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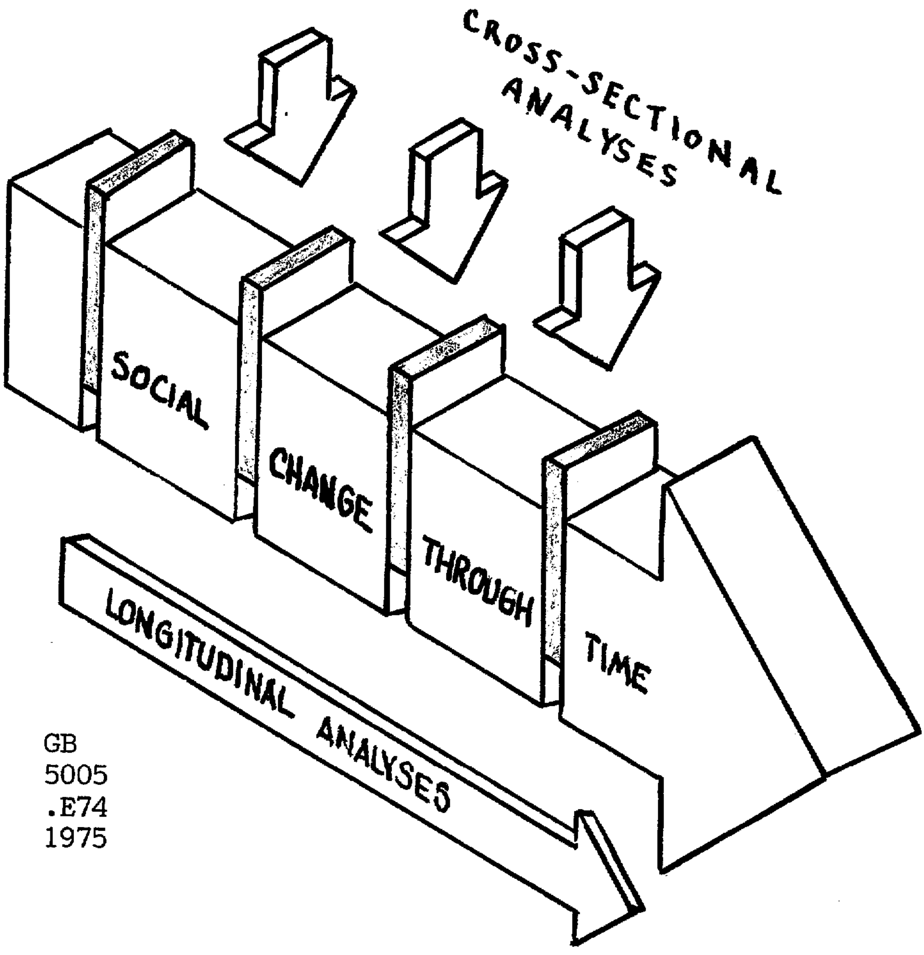
# SCENARIO METHODOLOGY IN NATURAL HAZARDS RESEARCH

**Neil J. Ericksen**





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Together, the entire staff of Assessment of Research on Natural Hazards (J. Eugene Haas and Gilbert F. White, Co-Principal Investigators) developed the objectives, approaches, methods and procedures, and gave assistance which contributed to the production of this volume.

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## ASSESSMENT OF RESEARCH ON NATURAL HAZARDS
## AIMS AND METHODS

The Assessment of Research on Natural Hazards is intended to serve two purposes: (1) it provides a more nearly balanced and comprehensive basis for judging the probable social utility of allocation of funds and personnel of various types of research on natural hazards; (2) it stimulates, in the process, a more systematic appraisal of research needs by scientific investigators in cooperation with the users of their findings.

The basic mode of analysis is to examine the complex set of interactions between social systems and natural systems which create hazards from the extreme geophysical events. The chief hazards investigated relate to: coastal erosion, drought, earthquake, flood, frost, hail, hurricane, landslide, lightning, snow avalanche, tornado, tsunami, urban snow, volcano, and windstorms. For each of those hazards the physical characteristics of the extreme events in the natural system are examined. The present use of hazardous areas and the variety of adjustments which people have made to extreme events are reviewed. The range of adjustments includes measures to modify the event, as by seeding a hurricane; modifying the hazard, as by adjusting building or land use to take account of the impact of the extreme event; and distributing the losses, as by insurance or relief. Taking all of the adjustments into account, the impact of the hazard upon society is estimated in terms of property losses, fatalities and injuries, and systemic disruption. An effort is made to identify the directions of change in the mix of adjustments and in their social impact. As a part of this review, those forces in the national society which shape the decisions about adjustments are appraised.

Authorities in the field are consulted through the medium of literature review, workshops on specific hazards, a national conference which was held in October, 1973, and individual reviews. Where appropriate and practicable, simulations of the extreme events and of their social impacts are carried out. In selected areas scenarios of past and possible future events and their consequences are constructed.

In the light of this analysis the possible contributions of research to amelioration of the national condition with respect to each hazard are assessed. Each set of adjustments is reviewed in terms of its potential effects upon national economic efficiency, enhancement of human health, the avoidance of crisis surprise, the equitable distribution of costs, and the preservation of environmental options. Evaluation of particular research activities includes (1) the average sum of social costs and social benefits from application of a given adjustment in changing property use, and (2) reduction in average fatalities and casualties. In addition to the direct impacts of extreme events upon society, account is taken of the costs and benefits which society reaps in seeking to cope with the hazards, as in the case of costs of insurance or of control works.

In addition to calculating the average effects of hazard adjustments, an effort is made to estimate the degree to which the occurrence of a very rare event which has dramatic destructive potentialities, such as an 8.0 earthquake or a 200-year flood, would disrupt society.

Estimates also are made of the extent to which the adoption of an adjustment reduces the options of maintenance of environmental values, and the degree to which the pattern of distribution of income among various groups in society may be changed.

Research proposals are appraised in the light of the likelihood that the research undertaken could yield significant findings, and the likelihood that once the research is completed satisfactorily, the findings may be adopted and practiced by the individuals or public agencies in a position to benefit.

The United States as a whole is doing a competent job of dealing with some aspects of its natural hazards and a very ragged job of handling other aspects. The overall picture is one of rising annual property damage, decreasing loss of life and casualties, coupled with a marked growth in the potentiality for catastrophic events. On the whole, the public costs of adjustments are increasing.

The assessment reveals that very little is known about the dynamic relationships among many of the adjustments. It is difficult to predict with any confidence what the consequence of new Federal investments or initiatives will be in particular adjustments.

For each hazard a set of research opportunities deserving special consideration for early adoption is presented. In addition, three types of research which cut across the various hazards are assessed: warning systems, land management, and relief and rehabilitation.

Among the research basic to other aspects of natural hazards activity are: carefully planned post-audits of certain disasters and of adjustment measures by interdisciplinary teams; community observations over time of critical points (recovery policies and administration, health, mental health, and preventive measures) of change and of the effects of Federal-state-community interaction; and a clearinghouse service.

