage decison makers to begin to consider approaching their responsibilities from a more analytic, more comprehensive perspective. In conjunction with the workshops, written materials could be prepared that would serve to both facilitate discussion, as well as to furnish a reference guide for on-going use by officials.

(2) Smaller communities should be encouraged to enter into consortium agreements to pool resources for risk management services. Currently, smaller communities are highly dependent on either state or federal agencies to provide services such as hazard analyses. Because of fiscal constraints on any outreach in so many directions at once, assistance tends to be sporadic, and does not reflect the objective needs of the constantly changing risk problems that face communities at any given time. The deterioration in water quality in sparsely populated counties and municipalities in Oregon, for example, reflects the lack of adequate monitoring capacity by the Environmental Protection Agency. Communities could pool their resrouces for the following:

- o hire a full-time or part-time manager.
- o purchase or lease equipment to monitor hazards, e.g., air and water quality.
- o contract with consulting services to do regular hazard analyses.
- o establish a data bank that would collect information about efforts made in small communities to manage particular hazards so that experience could be shared.

(3) Federal assistance for risk management activity should be continued through categorical rather than block grant dispersal. State and local government remain heavily dependent on federal grants to assist in risk management. Proposed shifts in resource allocation from categorical to block grant funding may have advantages in certain areas, but would compound difficulties in state and local risk management. Since risk management activities form a unified process, decisions taken by federal agencies in the area of risk acceptance find their concrete results at the state and local level. These jurisdictions must keep abreast of the hazards they will be responsible for managing. There is no guarantee that discretionary funding given to states will find their way to needed risk management acitivity. Fiscal constraints are so great at this point that additional resources which become available could be easily channeled into areas considered as more pressing. Moreover, because people (including public officials) respond to the

hazards they perceive, hazards not readily "imaginable" such as those with chronic long-term effects, may not be given the attention they deserve.

(4) A state office of risk assessment should be established. A State Office of Risk Assessment (ORA) would be a useful institutional asset *if* it contributes to generic decision making on risk. State and local agencies find themselves so enmeshed in the everyday details of management that a long-term comprehensive view of risk is regarded by officials as an unaffordable luxury, even though it might eventually be justified from the standpoint of cost. An ORA would appropriately be located at the state level. States occupy a strategic "swing" position in risk management. They have the potential resource base to engage in comprehensive risk management, and they also are close enough to more local communities to have a familiarity with more immediate problems. An ORA could be justified by providing state and local officials with a broader perspective of their operational responsibilities. Some of the services an ORA could offer would be the following:

- develop taxonomies of risk found at both the state and local level.
- provide communities and other state agencies with a resource pool or "bank" of expertise and information. This could include historical records that were frequently updated.
- suggest or establish priorities for hazard regulation based on best available statistical evidence.
- address jurisdictional disputes between agencies involved in risk management; insure consistency of standards between different sources of risk; help in identifying multi-hazard effects, e.g., the type of analysis that might slip through the seams of traditional risk management agencies.
- engage in public educational and informational services on risk. Since states are the most "local" jurisdictions in which authoritative decisions on risk take place, the need for public involvement is crucial.

Chapter 9. AN INCENTIVE APPROACH IN RISK MANAGEMENT

A growing literature implores that risk management be instituted as a formal activity within local government. Many authors, including some writing in this volume, suggest that a local Office of Risk Management (ORM) proceed with the tasks of hazard identification, risk estimation, and social evaluation. Beyond these generalities there is little agreement on the details of just how these steps are to be accomplished. This paper continues along the lines of Chapter 7 and explores alternatives to more standards and more regulations. Instead, strategies which rely on the management of incentives and disincentives are explored. Much of the discussion rests on the economic theory of insurance and property rights (or liability).*

9.1. Preliminaries

The histories of local city planning (including subdivision review and enforcement of building codes) and (much shorter) federal (and state) mandated environmental protection legislation show a marked political preference for regulations and standards over the manipulation of incentives and disincentives. Although the weight of the body of welfare economics strongly endorses the latter as more efficient, that path has been almost entirely eschewed.

Economics textbook authors are fond of sketching cases where the costliness of regulation is made apparent: A river is polluted by two firms and scientists determine that it is ecologically desirable to reduce emissions by one-half. The choices are to order each firm to cut contaminating activities by one-half <u>or</u> to find a pollution tax which does the job. In the latter case, each firm has the choice of meeting the tax <u>or</u> engaging in clean-up activities. Clearly, that firm which finds it cheaper to clean up will do so; the firm which finds it cheaper to pay the tax will do that. The same environmental standard is met yet, in the case of the pollution tax, it is met at lower cost.

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*Indeed, the formal economic theory of private insurance predicts that inefficient market outcomes will result even where there are no property rights or liability ambiguities. This theory dwells on "adverse selection", in which the insurer cannot determine some key characteristics of the insured that are relevant to the determination of expected claims. This body of theory prescribes some sort of corrective public sector intervention. The problem of "moral hazard" (where individuals engaged in risk sharing can affect the probability of an unfavorable event) causes further difficulties. See Pauley (1974) for the formal exposition. The problem of "insurance failure" for "uneconomic" reasons is treated by Kunreuther (1976), see p. 9-6.

The more orthodox economic position goes a step further and suggests that the standard itself be economically endogenous. That is, pollution (or congestion) should be reduced to the point where the marginal benefits of further reduction just equal the marginal cost of doing so. This procedure requires the valuation ("monetizing") of benefits (of less dirty air, less noise, etc.). The latter course is often criticized as being informationally demanding. The former procedure is dismissed on a variety of other grounds. Regulation is the costly political favorite for reasons which cannot be fully explored here.*

This paper will advocate that the ORM help to organize the provision of insurance risk-pooling where such pooling cannot otherwise take place. Two classes of "insurance failure" will be addressed, each with peculiar characteristics which require some sort of public sector intervention. What we call the "Class I" problems result from the defective assignment of property rights (liabilities are poorly defined or ambiguous). In that case, there is the task of transferring risk from the public-at-large to the liable parties. "Class II" insurance failure has less to do with ambiguous liabilities but, instead, concerns the various impediments to risk-pooling which prevent willing risk-averse parties from spreading common risk and avoiding

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*Many authors (most notably, Tullock, 1981) view regulation as the net result of political influence used for self-serving ends:

> "...overwhelmingly, the most important reasons for income transfers in our society is or was the desire on the part of recipients to receive it. The farm program, high wages of civil servants,..., the price controls which have the purpose of transferring large amounts of wealth from American owners of oil wells to Arab sheiks (about two-thirds) and American consumers (about one-third of the transfer) are all examples."

Tullock leaves room for the traditional role of government, but fears that it will inevitably deteriorate:

> "Economists have for a long time talked about government as a mechanism for providing public goods or dealing with externalities. It undeniably does this, but in order to do so it must have coercive powers, and the use of coercive powers to benefit people in terms of their political influence seems an obvious thing to expect from profit maximizing individuals."