In most research fields it is noted that certain types of research which have claimed substantial amounts of public support offer little prospect of effecting a basic change in the character of the national hazard situation. In those instances there are new lines of emphasis which promise larger returns. Many of these involve more explicit collaboration of social scientists and natural scientists than has been customary in past. Wherever appropriate, the research recommendations include explicit provision for the translation of research findings into action by individuals or public groups.

To initiate effectively the desirable new lines of research will in some instances require a readjustment in legislative authority. In other cases it will require an increase in or reallocation of public funds for research. Much of it will involve changes in administrative procedures and policies of the responsible funding agencies. In many instances the effectiveness of the research will be linked strongly with the resolution of issues of public policy. These issues evolve around national land use management, financial assistance to sufferers from disasters, and the sharing of responsibility among local, state, and Federal agencies in designing and maintaining community preparedness.

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## AUTHOR'S PREFACE

Although speculative and often highly dramatic in nature, scenario writing involves "constructive, scientifically controlled imagination" (Helmer, 1966, p. 10). As such, it provides but one means among many for exploring alternative futures. This monograph examines the scenario method and attempts to develop and adapt it as a means for evaluating linkages within natural hazard systems and options for managing their future at the local community level. The method is applied in detail to flood hazard at a single place--Boulder, Colorado.

At a time when yearly losses and catastrophe potential from many natural hazards appeared to be increasing dramatically, the Assessment of Research on Natural Hazards Project was concerned with analyzing the degree to which changes in research would lead to a systematic reduction of the negative social consequences of such natural hazards as floods, earthquakes, hurricanes, tornadoes, and the like. In providing a basis for evaluating alternative public policies and new research programs for dealing with these hazards, the Assessment Project attempted to appraise the possible social costs and benefits of a range of alternative public policies, and to outline the nature and degree of needed research tasks and their expected future payoffs.

Trying to assess the impact of research efforts that could possibly lead to the adoption of new adjustments or to changes in the adoption level of existing adjustments to various hazards is a difficult task, especially when tied to the need for knowing the likely future outcomes of any one change or combination of changes. Essentially, this is a problem in social dynamics. It involves speculation about the evolution of a complex social system over time: the anticipation of an unknown future.

In treating the dynamics of natural hazard systems, the Assessment Project employed two main methods of analysis, computer simulations and scenarios; each heavily reliant upon information derived from previous empirical research. The computer simulation model and its various applications may be found in respective project monographs (Friedman, 1975; White, *et al.*, 1975; Ayre, *et al.*, 1975; and Brinkmann, *et al.*, 1975). An evaluation of the scenario method and its application to urban flood hazard is the subject of this monograph.

The idea for using scenarios emerged from the project's first workshop on flood hazard in September, 1972, when the advantages of its application were first broadly outlined by Professor Robert W. Kates. At that time one reason for employing scenarios at the community level was to provide a link between the social effects of changing public policy on hazard adjustments at national aggregate--arrived at principally through computer simulations--and those that might conceivably occur at local level.

While computer simulations of future alternatives can be, and have been applied at the local level (Ayre, *et al.*, 1975), it is difficult to capture in them the complexity of decisions that help generate dynamic social systems, and the sudden shifts in a system's direction of evolution that accompany unexpected events or developments. That is to say, the curves of change-over-time that are produced as computer output tend to smooth over the complex decisions that help create change--change which may more often than not be sudden and dramatic rather than gradual in effect. It was envisaged that scenarios would have some capacity for illustrating, at least partially, these aspects of system change.

In its final form, the monograph has been divided into two parts. In Part I the need for viewing natural hazards as dynamic systems and some of the shortcomings in earlier perspectives and methods are discussed in Chapter I. Because the scenario method is new to natural hazards research, a general evaluation of its nature and use is given in Chapter II. In Chapter III, a scenario model and method is developed and adapted for research into natural hazard futures in general and flood hazard in particular. The scenario method is then applied to the flood problem of Boulder, Colorado.

The application of method forms the substance of Part II. It includes: an historical evaluation of flood plain management in Boulder (Chapter IV); a hypothetical catastrophic event under existing conditions of flood plain development (Chapter V); and scenarios of alternative past and alternative future flood plain management policies (Chapters VI and VII). The findings from the scenario applications are synthesized in Chapter VIII and their implications for changed research at local and national levels are discussed in the concluding chapter.

Numerous individuals have contributed information, time, and effort to this study. First, the author owes a great debt of gratitude to the co-principal investigators of the project, Professors Gilbert F. White and J. Eugene Haas, for first inviting him to participate in their investigation and later in allowing him to develop and apply the scenarios as he saw fit. Their flexibility, patience, and insightful criticisms were a much needed source of encouragement to the author as he groped his way towards some understanding of the task set him.

He benefited, too, from the stimulating atmosphere engendered by the project staff. Discussions, both formal and informal, often focused upon the scenario. To several persons go very special thanks: to Dick Warrick for his many critical reviews of early ideas and drafts; Hal Cochrane for the dynamic systems perspective he brought to bear, and Wally Brinkmann for her helpful and timely discussions. To Sarah Nathe go thanks for editing the early and final drafts and to Doris Knapp and Karen Bird for typing them. Dick Nervig skillfully drew the maps and diagrams.

A case study is not possible without the help of local people. In this instance it was always obliging and generous. Personal thanks are necessary to Mr. Ted K. Dieffenderfer, Director of Operations, City of Boulder and Councilman Kenneth R. Wright for lengthy discussions and review of materials.

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It is hoped that intelligent use has been made of the critical comments provided by reviewers of earlier drafts. From the University of Toronto, Department of Geography they include: Professors Larry Bourne, Ian Burton, Lino Grima, Allen Scott, Jacob Spelt, and Joe Whitney, and fellow students Ed Jackson and Paul Wilkinson; Donald Janelle, Department of Geography, University of Western Ontario; and staff and consultants to the Assessment Project, Gilbert White, J. Eugene Haas, Ian Burton, Robert Kates, and Dick Warrick.

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Neil J. Ericksen

<u>Boulder</u>
<u>February, 1974</u>

# PART I

# A SCENARIO APPROACH TO NATURAL HAZARDS: CONCEPTS AND METHODS

# CHAPTER I

# NATURAL HAZARDS AS DYNAMIC SYSTEMS

This work adapts and applies the scenario method to natural hazard management strategies. Before discussing the method, the nature of the problem area--natural hazards--is outlined. Since the scenario method is generically systemic in approach, it is essential that the problem of natural hazards be discussed within a systems framework. Fortunately, models already exist for doing so (Kates, 1970).