Such drives for the (usually regressive) redistribution of wealth under auspices of the state, routinely accept the accompanying massive inefficiencies.

catastrophic outcomes in any period. The resulting absence of insurance can have serious and negative spillover effects (as did the absence of medical malpractice insurance, for example) even though this is not strictly a problem of unclear liabilities. An ORM would seek solutions such as co-insurance from the state.

In fact, both classes of problems provide scope for some risk management activities. Moreover, both sorts of problems may, on occasion, be found to co-exist with respect to some particular hazard.

Risk management may well be the next area of local public sector extension; new risks are the inevitable price that we pay for progress in an advanced industrial society.* We have good reason to study alternatives to standards and the regulatory apparatus they require. Aside from the standard problems associated with regulation, risk management by admisistratively imposed criteria would have to grapple with competing notions of "acceptable risk". Very little in the literature sheds light on this concept. In fact, it is disconcerting that so many authors have been content to introduce this vague concept without addressing the problem of its vacuity. Risk management via incentives avoids much of this problem.

Principles having to do with the internalization of external costs (and benefits) are well known. They are especially relevant to environmental management: we will have dirty air and polluted streams as long as economic agents (consumers, producers, governments) view them as common-property resources--or a free "sink". Welfare economics describes just how economically efficient internalization can take place: taxes or subsidies equal to the difference of private marginal cost and social (actual) marginal cost at the efficient level of output are to be levied on the producers of external diseconomies or economies. While these are well-known principles, much less is known about risk internalization, but it will be seen that there are strong parallels.

The remainder of this essay will sketch the elements of risk internalization with a view to having the ORM responsible for that process. We will touch on the economic theory underlying the insurance principle, note some cases in which the principle fails, and discuss how the correction of insurance failure can pave the way for socially desirable incentive schemes which diminish societal risk.

*Indeed, Kates (1977) views the whole problem as one of the "proliferation of risk". Of course, we focus on involuntary risk, by maintaining the distinction between risk which is voluntarily chosen and that which offers no associated utility; we avoid Wildavsky's (1980) argument that individuals are inconsistently demanding high standards of safety when acting as a polity but are willing to accept high stakes in, say, recreational activities.

9.2. Class I Problems

Situations where there are property rights (or liabilities) problems can be introduced via the following example. Writing about an economic solution to the problem of oil spills on the high seas, North and Miller (1980) concluded that:

> "...In order for the (prospective) laws to be effective against oil spills, they must contain unlimited-liability clauses...Oil carriers would be forced to carry insurance sufficient to cover damages. The high costs of such coverage would probably eliminate giant tankers from some enclosed waters such as Chesapeake Bay, where the potential liability from a major oil spill would be of immense magnitude. Insurance premiums would decline with improvements in safety devices designed to prevent accidental oil spillage. Operators would therefore be encouraged to install such measures. There would also be an incentive to improve the technology of cleaning up oil spills and thereby reduce the costs of damages."

Part of the premiums would, of course, be borne by the consumers of oil products--who otherwise consume these products at less than their full social cost, viewing the absorptive capacity of the environment as a common property.

There are even episodes where policy makers have implemented limited liabilities in order to attract private insurers. Clearly, this sets up the "wrong" incentives and is the reverse of risk management. It avoids the alternative possibility of the state being a co-insurer.

Other insurance problems (see footnote, p. 9-1) aside, cases where liabilities must first be clearly assigned are perhaps of most concern to risk managers. There are two major reasons:

1) Until the liability assignment is made, risk may accrue to the public-at-large rather than to the liable parties; and
2) Until that transfer of liabilities has occurred, the liable parties face the wrong incentives, encouraging inefficient and unsafe behavior; this appears to be a situation where far greater inefficiencies may result than from the widely studied moral hazard and adverse selection problems.

The cited examples are more general than may at first appear. Legal institutions appear to require much time to sort out actual liabilities. On-going litigation following the Three-Mile Island accident is a case in point.

9.3. Class II Problems

Apart from the property rights assignment difficulties just illustrated and apart from the inherent characteristics of insurance which may prevent efficient outcomes (footnote, p. 9-1), there are a variety of other possible barriers to successful risk-pooling. The public-at-large would be exposed, or desired services would be withdrawn from the market--or both. An ORM could intervene, correcting the problem, allowing insurance to become available, relieving the cited possible adverse outcomes. Again, we begin with some examples:

1) For some time, earthquake insurance had been unavailable in Southern California (and other regions). It became available only after insurance firms had accumulated sufficient actuarial experience. And, they began gathering the data only after they anticipated that expected annual claims would be covered by what individuals would willingly pay for such coverage, and that there would be enough subscribers.

   An ORM could assist if there was simply a data problem. An ORM could suggest publicly provided co-insurance if it was determined that the absence of insurance was socially undesirable, that it preempted certain desirable activities or exposed individuals to great risks.

2) Recent medical malpractice settlements have increased the dollar value of the risk of malpractice. In a sense, extraordinarily large awards by juries are an allocative inefficiency brought about by the very existence of insurance: juries have made large awards simply because the insurance is there. This has caused insurers to raise premiums. In response, private physicians have, in some cases, correctly reasoned that expected claims against all lienable assets make legal bankruptcy the preferred alternative to high insurance premiums and have avoided insurance. Others have withdrawn services altogether (refusing to offer emergency care to randomly encountered accident victims on the roads). The latter results may be socially unacceptable.* What could

*"Socially unacceptable" is not rigorously defined here. Large-scale inefficiencies are measurable and could be suggested to be socially unacceptable by the risk manager. Large-scale inequities are determined more subtly in public discourse and the political process. Yet, the withdrawal of medical services in life threatening situations can be deemed to be socially unacceptable without a rigorous definition at hand.

the risk manager do? If the problem is linked to moral hazard-type behavior by doctors and juries, the insurance would have to be revised to contain effective deductability clauses, aimed at altering the behavior of physicians. If the insurance industry fails to take the lead here, the risk manager could offer to do so. If alternate insurance programs are privately infeasible (deemed to be unprofitable), then publicly provided co-insurance mught be suggested by the risk manager.*

3) Vanpools are thought by many city planners to be an attractive form of public transportation. Experience suggests that vanpools divert proportionately more solo automobile drivers to transit than does conventional bus or rail transit. The reason appears to be that it offers a service which approximates the door-to-door service of the private auto. Yet, until recently, the only liability insurance available to vanpool operators was taxi insurance. The premiums were inappropriate, since most vans are parked most of the day. The absence of special vanpool insurance could be traced to either: a) the small number of actual vanpools in operation, indicating a group too small to allow risk-pooling; and/or b) an absence of sufficient actuarial experience with vanpools to assess expected liability and claims.

Clearly, if vanpool use (and the removal of low occupancy vehicles from highways) offers benefits beyond those directly experienced by vanpool passengers, then a public subsidy can be justified on efficiency grounds. That subsidy could take many forms. One of them might be the provision of insurance as long as it was unavailable from the usual providers.

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* This problem should <u>not</u> be confused with the one discovered by Kunreuther (1976) and Slovic et al. (1977). These authors have detected instances where the avoidance of <u>available</u> insurance indicated some sort of economic "irrationality". Though a "spillover" inefficiency due to moral hazard-type behavior (with respect to publicly provided disaster relief) is cited by these authors, the alternative of incentive manipulation by an ORM to induce insurance purchase is skipped over. In other words, charge the ORM with inventing a subsidized (reduced premium) policy which would be cheap enough to be bought, but which would represent less of a subsidy than comprehensive disaster relief (wherever possible). This would also bear favorably on incentives facing those at risk.

4) Medical insurance for elderly citizens had not been privately profitable, given the ability-to-pay of the group and the expected annual claims. It could only be provided by the public sector once society decided that a higher level of health care for the elderly was generally desirable--a clear case of subsidized co-insurance and a merit good.

The traditional response to risk has been the private purchase of insurance. Yet, insurance is not available against all risks. Insurance has been available for purchase whenever suppliers have had enough actuarial experience to predict expected costs (claims), allowing the posting of premium schedules. The venture, then, succeeded whenever posted premium costs did not exceed individuals' willingness to pay for the available coverage--for a pool of liable parties large enough to allow a periodic profit to the provider after the period's expected claims had been covered. The absence of any of these conditions is sufficient for insurance to be inadequate or withdrawn. We have looked at some examples. They suggest that risk would be transferred away from the liable parties. This means high risk to the public-at-large as well as a skewed incentive structure.

This fourth class of insurance problems involves cases where there are barriers to successful risk-pooling even though there are no property rights ambiguities. Insurance may not be a profitable activity for either the buyer or the provider. The consequent absence of insurance may expose the public to danger, making a case for insurance provision here as a part of normal risk management.

The many instances of risk and possible risk-pooling are depicted in Figure 9.1.

These explorations have been quite general. The many episodes that are encompassed would each require a particular treatment which cannot really be anticipated here. Yet, the purpose of this brief essay has been to divert attention from the almost reflexive move to standards and regulations. Simply because these have been the political favorites in environmental management and local administration does not guarantee that they are desirable. In fact, a large body of thought exists to challenge the choice of regulations over incentive schemes designed to achieve social objectives. We have attempted to show that such incentive schemes can be a part of effective risk management and that these concepts follow from the implementation of successful risk-pooling.

Thus, we have a conceptual framework. What does it suggest that the ORM actually do? In short, the previous arguments indicate that the ORM should seek to determine whether risk can be transferred away from the public-at-large to the producers of hazards via the implementation of full liability insurance. In so doing, incentive structures favorable to risk management would be put in place.

There are at least two parts to this task. First, do existing laws result in less than full liability assignments? If so, the ORM would have to conduct studies designed to make lawmakers and voters aware

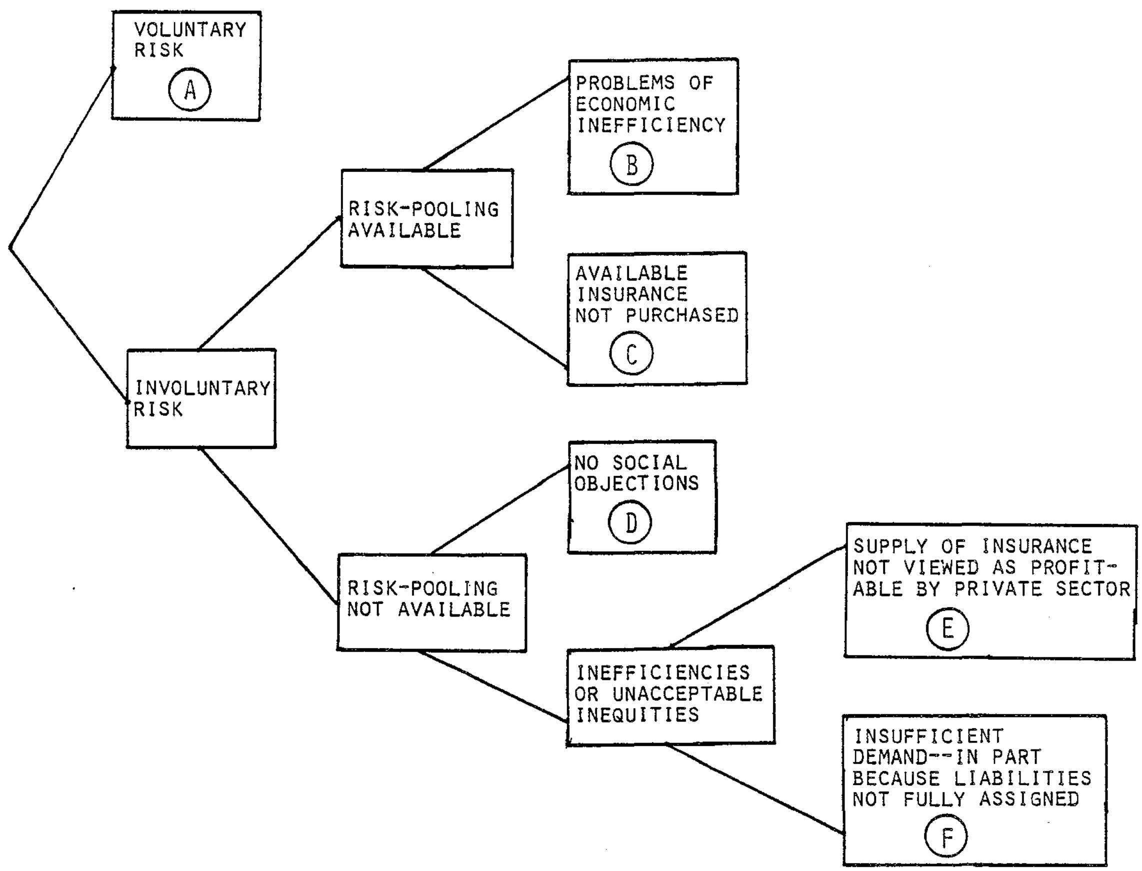

FIGURE 9.1. A SCHEMATIC REPRESENTATION OF CASES AS OUTLINED IN THE TEXT. BRANCHES B AND C REFER TO CASES WHICH HAVE BEEN WIDELY ANALYZED IN THE LITERATURE ON RISK-POOLING. TWO INSTANCES WHERE RISK-POOLING MIGHT BE DESIRABLE (BRANCHES E AND F) CAN BE RELATED TO THE RISK MANAGEMENT ACTIVITY.

of the fact that such laws transfer liability away from hazard producers and to the public; in so doing, these same laws provide the producers with incentives to be less concerned with safety than they otherwise might be.

Second, the ORM would seek to detect instances where publicly provided insurance (or co-insurance) would accomplish the same sort of risk transfer. The ORM would suggest the specifics of public sector insurance in such cases. As already pointed out, this requires the gathering of substantial actuarial data.