## The Human Ecology of Natural Hazards

In simplest terms natural hazards may be defined as "those elements of the physical environment, harmful to man and caused by forces extraneous to him" (Burton and Kates, 1964, p. 413). Thus, by definition, a natural event in itself--be it flood, earthquake or hurricane--is not necessarily a hazard, for its hazard potential is not realized until related to man and his works. The hazard potential, which is realized primarily in terms of human casualties, property damages, and social disruption, depends not only on characteristics of the natural event (such as variation of the magnitude from the norm), but on characteristics of human activity (such as the culture and society and related land use practices and the degree to which people are prepared to meet the event). But, whatever their type, extreme natural events may be seen as representing environmental threats to which man will adjust or adapt, or, perhaps even largely ignore, according to his perceived needs and wants and his abilities for converting environmental resistances into resources (Hunker, 1964).

Recently, natural hazards research has come to view natural events and their damaging consequences in the context of man's ecology (Burton, *et al.*, 1968; Hewitt and Burton, 1971; Kates, 1970). Since natural hazards may be considered as the more extreme and damaging manifestations of events that under normal conditions are closely integrated with man's activity and sources of livelihood, it seems appropriate to consider a community's level of tolerance in terms of its ability to absorb damage and the means by which man adjusts to perceived environmental threats. This requires establishing thresholds at which levels of "normal" environmental events end and damage begins. The consequence of this ecological perspective is stated by Hewitt and Burton (1971):

> Hazard and disaster potential relate as strongly to the normal activities of a community as to the particular nature of the extreme event. In the long-run it is necessary to view hazard events not simply as unique situations unrelated to ordinary conditions. Rather, hazards are largely implicit in the ordinary conditions, and it is important to define the latter as well as the former.

Implicit in this statement is the notion that in coping with natural hazards, their dynamic and systemic nature should be taken into account.

## Natural Hazards As Dynamic Systems

This ecological perspective of human response to natural hazards has been modelled by Kates in a systems framework. It is portrayed schematically in Figures I-1 and I-2. As seen in Figure I-1, the model includes a natural events system (characteristics of which include the magnitude, frequency, duration, and temporal spacing of an event) and a human-use system (including human occupance, activities, damageable materials, and state of preparedness to meet the natural event) which interrelate to produce a natural hazard. The hazard event evokes three sets of responses according to criteria defined in the adjustment process control sub-system (shown as the shaded box in Figure I-1 and in more detail in Figure I-2). In gross terms, the responses may include: 1) post-event emergency adjustments; 2) natural event modification adjustments; and 3) human-use modification adjustments. A more detailed classification of adjustments as they relate to flood hazard is given in Table III-1.

The adjustment process control sub-system may be considered as the "black-box" of the model. It is on this essentially perception-adoption process that much geographic hazards research in the 1960's focused. Conceptually, there are three major "sequential components" of the adoption process. First, there is the hazard perception threshold. Threshold levels are seen to be a function of hazard perception, hazard experience, and a range of personality characteristics. The personality characteristics thought to be most relevant are: attitudes towards fate; belief in the efficacy of action; views of the man-nature relationship; tolerance of dissonance; and the propensity to seek stimulus or stress or to take risks.

HUMAN ADJUSTMENT TO NATURAL HAZARDS:
A GENERAL SYSTEMS MODEL*

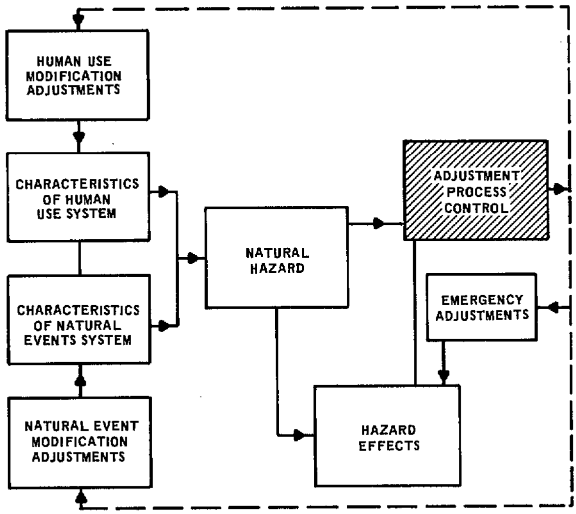
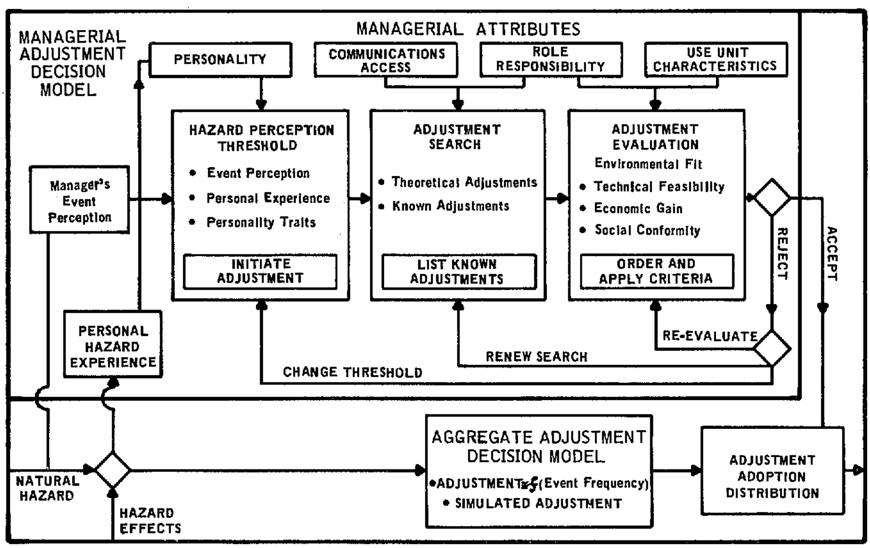



FIGURE I-1

ADJUSTMENT PROCESS CONTROL MODEL




(From Kates, 1970)

FIGURE I-2

Second, when the threshold level is exceeded, that is, when hazard is perceived as warranting consideration for action, a search for adjustments begins. This search almost never approaches the range of those adjustments that are theoretically possible, and continues dependent upon the extent to which the threshold level has been exceeded and may be exceeded subsequent to future action (White, 1961).

Third, decision criteria specify four main constraints on the adoption of any perceived alternative: 1) that it be technologically feasible; 2) that it be economically gainful; 3) that it be socially acceptable, and 4) that it be environmentally attractive (see Hunker, 1964; Firey, 1960; and White, 1961).

From this model of natural hazards, three important characteristics emerge. First, natural hazards are to be viewed as *systems* with identifiable components or subsystems. Although disruption of the social system is the direct result of the impact of the physical event, the model suggests that social development through time forms an essential aspect of hazard potential--and, therefore, disruption--when the event occurs. Thus, the natural hazard system may be thought of as a social system. Second, since components of the natural hazard system interact in ways that produce positive and/or negative feedback effects upon each other, natural hazards can be thought of as *dynamic* systems. Thus, in the manner of Meadows, it is possible to define principal parameters of the natural hazard system, establish rates and levels of interaction between them, write differential equations for these interactions, and, in a computer, simulate the system's change over a given period of time (Meadows, *et al.,* 1972). An important limitation on this view of a dynamic system is, however, that it is *mechanistically* causal. This broaches the third characteristic of natural hazards--the type of dynamism manifested by it. As with all social systems, natural hazards are *evolutionary* in nature. This means that, unlike a mechanistic system, they are largely *unpredictable as to future outcomes.* In other words, social systems, such as natural hazards, are not constant. They change over time as elements within the system interact and modify. Because of the learning and adaptive capacities of man--as described by the adjustment-adoption process in Figure I-2--the natural hazard system is unlikely to follow a prescribed and, therefore, predictable path (as in a mechanistic system), but will deflect as parameters within it change in tandem with the system's evolution. It is with this unpredictable aspect of system change that scenarios are particularly concerned.

While it is possible that the occurrence of the hazard event may itself cause massive disruption of the hazard system with consequences that, in the short-term, may be viewed as *revolutionary* in nature, it is still appropriate to view natural hazards as systems that behave in an evolutionary and adaptive manner. This is so for two main reasons. First, in purely physical terms, occurrence of extreme and severe hazard events is rather infrequent. Mostly, occurrences are minor and frequent, and this may be reflected in the social state of the hazard system in that disruption may be low and easily absorbed. Second, as already described, hazard potential changes over time as social organization evolves in relation to exposure to natural events of any given size--the 100-year or 1% flood, for example.

Thus, whereas a mechanistic system does not allow for change in its internal organization, the evolutionary system adapts to changes in the environment through changes in its internal structure according to available levels of information (Jantsch, 1972, p. 494). For natural hazards, this would refer to information about the natural event in relation to social organization.

Modern man does not, however, passively adapt to the environment, but makes conscious, purposeful efforts to adjust to it: a process that may take place by modifying either the natural event system or the social organization system (Figure I-1). Thus, natural hazards may also be thought of as *inventive* or *human action* systems since, through planned action, they have the capacity to alter the environment intentionally through the internal generation of information. In so doing the system purposefully changes its internal structure (Jantsch, 1970; 1972). It is with the possible future course of planned action and, therefore, natural hazards as dynamic inventive systems, that this monograph is primarily concerned. In particular, it is concerned with scenarios of alternative futures of flood hazard in Boulder, Colorado. But for illustrative purposes, the focus for scenarios could just as easily have been for landslides in Telluride, Colorado; hurricanes in Sarasota, Florida; or earthquakes in Los Angeles, California.

The foregoing discussion on the nature of natural hazard systems can be illustrated by reference to some specific, but brief, examples about the management of flood hazard.

Research and Policy on the Flood Hazard System

Although for many years there has been research into the social implications of natural hazards by geographers, sociologists, and economists, the undesirable consequences of human inaction or injudicious action, vis-à-vis natural hazards, have been phrased mainly in terms of past and present problems. There has been little, if any, attempt at systematically exploring the paths along which future long-term outcomes--desirable or undesirable--might come into being.* What is more, much research and policy on natural hazards has failed to treat the systemic and dynamic aspects of the problem adequately. For example, they largely omit consideration of exogenous factors of choice--both hazard and non-hazard--that help mold the hazard system. That is to say, there are forces in society that can be conceived as operating outside of the natural hazard system, but which nevertheless affect it. Decisions relative to these external or exogenous forces, such as the broad cultural value of economic growth, affect damage potentials in no less an important way than a decision to adopt or reject a specific adjustment. Thus, problems of man coping with environmental threats have been assessed primarily in static isolated terms: by examining, for example, a single adjustment adopted at a specific point in time and without due regard for forces that may adversely alter its efficacy over time.

Take the case of flood hazard as an example. Post-audit evaluations show that solutions to flood problems offered by several Federal agencies have, in the past, failed to the extent that flood losses have been continually on the increase in spite of increased budgets for the construction of engineering protection works. They failed in meeting their goals because expected outcomes were based upon the assumption that man would react to protection works in an economically rational manner (White, 1966). In other words, Federal agencies assumed that the efficiency criteria used by them in evaluating flood plain occupance and human response to flood plain projects were the same as those used by

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*The suggestion that exploration be made of paths along which future outcomes might be reached contradicts the statement made in the previous section that social systems are largely unpredictable as to future outcomes. As de Jouvenal points out, knowledge about a future yet to come is a contradiction in terms. This need not mean, however, that we should not think or conject about future possibilities as is explained further in Chapter II (see de Jouvenal, 1967).

individual flood plain occupants. Perception studies indicate that such is not the case, for individuals have been observed to act in a boundedly rational, suboptimal, or satisfying manner (Kates, 1962).

In other instances, benefit-cost analyses of urban flood projects have revealed ratios unacceptable to the sponsoring agencies so that requests by local authorities for Federal flood protection works have been denied. Such was the case at Rapid City, South Dakota where three Federal agencies carried out six project evaluations between 1931 and 1969. On each occasion the city was informed that project costs outweighed the benefits in flood-loss reduction. Yet, on the night of June 9, 1972, Rapid City suffered the worst flash-flood disaster in the nation's history. What flaws in the benefit-cost method or use of it by Federal agencies contributed to the 236 deaths and more than $80 million in direct property losses in Rapid City that night? Scenario analyses carried out after the disaster suggest that an integrated flood plain management program adopted during the 25 years 1947 to 1972 could conceivably have reduced property losses to under $25 million and lives lost to less than one score (White, *et al.*, 1975; Ericksen, 1975).

Although the Federal solution to flood problems has recently progressed from its early focus on dams and levees to include a range of social solutions (such as flood-proofing buildings, land use management, warning systems, and flood insurance), there has been little or no research on the possible social consequences of adopting single or integrated flood-loss reducing policies at the national or community level. Given the experience of the past 40 years in flood-loss reduction efforts, the nation cannot afford to await the passage of time appropriate for carrying out future post-audit evaluations of current policies in order to assess their effectiveness. As the outcomes from scenarios of alternative futures in Chapter VII indicate, social adjustments that are currently seen as fundamental to the new unified perspective on flood-loss reduction carry within them seeds of change that could conceivably increase rather than decrease catastrophe potential in flood-prone communities. Policy seen as intuitively effective from the Federal viewpoint in reducing flood losses may--through its interpretation and application by individuals and groups who make decisions which directly or indirectly influence the flood-loss potential--prove pragmatically ineffective at community level. Will people really go out and buy insurance against a physical event the nature of which may be poorly perceived? Will people buy flood insurance if they have been forced through social regulation to flood-proof their houses and buildings? Are there more powerful factors that lie outside of the immediate flood hazard system that will countervail new flood-loss reducing policies? Will regulating the social system via land use management lead to perversities in the hazard system similar to those already observed in regulations of the physical system through flood control schemes? At the community level, the answers to these and similar questions remain largely unknown.