Of course, there will be cases where both problems beset the same hazard. LNG shippers benefit from legally sanctioned limited liability. Yet, in the absence of that shelter, insurance would simply not be available from the usual providers. Enforcing full liability and insisting on risk internalization would require the offer of some sort of publicly provided insurance.

This introduces another issue--and another task for risk management. The cited public insurance is, of course, an economic subsidy. Who would pay and who would benefit? Which tax instruments are used to raise funds for the subsidy? Are they regressive or progressive? Further, who benefits from the transfer of risk away from the public-at-large? Which group? If the removal of risk is across-the-board rather than to an identifiable population, then there is less of a problem. Nevertheless, in the interests of explicitness and full information, these effects would also have to be investigated.

The internalization of costs and benefits is at the heart of applied welfare economics. The application of these concepts to environmental management has not really taken place. One of the reasons given (in addition to those cited earlier) has been that this approach would be quite data demanding. Extending similar concepts to problems of insurance failure is conceptually simple but, perhaps, even more data demanding. For example, the cited oil tanker case helps to make the point that unlimited liability assignments have the effect of changing the "common property" status of the oceans--in the eyes of shippers and their customers. Yet, in contrast to the steady pollution caused by waste disposal into rivers and lakes, the tanker pollutes the seas with a probability--less than one and greater than zero. Thus, full liability insurance against legally mandated unlimited liability requires actuarial rather than determinate data. This is the key difference between economic management of the environment and economic management of hazards. A new dimension of data is to be required. Other than that there is little here which is new.

This last point introduces the key recommendation of this report. Since there are few conceptual riddles associated with the sort of economic risk management advocated, many of the remaining problems would be encountered in an actual application. What is sorely needed is a revealing test case or pilot study. Just as (described by Frieden, 1980) the U.S. Department of Housing and Urban Development has sponsored a small scale "Housing Assistance Supply Experiment" (HASE) over the last five years--and has hired researchers to monitor it carefully--a test case would be revealing. The position of the U.S. Government had been that the efficiency to be gained by replacing subsidies to builders with subsidies to consumers was an hypothesis worth testing. What are the, perhaps unanticipated, secondary effects on which the body of theory was silent? It is now safe to report that studies by RAND and MIT--Harvard's Joint Center for Urban Studies have been quite favorable to the results of HASE, vindicating the underlying theory.

The National Science Foundation and others may find that we are at a similar juncture with respect to Economic Risk Management. Rather than following the example of environmental management and adopting a new assemblage of standards--which are even now being critized--why not pursue the investigation of risk-pooling and consequently revised incentive structures? Again, careful monitoring of such pilot schemes would be required by teams of policy analysts. Such a program would probe the important middle ground between theory and operations; it would uncover some unpredicted difficulties (and their resolution, it is hoped), and it could demonstrate that economic concepts of risk management can be widely applied.

9.4 Summary and Research Agenda

In summary, there are four "problem areas" associated with insurance and risk pooling. The first (branch B of the schematic) has to do with the inefficiencies which follow moral hazard and adverse selection. These are essentially problems of inadequate information (auto insurance companies do not find it economic to monitor miles driven by the insured; also, individuals who are really different are often pooled as though they are really the same) which are thought to lead to inefficient outcomes. Another problem reported in the literature (branch C) has to do with individuals' unwillingness to buy available insurance for seemingly irrational reasons. These difficulties are not treated here, although information dissemination by an ORM would seemingly be appropriate and could fit Kunreuther's proposed "sequential decision" insurance purchase model.

Of greater concern to risk management are the other difficulties outlined above. The most important have to do with vague or inadequate liability assignments (branch F) and/or a demonstrable need for co-insurance (branch E). The former dissuade risk-pooling among the liable parties and transfer risk to the public-at-large. A critical side effect is the low level of precautions which producers of risk are enticed to take. Part of risk management, then, is the identification of these property rights problems and the suggestion of programs to correct them. Analagous to the theory of market failure, where the public sector has an acknowledged role, helping to avoid insurance failure could be one of the roles of an ORM.

The provision of risk-pooling opportunities where they are currently absent and where they are deemed to aid risk management may lead to the allocative problems associated with branch B. Clearly a trade-off is implied: which social problem is least acceptable? Are compromises along the range of available trade-offs desirable? Much more theoretical work remains to be done before we have clear answers to these questions.

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Part IV: A Summing Up

Chapter 10. Synthesis and Conclusions (Okrent)

Chapter 10 SYNTHESIS AND CONCLUSIONS

10.1. Some Introductory Comments

In view of the many difficulties facing the development of a significantly improved approach to risk management at the state and local level, it becomes relevant to ask whether there are strategies that might be effective in leading to measures that are meaningful, workable, and cost-effective.

It may be useful first to restate some of the points made previously in this report.

- The terms state and local government encompass a very wide range of governmental entities ranging from large, industrialized states with very large budgets to poor, sparsely populated localities with minimal resources and personnel, mostly committed to public protection. Not only do these governmental entities differ in resources, they also vary widely in their attitudes toward regulation of industry, agriculture, mining, etc. Such diversity renders any single risk management strategy unsuitable for all states or local governments.

- Many hazards and risks are still poorly known or understood by society. Others are understood in a generic sense, but are very difficult to evaluate in specific instances. One such example is the probable future risk from drinking water due to disposal of hazardous chemical wastes that, decades later, creep into an aquifer used as a source for a city water supply.

- Society is not and cannot be made risk free. Nevertheless, there are some risks that can be prevented, removed or reduced cost-effectively. There have been many risks that, once identified and quantified, were judged to have been intolerable.

- Risks vary widely in their nature and seriousness. Risks also interact. Mitigation of one risk may exacerbate another. For example, the use of Tris to reduce the flammability of children's sleepwear appears to have exposed many children to a potential carcinogen.

- The benefits society derives from activities which act as sources of risk vary widely.

- There is a paradox with regard to the quantification of risk. Elected officials at the state and local level appear very much to prefer categorical statements that something is "safe" to quantitative estimates of risk (coupled with an opinion that the particular risk is low enough to be acceptable). On the other hand, quantitative risk estimates are needed to perform meaningful analyses to determine whether acceptable levels of risk have been exceeded, and, if so, to decide among various corrective actions.

- Although some risks are ubiquitous, others are highly localized; (for example, asbestos fibers in drinking water from a large industrial point source of contamination).

Our research began from the premise that risk management was not being performed optimally at the state and local level, and that it should be possible to develop a framework for the implementation of an improved approach towards preventing or reducing risk. Implicit in this idea was an engineering rather than a socio-political concept of risk management. It was anticipated that case studies of several specific kinds of risk would provide insights that could be valuable for structuring a framework for risk management.

The research team included a psychologist, a sociologist, a decision analyst, a policy analyst, a political scientist, an economist and a few engineers. Several in this team were unfamiliar with the general matter of societal risks prior to beginning this study. Few members of the team had preconceived notions of how state and local governments were dealing or should deal with risk management.