Insofar as current techniques and methods permit, serious attempts should be made at trying to anticipate the beneficial and adverse social consequences of implementing new policies on flood and related hazards. Yet, at a time when Federal agencies, such as the United States Army Corps of Engineers, are honing their evaluative tools to handle not only first but also second order effects of implementing engineering protection in urban communities, they find themselves hamstrung by the lack and inadequacy of methods for evaluating the social adjustments that they are increasingly being called on to consider.

The scenario method provides an approach for thinking about elements of strategies for coping with natural hazards within a dynamic systems perspective. In this vein, scenarios may be used to explore the paths along which futures, dependent upon critical decisions, may trend. In so doing, it is possible to illustrate how current processes may operate into the future and the possible consequences of such operations. In speculating on possible trends and outcomes, the scenario method may prove useful in identifying important linkages within the natural hazard system itself.

More specifically, the objectives of the scenario approach used in this study of flood hazard in Boulder, Colorado are to provide some understanding about why adjustments are or are not adopted; to assess how changes in the flood hazard system might have occurred if constraints to the adoption of adjustments had been removed; and to assess the interaction among adjustments and the consequences this holds for reducing or increasing hazard potential. These are very limited objectives when compared with the problems raised above. Thus, rather than trying to treat the cosmic problem of social costs and benefits that stem from changes in flood hazard policies, this monograph will focus upon the negative aspects of future flood-loss potentials in relation to alternative flood-loss reducing policies. This is an essentially speculative task, one that requires anticipation of changes in the progression of the flood hazard system under varying initiating conditions or assumptions. The scenario method is employed to help deal with this task.

## CHAPTER II

## AN EVALUATION OF THE SCENARIO METHOD

### The Image of the Future

Inasmuch as this study has as its basis the development of a methodology that aids in specifying progressions towards alternative future environments, it seems useful to begin with discussion, however brief, of imagery--not imagery in terms of the past and present and its implied significance for future environments, as behavioral geography would now have us do, but the image of the future explicitly treated as a fundamental element in the relationship between humans and their environments (Downs, 1970).

Polak, in his study of major civilizations, demonstrates not only how each culture appears to have held its own unique image of the future, but that the image's strength reflects the degree of its cultural dynamism (Polak, 1961). Thus, "positive images of the future can be regarded as a primary causal factor in cultural change" (Bertaux, 1968, p. 19).

From the perspective of our own experiences, we know that decisions made now will influence future conditions, just as conditions today are the result of past decisions. We know, too, that today's decisions have not only grown from past experience, but reflect future expectations. We are not only pushed by history, but pulled towards the future by powerful images of it.

Although we are constrained by our history and existing environment, by and large we are free to choose our own image of the future. According to Bertaux (1968, p. 20), this means that:

> The future--in the form of the psychological fact of the image of the future--is capable of becoming an element of determination in the causal chain. Through an image of the future, the time-to-come is already affecting the present.

If, however, half of men's actions are ruled by chance, and the other half are governed by men themselves, as Machiavelli would have us believe (Machiavelli, cited in Kahn and Wiener, 1967, p. xxviii), then, in this age of rapid change and socio-ecological crisis, it behooves the researcher to reduce random outcomes by producing research results that will help create sharper images on which to base a better future.

The purpose of this chapter is to examine the scenario not only as an analytical and synthetical method, but as a tool that can be used for guiding decision-makers in the decision process. This review will then serve as the basis for developing the scenario as a method for exploring alternative adjustments to natural hazards in Chapter III.

## The Nature of the Scenario Method

### 1. An Overview

The scenario method is an explication of possibilities. Typically, it attempts to set up a logical sequence of events in order to ask how, starting from a given condition, alternative possibilities, good or bad, might evolve (Kahn and Wiener, 1967, p. 8 and pp. 262-267). As exploration progresses along one possible path, a point of fundamental change in the system serves as a new starting point from which new paths may be explored (Polak, 1971, p. 401).

Scenarios allow us to think about elements of a social system "as if" they really did function in the manner described (Vaihinger, 1935). Thus, they do not set out to test hypotheses, but rather, like all scientific fictions, are expedients which enable us to examine such questions as, "What would happen if a given hypothesis were to hold true?" These questions are, however, drawn from a base of real data which is, in turn, varied in an imaginative way by using strict criteria of logical consistency (Polak, 1971, p. 401).

The usefulness of scenarios lies in their ability to help provide insights into decisions needed for preventing, diverting, or encouraging the evolution of a social system at specific points in time (Kahn and Wiener, 1967, p. 6). Clarifying potential directions and destinations helps improve understanding of present-day emphases, major alternatives, and the consequential differences between these alternatives (Bell, 1964, p. 873). As such, scenarios can serve as tools in the decision-making process.

### 2. Scenarios and Forecasting

As one of a great range of techniques employed in future-oriented research, scenarios may be placed within that class of prediction or forecasting that Bunge (1967) calls *prognosis*. As such, scenarios are common-sense forecasts made with the help of empirical generalizations. Each scenario is a logically constructed model of a possible future for which the degree of "confidence" as to progression and outcome remain undefined (Jantsch, 1967, p. 15). Thus, the scenario is not a *scientific prediction,* for neither the initial state of the system nor the laws governing it are known (Bunge, 1967, p. 85). Nor does the scenario prediction rest on positivistic hypothesis testing procedures, for they do not set out to test hypotheses, but are expedient constructs of use in surmising about the consequences of an hypothesis given to hold true (Vaihinger, 1935). In this sense, then, scenarios are intentionally unreal and may therefore be regarded as fictions.

### 3. Scenarios as Scientific Fictions

For Vaihinger (1935), the scientific nature of a fiction is characterized in four main points. First, scientific fictions arbitrarily deviate from reality, for neither premises nor conclusions drawn from ideas and judgments harmonize with reality. Second, the ideas and judgments disappear in the course of history or through the operation of logic, for contradictory ideas have only provisional value until experience is enriched to the point that they can be finally eliminated. Third, since scientific fictions are provisional deviations from reality, there is an express awareness of their fictional nature and absence of any claim to reality. Fourth, it therefore follows that scientific fictions are means to a definite end; they are expedients.

It is this fourth point, that of expediency, which distinguishes scientific fictions from aesthetic fictions or figments (for example science fiction). As Vaihinger (1935, p. 99) notes:

> Where there is no expediency the fiction is unscientific... For us the essential element in a fiction is not the fact of its being a conscious deviation from reality, a mere piece of imagination--but we stress the *useful* (italics mine) nature of this deviation.

The distinction between scientific fictions and higher order scientific concepts, especially the hypothesis, should be apparent. Whereas the hypothesis is an ideational construct that is directed towards reality and demands verification as an expression of reality, the fiction is only an auxiliary construct that becomes superfluous in the course of time. And, whereas the hypothesis attempts to do away with observed contradictions, the fiction brings them into existence. Thus, "the hypothesis tries to discover, the fiction to invent." However, "fictions that do not justify themselves, i.e., cannot be proven to be useful and necessary, must be eliminated, no less than hypotheses that cannot be verified." Yet, as earlier implied, "what is untenable as an hypothesis can often render excellent service as a fiction." (Vaihinger, 1935, p. 85-90).