The original intent was that this range of disciplines could be brought simultaneously to focus on the development of one or more risk management approaches. However, as the study progressed, it became clear that the investigators had a range of opinions concerning the merits of trying to implement a strong structured, generic approach to risk management; there was some opinion that even incremental modifications in current approaches, which ranged from ad-hoc to almost non-existent at the county or small community level, might not be universally practical. Furthermore, a principal conclusion drawn by Solomon and Meyer in their case study of the risks from drinking water is that local communities can usually do little, save monitoring particularly noxious contaminants that had been previously identified by the Environmental Protection Agency (EPA). Even state governments have the resources only to deal with limited aspects of the overall risk management problem. (See Solomon and Meyer, 1982a and Chapter 3).

Sarin, on the other hand, in his case study of safety problems arising from seismically substandard, old masonry buildings in Los Angeles, concludes that this risk should be managed by the local government involved. (See Sarin, 1982 and Chapter 4) Meyer notes, however that this recommendation is facilitated by two properties of earthquake hazard; it is localized, and building regulation has always been a local government function.

Drinking water introduces a very small, difficult-to-quantify risk affecting all members of the community. The contaminants which are likely to be harmful have not all been identified. They are not all easily measured. The risks are poorly known. The federal government has prescribed standards for "safe" water, although the risk involved is not quantified. A better scientific resolution of the risks from drinking water is beyond the capabilities of local government.

Seismically substandard buildings, on the other hand, introduce a risk primarily to an identifiable subset of the total population. At least in Los Angeles, the risk to these individuals is substantially larger than that posed by drinking water to any individual in the same city. The risk may be large compared to other accidental risks. In Los Angeles, the city government contains employees knowledgeable in the detailed technical aspects of seismic design and of seismic risk, employees who not only understand the situation but are able to formulate possible alternatives and to evaluate (with the assistance of consultants) both the direct costs and the likely benefits (via risk reduction) of various alternatives. Hence, this is a risk which can be identified and evaluated by the local government involved. Furthermore, the responsibility for building safety clearly lies with the local government.

If risks from seismically substandard buildings can and should be managed by Los Angeles, should the same conclusion automatically be drawn for all other local governments, not only in California, but throughout the United States? If not, what are the factors that might militate against such risk management? It may be that the risks are negligible from this source in many local communities. But what is the definition of negligible, and if it has been defined, how does one know if the risks meet the definition if they have not been estimated? It may be that many communities lack the expert knowledge available within the Building Department in the City of Los Angeles. However, if financial resources are available, it would be possible to hire consultants to survey and assess the situation for any local government so inclined. It may be that the lack of local expertise is so great that there is neither knowledge of the risk nor an ability to assess adequacy of seismic design on a continuing basis. This would increase the dependence of a local government on outside consultants and complicate greatly the matter of monitoring this aspect of risk via the enforcement of new regulations.

In any event, it may be readily ascertainable in many communities that the risk from earthquakes does not require the attention of a risk manager. Conversely, some local communities may need the equivalent of a full time risk manager to guard their local water supplies, contrary to the conclusion of Solomon and Meyer. This situation could obtain in localities where (1) a single, irreplaceable source of water supply exists; (2) there are identifiable sources of possible water contamination, and (3) there is a non-trivial probability of contamination by these sources. With such a situation it would behoove the local government entity to take the necessary action, unless it was clear that a higher governmental group, say the state, was acting definitively in their behalf on a continuing basis. Thus, one may need to exercise care in generalizing prescriptively from either of the two case studies.

Although, as is illustrated in Chapter 1, we are surrounded by a host of risks in the world in which we live, both Bordas (1982) and Meyer (Chapter 2) found the quantitative concept of risk to be foreign to, or extremely limited in, local government and that there was a near absence of formal risk management activities. Meyer identifies formal risk management as normally involving the following:

1) A suspected source of risk is identified.

2) The risk is analyzed and quantified.

3) The level of risk is compared to previously established risk acceptance criteria.

4) Policies are developed and implemented so that the risk does not exceed acceptable levels.

5) A system of monitoring is set in place to insure the effectiveness of the policy.

Meyer finds that where any of these steps are practiced at the local level, it is typically only the last step, that of monitoring performed in response to regulations usually established by the federal authorities. Meyer terms this "risk management by compliance." The other form of risk management that he finds in local government is risk management by reaction, either to deal with emergencies, or stimulated by some serious, highly newsworthy event. Meyer and Bordas separately provide a considerable description of their assessment of the current state of affairs and some of the reasons for it in their topical reports. We will not repeat this here. We will next examine and compare some of the conclusions and recommendations made in Chapters 3-9 of this report.

10.2 An Examination and Comparison of Some Findings and Recommendations

10.2.1. Drinking Water

In Chapter 3 Solomon and Meyer state that the following are characteristic of the problem of organic contaminants in drinking water.

1) The hazard is chronic, not catastrophic.

2) The hazard is widespread, not localized, although levels and types of contaminants vary across localities.

3) The hazard is in some instances unknown or undetectable, in other cases not known although visible.

4) Substantial rather than moderate uncertainty is associated with risk estimates.

5) Management of the hazard conflicts with, rather than augments, the traditional service delivery and public protection functions of local government.

Solomon and Meyer conclude that all these characteristics tend to diminish the local role in risk management. Chronic risks of low magnitude do not stimulate immediate demands for protection; risks common to many localities and concentrated in none are not viewed as principally local problems; hazards eluding easy detection exceed the capacity of local governments to identify or detect them; highly uncertain risk estimates pose political perils for local officials; and risk management practices impeding or increasing the cost of service delivery may also be perilous for the official. Thus, for the management of the risk from carcinogens and other dangerous contaminants in drinking water, Solomon and Meyer do not advocate a significant responsibility or changed role for local government. They place a principal responsibility on the federal government for identifying dangerous contaminants and setting "safe" levels. They would have the states take an active role in overseeing action by local communities in monitoring for contaminants and in preventing future contamination, as practical.

Solomon and Meyer state, however, that other risks which are localized, understood, potentially catastrophic, and whose management is consistent with the traditional role of local government, might be more amenable to effective local management.

10.2.2. Seismically Substandard Buildings

Sarin examines in Chapter 4, a risk which meets all the conditions which Solomon and Meyer attribute to a hazard which is logically subject to local risk management. In Los Angeles the risk from seismically substandard buildings is localized, understood, potentially catastrophic, and of a type normally handled by local government.

Sarin does not question whether Los Angeles should manage this risk, merely how. Sarin finds that for occupants of unreinforced masonry buildings, the risk appears to be about ten times the risk from fire and that it could be 100 times as large. He finds that some amount of seismic upgrading is cost-effective with almost any reasonable set of assumptions, and the real question is how much and who should bear the cost (a question which is complicated by the existence of rent control). Although Sarin does not provide a specific quantitative definition of unacceptable risk, he does conclude that the risk to residents of these buildings is too large and an improvement in safety is required. For non-residential buildings he also favors improvement, and states that if this is not done, the city has an obligation to inform the public of the risks involved.

Several aspects of Sarin's analysis and discussion are of specific interest, including the following:

- He uses a measure of society's willingness to pay to reduce the likelihood of a statistical death which is non-linear, one which increases with higher probability of death to the individual, as has been previously suggested in the literature.
- In a very limited survey of individual opinion, he finds, not surprisingly, that older residents (> 70 yrs. of age) are less willing to pay an increased rent to reduce seismic risk, and that the general public do not distinguish critically between a risk of 1 in 100 and 1 in 10,000 with regard to an increment in rent to eliminate such a risk.
- Even in Los Angeles, which has an acute well-defined problem and knowledgeable employees, he finds evidence that the city has been unable to enforce seismic design regulations because of financial and trained manpower shortages.
- Sarin recommends that the regulatory approach should consider who benefits directly from the action and, if possible, provide incentives to those bearing the cost.

In the topical report on which Chapter 4 is based, Sarin (1981) offers some suggestions for a general guide to risk management at the local level. Sarin's suggestions can be posed as a series of questions, as follows:

- Is the risk significant?
- What are the mitigation alternatives?
- What are the costs and benefits?
- What are the legal, social and political ramifications?
- What constitutes a balanced approach?
- What are the enforcement and implementation issues?

10.2.3. Classification of Risks

In Chapter 5, Solomon and Meyer do not present a detailed, recommended classification of risks to be used by a risk manager. Instead, they conclude that no single taxonomy is likely to be sufficient, and outline nine different approaches to risk classification, using the following categories:

- situation in which the hazard or risk is encountered.
- cause of the hazard or risk
- the hazard or risk itself
- manner in which the hazard or risk is perceived
- magnitude of the hazard or risk
- geographic division of hazard or risk management responsibility
- dollars expended to manage the hazard or risk
- ratio of dollar damage to dollar benefit
- the way the hazard or risk is already managed

Solomon and Meyer provide a definition of each of these categories and some examples. More detail is available in the topical report from which this chapter is derived (Solomon 1981b).

They also present segments of a risk profile, that is, a quantification of risks for a couple of communities. However, the data provided is limited and the profile does not include a geographical distribution of hazard sources, superimposed on a population (residential and commercial density) distribution.

Solomon and Meyer argue that the multiple taxonomies (and their associated profiles), if completed and fleshed out, would provide one basis or framework for national decision making by identifying a more complete array of risks and profiling these risks for several geographic regions. They also argue that the taxonomy and profile may introduce the person(s) responsible for risk management to a new way to quantitatively represent risk. They state that the set of taxonomies and profiles, if completed, would provide information regarding the relative cost and benefits of making expenditures to reduce risk. While they state that this is true, in principle, they further concede that such information is in large part unavailable and furthermore, is difficult and expensive to obtain.

A major point made in Chapter 5 relates to a national risk management information system. It is argued that there is a need for risk classification not only in order to help accumulate and retrieve information, but also to help think about risks. It is stated that classification permits comparison, insures that some categories of risks are not altogether ignored, and is therefore a prolegomenon to systematic thinking about risks.

Solomon and Meyer state that the responsibility for initiation of a national risk management information system must fall on the federal government, since no state or local community has the authority or resources. They feel that the existence of a national risk management information system could overcome several of the weaknesses of local government in dealing with hazards, and that by providing local governments the information wherewithall on which to base risk management decisions, the federal government would reinforce the political process in states, counties, and cities.

Solomon and Meyer do not argue that this would necessarily lead to a more nearly uniform approach to risk management among the states. Indeed, there are many examples, including the matter of dam safety discussed in Chapter 1, which illustrate the widely differing approaches taken by states or local governments on how or whether to cope with risks, after information on risks has been provided to them.

The topical report on which Chapter 5 is based (Solomon and Meyer 1982b) includes a brief outline of the possible functional mode of a "risk manager" for a large city, assuming that the office of risk management was given responsibility for trying to prevent or reduce unnecessary risks and had a reasonable amount of resources available. This outline is as follows:

(1) Develop tentative threshold criteria for action appropriate to identification of potential sources for each category of hazard or risk developed from the taxonomy. For example, for health effects from pollutants in drinking water, there might be five or more thresholds for each chemical or pollutant. Some threshold quantity of waste disposed of per year would require notification of the responsible agency, including means of disposal. For some larger quantity of a chemical, a risk evaluation would be required to be provided by the disposer to the agency. Each chemical that could pose a threat to drinking water in an accident would require notification of an agency. For each of these, some larger quantity might require a risk evaluation.

(2) Develop ordinances to identify hazard and risk sources which meet threshold criteria.

(3) Formulate a basis whereby governmental entities can, in practical ways, assess risks that may exceed "acceptable" limits.

(4) Prepare evaluation processes, methodologies, etc., whereby source identification methods can be checked for adequacy. For example, how would PCB-containing transformers be detected; how would asbestos in buildings, specifically schools, have been thought of as a possible source of air pollution and how would the use of uranium tailings for home building material have been identified and detected?

(5) Arrive at a methodology for determining other attributes which may be relevant to decision-making for risk sources which exceed

threshold criteria for possible action. For example, such factors would include the benefit associated with the technology responsible for the risk, the dollar cost of reducing the risk, and various socio-economic-political issues.

(6) Suggest methods for acquiring appropriate information about other attributes.

(7) Identify and bring forth factors which will potentially enter in judgment on risk acceptance and risk management.

(8) Formulate a proposed risk management policy for each hazard class.

10.2.4. The Office of Risk Assessor

In Chapter 6, Apostolakis takes the point of view that while the elected representatives will ultimately need to make the policy decisions concerning risk, the structuring of the alternatives and the assessment of the probabilities of uncertain outcomes is largely of a highly technical nature and should be done by a technocratic agency to which he gives the title of Office of Risk Assessor or ORA. After discussing some of the detailed aspects of hazard identification and quantification, he concludes that the task is too formidable for local government and is inappropriate for the federal government, and that hence, the management of risk must start at the state level with strong regional offices which would interact both with the central office and with local officials.

Apostolakis identifies the need for criteria by which the ORA can judge whether a hazard requires further attention, and notes the usefulness of decision analysis for the entire task faced by the ORA.

Apostolakis does not rule out an important information support role by the federal government; however, he does suggest that the states need a strong technical capability, either singly or cooperatively.

10.2.5. Some Policy Alternatives

In Chapter 7, Meyer and Solomon (1982) propose several policy alternatives for risk assessment and risk management in the light of the following postulated constraints:

- Risk judgments are comparative and comparison entails quantification.
- Risk judgments may vary across localities.
- Risk judgments need legitimacy.
- Risk judgments may need revision in light of information concerning new hazards and new information concerning the riskiness of known hazards.

- The costs of obtaining the information needed for risk management judgments can be high and should be distributed equitably.