In summary, then, as scientific fictions, scenarios are expedients in that they provide useful constructs or "as if" statements about possible future real world situations.

4. Exploratory and Normative Scenarios

Although primarily exploratory in nature, scenarios can be used for either exploratory or normative purposes. As an exploratory tool, scenarios may be used to emphasize the evolution of an alternative possibility in the absence of purposeful human intervention (Durand, 1972, p. 328). Alternatively, paths consequent upon critical decisions may be systematically explored--each path itself becoming a named possibility (Kahn and Wiener, 1967, p. 6).

Use of scenarios as a normative tool requires alternative futures to be specified as desirable goals. Scenarios are then used to reach these goals through exploration of alternative paths and decision nodes (Kahn and Wiener, 1967, p. 6). More complex normative scenarios treat goals in a dynamic way such that they feed back to influence points of decision, which may in turn lead to the setting of new goals and alternative paths of achieving them. This distinction between normative and exploratory scenarios is illustrated in the diagrams in Figure II-1.

Thus, whereas exploratory scenarios tend to stress the progression or change in a system over time towards "what could be," normative scenarios focus more upon future outcomes as predetermined, yet dynamically changing, goals of "what should be." While exploratory scenarios may lead to either optimistic or pessimistic outcomes, normative scenarios are typically utopian. This need not mean that the two scenario types are clearly dichotomized; undesirable outcomes generated in exploratory scenarios can serve to identify the means by which normative scenarios may attain more desirable future possibilities.

SCHEMA FOR EXPLORATORY AND
NORMATIVE SCENARIO MODELS

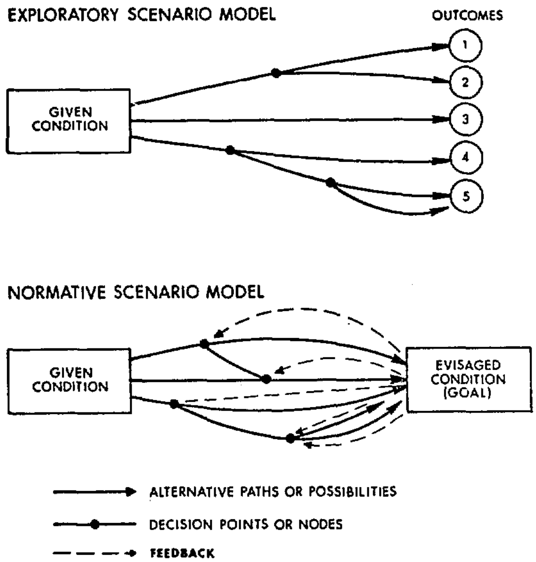


FIGURE II-1

5. Analytical and Synthetical Scenarios

To this point, scenarios have been discussed as a tool for evaluating future alternatives, and, indeed, they are almost always used for that purpose. Scenarios can, however, be used in any time frame--past, present, or future. Thus, for example, Chesterton has written of alternative pasts, or, what he terms the "prophetic past" (Chesterton, cited in Bell, 1964, p. 867). In either case, future or past, the scenario method is a diachronic tool in that one of its functions is to analyze social changes that could occur (future), or could have occurred (past) over a period of time. Scenarios, then, can be used in the longitudinal analyses of the hypothetical histories of either the past or future (Figure II-2).

In addition to its diachronic and prognostic abilities, the scenario can be employed equally well as a synchronic and diagnostic tool. By this it is meant that the scenario is capable of being used to diagnose or identify the characteristics of a given or hypothetical social system. And as a synchronic tool, the scenario brings together or synthesizes the elements of a dynamic system into one cross-sectional picture at a given point in time (Figure II-2). As with longitudinal analyses, these

SCHEMA OF SCENARIOS AS
SYNTHETIC AND ANALYTIC TOOLS

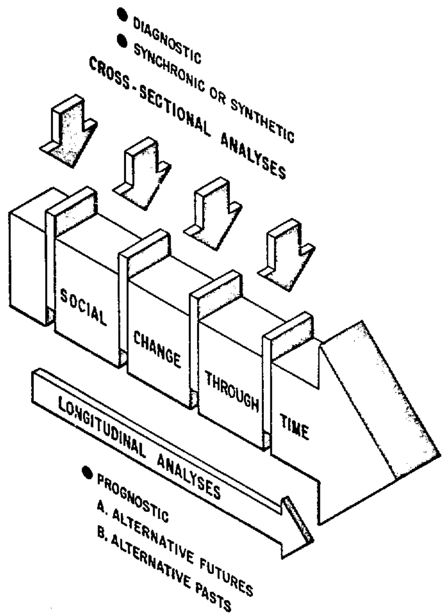


FIGURE II-2

cross-sections can be drawn in any time frame--past, present, or future. The analytical and synthetical properties of scenarios are depicted graphically in Figure II-2. They are expanded upon in the following chapter both in conceptual and operational terms in relation to the flood hazard.

## The Utility of Scenarios

Apart from the analytical and synthetical properties of scenarios which provide some feel for the way interacting elements of a system lead to social change, the scenario has several other important functions. Some of these functions are not necessarily unique to scenarios, but are worth stating. First, scenarios are an heuristic method for studying alternative possibilities. That is to say, they serve as a means for thinking about complex problems that have uncertain outcomes. To paraphrase Kahn and Wiener (1967, p. 263), scenarios help reduce carry-over effects by forcing the analyst to think about the large range of possibilities that accompanies the unfamiliar and fast-changing conditions of the present and future. Scenarios also force the analyst to think about details and dynamics of a system that might easily be avoided in abstract considerations. This would include the interactions of personal, social, and physical forces at play in the system evaluated in a comprehensive and synoptic way. They would also consider the constraining forces that inhibit the operation of more optimal systems. Thus, a scenario makes the analyst think about issues that could be ignored if focus were only upon the real world.

A second function of the scenario method is to help the researcher structure existing information into some sort of coherent whole. But more than this, the scenario has, in the structuring or restructuring process, the potential for generating new information. Certainly, this represents the ideal outcome of scenario applications.

At a less ambitious level, scenarios have the capacity for identifying problem areas where needed new or additional information through research could prove helpful in developing more socially efficacious policies. More specifically, scenarios can be used as a preliminary sorting procedure for identifying a range of problems that may be subsequently evaluated by more quantitive, analytical procedures. Scenarios do this by exploring multiple futures and specifying options; by focusing on interrelationships or linkages between key elements in the scenario system; and by concentrating on forces that make for change in the system's direction of evolution.

Alternatively, scenarios may be used to synthesize possible changes detected in long-term trends by computer simulations (Breck, 1963).