Meyer and Solomon define and discuss the following five models of risk management:

- the existing system which is largely dominated by the federal government
- the "weak" risk manager in which the existing system is buttressed by strengthening local capacities to utilize competent professional judgment in managing diverse risks
- the network of risk managers which ties relatively weak offices at the state and local level into a network that facilitates sharing of data on hazards, risks, risk acceptance criteria, and risk policies
- the "strong" local risk manager who is charged with the full spectrum of risk management activities, from risk identification to policy and implementation
- a radical decentralization of risk management whereby prima facie evidence of riskiness above a low threshold compels the source of risk, no matter whom, to obtain appropriate risk studies showing the acceptability of the safety of proposed activities before proceeding with them.

After discussing some of the advantages and disadvantages of each of the above models, Meyer and Solomon indicate a preference for the approach involving a network of "weak" risk managers. They suggest that the basic elements of a network approach would involve the following:

- a system of classifying risks
- central storage of risk information
- means of developing needed information
- the maintenance of risk profiles for localities
- risk managers trained in the utilization of the information.

They caution that the network concept is novel and relies upon information technologies not heretofore utilized. They state that developmental work would be required prior to its implementation and that studies would be needed of the appropriate changes in federal role and policy.

10.2.6. Bordas' General Policy Recommendations

In Chapter 8, Bordas concludes that, to the extent risk management exists at the state and local level, the technical aspects of risk overwhelm the capacity of authorities to manage their responsibilities systematically. The press of special interest groups, the poor coordination between federal and local authorities, the legal impediments to a reasonable management approach, and the major constraints on resources, all militate toward a situation in which the institutional capacity of both states and local government to mobilize the needed resources is seriously deficient. As a consequence of technical, institutional and and cognitive problems, Bordas finds the character of state and local risk management policy to be reactive, piecemeal, episodic and dependent on the prevailing issues of the day.

Bordas makes several general policy recommendations to improve this situation as follows:

- workshops on risk management for state and local officials
- pooling of resources for risk management among smaller communities
- federal assistance through categorical rather than block grant dispersal
- the development of a state office of risk assessment.

Bordas' recommendations are similar to those of Apostolakis and of Meyer, where they deal with similar specific topics.

10.2.7. An Incentive Approach in Risk Management

In Chapter 9, Gordon proposes that an incentive approach be used for risk management, at least in part, rather than a reflexive move to standards and regulations. He argues that where property rights or liabilities are poorly defined, risk is transferred from the liable party to the public-at-large, and that this undesirable situation should be altered, if possible, by an internalization of risk. Where liability is currently limited, he would have the risk manager seek to determine if the risk can be transferred to the producers of the hazard by requiring full liability insurance, which would, somehow, have to be made available. Gordon argues that limited liability leads to the wrong incentives for the risk producer.

Gordon's analysis is similar to that which economists apply to common property resources with the main difference being that the degradation of the common property takes place with a probability less than unity.

Gordon argues that there are cases where, because the appropriate kind of insurance is unavailable, desirable societal ventures or services become unavailable or the risk is transferred to the public-at-large because of the absence of insurance. He would have the risk manager seek to detect instances where publicly provided insurance (or co-insurance) would transfer risk away from the public-at-large. The case of inadequate liability assignment leads to diminished demand for risk-pooling. The latter instances, however, have to do with problems in the supply side.

Gordon's proposals appear to be applicable primarily to hazards whose consequences are clearly attributable, e.g., drowning due to failure of a dam. It is not clear how insurance would be used to deal with chronic hazards whose effects are only inferable, e.g., pollution of air, drinking water or food. In principle, a risk tax could be used to internalize such risks. Gordon mentions this, but it is not included in his specific proposal.

While Gordon has examined herein in a bit of depth some aspects of insurance as an incentive approach to risk management, Baram (1982) has very recently discussed a wide variety of alternatives to regulation for managing risks to health, safety and the environment. These include common-law alternatives, private voluntary self-regulation, insurance and other compensatory plans and government influence. Baram examines these in the context of three case studies, including that of hazardous waste. Baram finds that alternatives to regulation seem to be most appropriate for deterring risk due to fires, explosions and poison gas emissions because the causes and injury effects would be clear in these instances. However, in his opinion, long-term, post-closure dangers of fire, explosion and poison gas emissions warrant regulation to supplement common-law and insurance mechanisms, because of their limitations even though they may provide incentives to responsible practice. Baram concludes that the hazardous waste problem creates certain risks that are too severe in their impacts to leave entirely to non-regulatory devices. Baram does not examine the risk tax as an alternative to rules and regulations, one which may at one and the same time internalize the cost of risk and provide an incentive to the source of risk to reduce the risk in a cost-effective fashion. The study group recommends that serious study be given to the formulation of pragmatic approaches to a risk tax.

10.3. Some Conclusions

There are some important commonalities among the findings and points of view presented by the various study participants in Chapters 2 through 9 and the associated topical reports. There is considerable support for an increased role by state government in risk management, supported by a central (federal) risk management information system. There is no support for the concept of a "strong" risk management office for each local government entity.

Meyer and Solomon conclude that the network model of weak risk managers may function most effectively within constraints bounding an overall system for local government risk management. This approach is not incompatible with Gordon's suggestion for the use of economic incentives via insurance for those situations to which it applies. Nor is it necessarily incompatible with Apostolakis' discussion of the sophisticated technocratic function of an office of risk assessor. Apostolakis and Bordas both conclude that the demands for such an office require that it be a state rather than local function. In fact, the demands are sufficiently great that it would require federal support for an information bank and for the more difficult problem areas, e.g., those requiring extensive research and development or highly sophisticated analyses; and it could benefit greatly from a network approach between states, reducing sharply the likelihood of wasteful repetition of analysis and permitting advantage to be taken from experience of others. However, even if many states found it meritorious to establish a relatively "strong" risk management function, it is likely that few, smaller governmental entities would do so, and a network of "weak" local risk managers should still provide an important function.

There may be merit in merging what Meyer called radical decentralization into the practice of network risk management for those hazards for which it is a suitable tool. Similarly, consideration should be given to the use of a risk tax both as a method of internalization of the cost of risk and to provide incentives for the use of cost-effective measures to reduce risk.

Meyer and Solomon suggest several studies that would be appropriate as a next step in examining the network approach. It seems that such studies might well involve groups like the National Conference of State Legislatures or the National Governor's Association.

Each state will have its own special risks to consider. Each state will have its own strengths and its own limitation on resources. One cannot expect to deal with all of these contingencies simultaneously. However, a joint examination of the feasibility and desirability of a network approach by several state and local governmental entities, together with an examination of the implications for a changing federal role, could provide the necessary information for a judgment on whether there is merit in some version of the network alternative to risk management.

An important finding, one which is central to an improvement in local risk management, is the need for introducing quantitative conceptions of risk at the local level, to complement the traditional political and social conceptions. The frequent absence of thinking of risk in quantitative terms necessarily leaves a void in the information entering the decision making process; this must be remedied if an improved approach to risk management at the local level is to be developed.

Bordas' recommendation that workshops on societal risk management be held for state and local government authorities may be worth pursuing, not only to provide individuals with information and a way of thinking systematically about risk, but to provide a mechanism for discussing alternative approaches that might be followed individually and cooperatively by state and local governments.

Although the study group has found that many governmental bodies at the local level do not deal with quantitative risk concepts or preventive risk management, there are, of course, situations which illustrate the converse condition. For example, a risk management plan has been drawn up for the Port of Long Beach (1981) in accordance with a requirement of the California Coastal Commission. The plan is intended to accomplish the following:

- o Identify, quantify and analyze the existing hazardous liquid bulk activities and sites in the two ports,
- o Develop the analytical methodology to measure the degree of risk for application to any proposed development, whether that project represents a defined hazardous facility or whether a proposed non-hazardous facility were physically to be sited within an area that might be subject to some degree of risk from a hazardous facility,
- o Develop criteria and standards based on the methodology and the policies to be applied at the inception of project development planning, and to serve as mandatory requirements for compliance as siting, design, construction and operating criteria as the basis for the granting and issuance of a Coastal Development Permit by the port governing body, and
- o Provide a relatively detailed working manual or technical reference as a guide in preparing the Risk Management Plan, and analyzing the risk factors in each future development project.

Similarly, it is clear that some agencies of state government do take quantitative approaches to the management of specific risks. For example, in connection with the contamination of water supply wells with trichloroethylene, the Department of Health Services of the State of California drew up quantitative guidelines in 1980 in terms of the excess lifetime cancer risks attributed to various exposure levels.

Nevertheless, even a major state like California has not addressed all risks in this fashion or organized a truly systematic approach to preventive risk management.

A considerable number of specific issues which require further study have been raised during this project. Several of these are discussed briefly below:

- o How should state and local governments approach the question, "How safe is safe enough?", for those hazards for which they have responsibility and for which guidance has not been provided by federal regulatory agencies or other recognized authoritative groups? Sarin, among others, points out that benefits and societal needs among other attributes, may enter into a judgment that something is "safe" or "unsafe". Thus there will not be a unique definition of "safe". Nevertheless, decisions are continually being made by state or local government which indirectly involve an imposition of risk on their constituents. And, frequently, by acts of omission, they permit risks later judged to be intolerable to be imposed on their constituents. How should society ascertain whether the upper threshold of acceptable risk is being violated for some of the people? At what point would resources expended to do this exceed the benefit obtained? Are there risks which are flatly unacceptable and which require a mechanism to assure their identification and correction?

- British law imposes a requirement on technological facilities to keep them as safe as practical. Is there a similar requirement in the United States? If not, should there be, and how should it be instituted? Would such a requirement provide the appropriate incentives for risk management or is it limited to "attributable effects"? If so, is there a workable mechanism which achieves the transfer of the cost of risk from the public to the liable party for non-attributable risks?

- Is there a mechanism for achieving a more cost-effective expenditure of societal resources committed to risk reduction? Should cost-effective expenditure for risk reduction be a goal of state and local government or should socio-political factors dominate?

- The safety of the storage of large quantities of hazardous chemicals appears to be the responsibility of local government for the most part. This is largely handled via regulations imposed by the fire and building departments, or their equivalent. Experience in the United States and elsewhere indicates strongly that catastrophic accidents are rarely evaluated in this process and that the risks involved to individuals living or working nearby can vary widely and sometimes be quite large. In view of the general conclusion that local governments generally lack the resources and expertise to regulate adequately the storage of large quantities of hazardous chemicals, what, if anything, should be changed? Should a federal or state approach similar to that under adoption in the United Kingdom (similar to model 5 of Meyer and Solomon) be adopted?

- Are the current EPA regulations with regard to the disposal of hazardous wastes and to local sources of ground, water and air pollution adequate? If not, how should they be changed? If adequate in principle, do they work in practice? What does it take at the state and local level to assure the necessary compliance?

- How should limitations on total available societal resources be factored into risk management at the state and local level? Can analysis provide meaningful answers on when further expenditures on direct risk reduction may lead to a net increase in societal risk because of economic or political disruptions? Are such considerations of importance only in a national sense or do they apply at the state and local level? If so, how?
- Frequently, measures taken to reduce one risk introduce a new risk, possibly of a different nature. Can the matter of competing risks be included into risk management at the state and local level? If so, how and under what circumstances?
- If the state has jurisdiction and responsibility for managing risks that can impact strongly on a local governmental entity, either from the point of view of health or economics (e.g., the costs of cleanup or of alternate and expensive facilities such as new wells made necessary because of contamination of the old ones), how should local government assure itself of the adequacy of the steps taken by others on its behalf?

The problems in developing a more systematic and more nearly optimal approach to risk management at the state and local level are difficult, to say the least. Nevertheless, the continuing series of episodes of local ground, air and water pollution reported almost weekly in the press are only one piece of evidence that all is not well in this regard. There has been some sentiment in the U.S. House of Representatives for the introduction of a coordinated program for improving and facilitating the use of risk analysis by federal agencies concerned with scientific and technological decisions related to human life, health and protection of the environment. Bill HR 3441, introduced into the 97th Congress by Congressmen Ritter of Pennsylvania, Fuqua of Florida and Brown of California, is one visible sign of such interest.

It is not clear that further study of existing risk management practices at the state and local level would necessarily yield useful outcomes. However, more systematic study than that undertaken here could be helpful if it were to precede exploration of, and experimentation with, alternatives to the current pattern of management primarily by compliance. Such research could provide a benchmark against which to compare effects of innovative forms of risk management. The impetus for state and local efforts to devise new risk management strategies may have to emanate from the federal government. However, this does not mean that states and localities would not have primary responsibility for devising their own risk management strategies and balancing their costs against both tangible and intangible benefits.

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APPENDICES

APPENDIX A

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ALTERNATIVE RISK MANAGEMENT POLICIES

FOR STATE AND LOCAL GOVERNMENTS

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APPENDIX B

Reports Emanating from Study Entitled

"Alternative Risk Management Policies
for State and Local Governments"

National Science Foundation Grant PRA 79-10804

Final Report, Alternative Risk Management Policies for State and Local Governments	UCLA-ENG-8240
Executive Summary, Alternative Risk Management Policies for State and Local Governments	UCLA-ENG-8241
Risk Management Practices in Local Communities: Five Alternatives, Meyer, M.W. and K.A. Solomon	UCLA-ENG-8242
Management of Risks Associated with Drinking Water at the Local and State Levels, Solomon, K.A., M.W. Meyer, P. Nelson, J. Szabo and R. Tsai	UCLA-ENG-8243
Risk Management Policy for Earthquake Hazard Reduction, Sarin, R.K.	UCLA-ENG-8244
Classification of Risks, Solomon, K.A., M.W. Meyer, P. Nelson and J. Szabo	UCLA-ENG-8245
Problems of State and Local Risk Management: An Overview, Bordas, W.	UCLA-ENG-8246

APPENDIX C

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ALTERNATIVE RISK MANAGEMENT POLICIES
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