A more pragmatic function of the scenario method may be seen in its educational and communicative value to user agencies and personnel. First, the scenario is intentionally dramatic and literary in style, which should enhance its comprehensibility by a large body of policy decision-makers for whom it is intended. Second, since a principal function of the scenario is to anticipate points in a changing system that are dependent upon critical decisions and the possible outcomes from various choices, they can, if properly communicated, serve as useful tools in the decision-making process. Quite obviously, an important danger in use of the scenario method lies in the implausibility of some possibilities, and, therefore, the complete rejection of them by policy-maker and analyst alike. Thus, the scenario must provide a believable interpretation of how decision-makers and others are likely to behave in the future. This may be done by relating the scenario to some reasonable version of the present and/or past. This does not mean to say, however, that only the most plausible, conventional, or probable situations and behavior should always be sought because, historically, the improbable has often come to pass.

This has particular relevance for the management of rare natural events or hazards. If decision-makers have little experience with environmental phenomena, then they will likely have a weak future image of what to plan for. Without a background of experience, the problem becomes one of *creating* strong enough images upon which adequate action may be taken. Such is the purpose of scenarios: to create images that help portray the consequences of specific actions or the resultant conditions of inaction.

Finally, the scenario can be used as a device not only for educating and communicating to decision-makers, but it can form the basis for public participation in the decision-making process. A recent example of scenarios functioning in this fashion comes from their use by the Local Government Relations Division of the State of Oregon. The scenario method was central to government presentation to the public of long-range future options for the Willamette Valley and was accorded a large degree of responsibility for decision-makers recently adopting environmentally sensitive land use management bills (Lawrence Halprin Associates, 1972).

The purpose of the next chapter, is to develop a scenario model and method which may elicit, at least in part, some of the functions and utilities of scenarios as discussed in this chapter for natural hazards, especially flood hazard.

# CHAPTER III

## SCENARIOS OF NATURAL HAZARDS: MODEL AND METHOD

In establishing a conceptual model for developing operational scenarios about natural hazards, a number of objectives and guiding principles need first be specified. These relate not only to elements of the scenario method already described, but to the nature of the empirical problem.

First, a basic objective is to derive data from which comparative evaluations of the nature and magnitude of changes in hazard-loss functions from given conditions to hypothetical conditions may be made. These changes denote the amount by which social disruption can be reduced over specified periods of time. Changes will depend on assumptions as to the nature of the physical event system, and the type of human adjustment adopted for ameliorating damage potentials in a given social system--the urban community.

Second, the concern is not only with providing a picture of the short-term socioeconomic impact of the hazard event, but also with providing a structure for assessing the long-term pattern of decisions. In this context, scenarios should be thought of as being used to throw light on four interrelated elements of the natural hazard system. They should provide:

1) some understanding of factors of choice that lead to the adoption or lack of adoption of specific adjustments for reducing hazard potential;
2) an opportunity to examine the constraints on adopting various adjustments;
3) a chance to assess how new changes in the natural hazard system could have occurred had constraints been removed, and to indicate how they might be removed by examining combinations of circumstances that lead to changes in cultural constraints; and
4) an evaluation of the interactiveness among adjustments in their social context, that is, to gain some insight into possible positive and negative feedback interactions.

To meet these objectives, a fourfold model is outlined within which the scenario method may be used to help anticipate and explore alternative possibilities--past, present, and future--for managing natural hazards in urban settings.

## Scenarios: A Conceptual Model

To provide a degree of rigor and replicability, and to treat all factors in an internally consistent fashion, Durand's (1972) four-part model is used. The relationships between the four parts (base conditions, environing factors, progressions in a scenario, and cross-sectional images in a scenario) in a natural hazard context are illustrated in Figure III-1.

### 1. Base Conditions

The base conditions consist of an historical review of a natural hazard in a particular place over a specified time, and choices of adjustment to that hazard which in fact were considered, rejected, or adopted. It is handled as a system whose dynamic elements and their relationships make up the essential characteristics of the scenario subject--a natural hazard. An historical review provides basic conditions against which scenarios of alternative pasts may be generated. Used in this way, scenarios help demonstrate the change in loss reduction possible had various types of adjustments (like engineering protection works or land use management) been adopted by a community at plausible points in historical time. Thus, the common use of scenarios as a means of exploring alternative futures is extended to a study of alternative pasts (Figure III-1).

Usually, base conditions are restricted to an analysis of current conditions. High priority is accorded to evaluating the past thoroughly as a prelude to prognosticating about the future. In general, understanding what in the past did or could have occurred can be as instructive and useful in formulating decisions that will influence the future as is an awareness of future possibilities themselves. Decision processes can be sharpened if an image of the present in a scenario compares the consequences of possible patterns of decisions in the past with conditions that currently exist. More specifically, there is evidence that scenarios are being written about hazards that simply transpose the hazard experience of one area to that of another without any examination of the differences in prior managerial experiences of the

SCHEMATIC REPRESENTATION OF SCENARIO MODEL

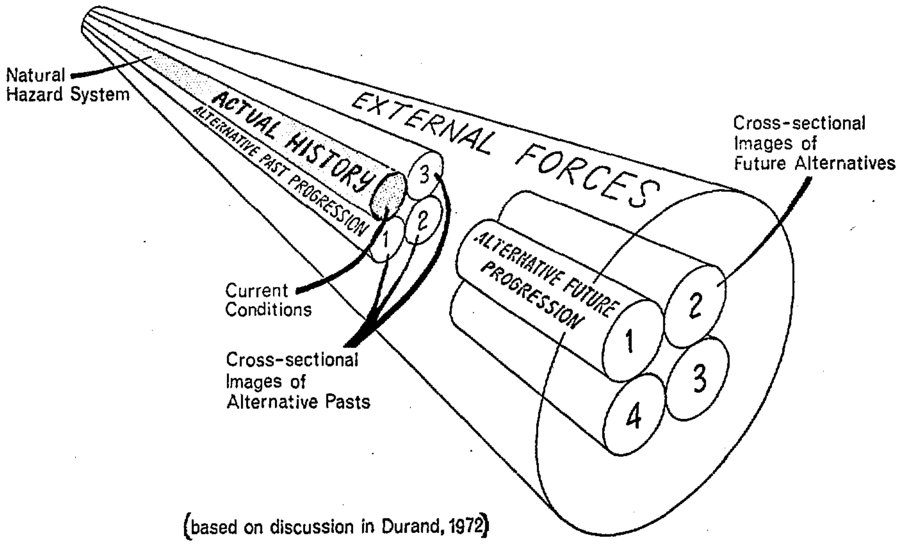


FIGURE III-1

*A system model of scenarios being developed by the author became much more clearly formalized upon his reading of Jaques Durand's "A New Method for Constructing Scenarios," Futures (December, 1972), pp. 325-330. The format and language used by Durand has been adopted for this study. Figure III-1 represents the author's visual interpretation of Durand's discussion.

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areas concerned (Connecticut River Basin Program, 1972). But the scenario is unique, it is site-specific. While much can be learned from the experiences of sites elsewhere, each case is built upon a base relevant to the experiences of the area in question.

2. Environing Factors

The natural hazard system is bound by environing factors which should not be ignored, yet need not be emphasized to the extent that they obscure the scenario subject. For example, one would not examine the new Federal revenue sharing policy in great detail, but would simply ask, "Given the new revenue sharing scheme, what impact would it have on the natural hazard system in an urban community?"

For urban communities, environing factors may be thought of as two basic kinds: those that affect the natural hazard system from within the community, such as urban growth and renewal, transportation, or open space programs; and those that impinge on the natural hazard system from outside of the community, including, for example, Federal cost sharing in flood protection projects or insurance, or state enabling land use management legislation.

Assumptions regarding environing factors can be changed during the progression of a scenario (or the evolution of the natural hazard system), but such changes increase the scenario's complexity. Assumptions about environing factors should not be mistaken for the aims of the scenario.

3. Progressions in Scenarios

The progression or evolution of the natural hazard system through time is derived from factors identified in the base of existing "real world" conditions, and is controlled by the environing factors. The progression is expressed in a scenario which qualitatively simulates the changes in existing conditions as elements of the natural hazard system interact over time. In specifying likely (or even unlikely) changes in key elements and their interrelationships, use can be made of quantitative models.

One of the main objectives in writing progressions in a scenario is to illuminate the possible impacts of any one adjustment on other elements in the natural hazard system over time, including its influence on decisions to adopt other adjustments, for example, "What effect would adopting sea-walls have on sea-shore encroachment and how would sea-walls influence the search for alternative means of protection, such as land use management or a hurricane or storm-warning system?"

4. Cross-Sectional Images in Scenarios

Whereas progressions are concerned with long-term patterns of decision-making that take account of decision nodes and alternative paths, cross-sectional images focus on the short-term impact of the hazard event. It is here, in a thin cross-section of time, that the efficiency of the system's change through time may be assessed.

The point in time at which a hazard event is hypothesized to occur and the assessment is made is arbitrarily chosen. The hazard's effect on the system is in part dependent upon assumptions as to its magnitude and intensity (as suggested by the historical review), and in part upon changes to society indicated in the progression. As a synchronic image or scenario of what might have been (a past alternative) or could be (a future alternative), the cross-section provides us with a new representation of a possible reality. It forms the consequential outcome of decisions assumed to hold true. As a synthesis of the hazard system, it provides a new, but hypothetical, base--perhaps one that is radically different from the real world base with which we began--from which a new progression of scenarios may be generated, and, therefore, new sets of possible impacts and outcomes assessed.

## Scenarios: A Method for Flood Hazard

The foregoing has provided a framework for speculating about changes that might be anticipated in the evaluation of a natural hazard system. In order to elicit information necessary for making these speculative evaluations, it is necessary to develop an operating methodology. This is done with reference to flood hazard, bearing in mind that while the basic procedure is transferable to other natural hazards, modifications would be necessary to accommodate the peculiarities of each type.

The conceptual model displays a logical sequencing of its elements (base system, exogenous factors, scenario progressions, and cross-sectional images). Each element of the model requires certain information before it can be executed.

### 1. The Base System of Flood Hazard

The base forms the beginning of the scenario. It identifies those elements and relationships of the flood hazard system that make up the essential characteristics of the scenario subject. The base was given as an "historical review of natural hazard and choice of adjustment to hazard." Thus, for the purpose of specifying information needs, the flood hazard system (the base) may be systematically appraised through: 1) its physical characteristics; 2) its human-use characteristics; and 3) flood hazard adjustment possibilities as identified historically through time. These elements are not discussed in great detail here, but are expanded upon in supplementary appendices and in the case-study application that follows in Part II.

#### a. Physical Aspects

An analysis of the physical event system, or surrogates thereof, allows determination of the flood risk to which human use on the flood plain is, or has been, exposed. It also provides limits to the physical feasibility of applying various adjustment types. Together with information on human use, an evaluation of physical phenomena also provides basic data for deriving the flood-loss relationships that are used in progressions of past and future alternatives and cross-sectional images as described in later sections.

The physical flood hazard can be evaluated by examining several attributes of the flood event including: sources of flooding; basin characteristics; seasonal occurrence; flood-to-peak interval; duration; magnitude; and frequency of occurrence.

b. Human Aspects

Evaluation of the human use of flood plain land is essential in establishing the nature of damage potentials, and for selecting feasible alternatives for reducing such losses. In order to evaluate the loss-reducing capacity of hypothetical past and future alternatives, it is necessary to illuminate *actual* development trends. This is done by first analyzing changes in human occupance on the flood plain through time (White, *et al.*, 1958).

At least two types of analyses are needed. The first is to describe morphological changes through time as expressed in patterns of urban development and land use in relation to the flood plain, and to evaluate the principal socio-economic forces or factors responsible for creating the morphological patterns.

Second, basic to understanding current relationships between flood losses and flood variables, land uses, and adjustments over time, is derivation of losses as a function of flood depth (stage) for selected land use types.

c. Choice of Adjustments

As part of the human-use system, choice of adjustment to flooding represents the conscious attempt by individuals and groups to effect measures that will help ameliorate the flood's deleterious impact (White, 1942; White, *et al.*, 1975). As the central element of the scenario subject, it is treated as a separate section.

There are four aspects of choice of adjustment to floods that are essential to the later elaboration of scenarios: types of adjustments; constraints on adopting adjustments; effectiveness of adjustments; and interactions among adjustments.

Alternative adjustments to consider in a flood plain management program are outlined in Table III-1. Therein, the adjustment typology is of three parts. First are those adjustments, technical in nature, that

TABLE III-1

**ALTERNATIVES TO CONSIDER IN A FLOOD PLAIN MANAGEMENT PROGRAM**

| POSSIBLE CHOICE OF ACTIONS | INDIVIDUAL ACTIONS | PUBLIC ACTIONS: STATE-COUNTY-TOWN-CITY-VILLAGE | PUBLIC ACTIONS: FEDERAL |
|---|---|---|---|
| 1. Bearing the Loss | Accept the Loss | a. Provide Flood-Hazard Information<br>b. Provide Disaster Relief | a. Provide Flood Hazard Information<br>b. Provide Federal Disaster Relief |
| 2. Energency Actions | a. Maintain Stand-by Preparations<br>b. Have Advance Plans for Evacuation and Rescheduling | a. Provide Work Forces and Equipment for Flood Fighting<br>b. Community Evacuation Assistance | a. Provide Work Forces and Equipment for Flood Fighting<br>b. Flood-Warning Assistance<br>c. Encourage Local Disaster Plans |
| 3. Building Changes and Land Elevation | a. Change Buildings to Better Withstand Floods<br>b. Raise Land for New Buildings Above Flood Level | a. Building Codes<br>b. Laws to Prevent Constriction of Floodway | a. Provide Information on which to Base Raising Land and Changing Buildings<br>b. Require Building Changes and Land Raising for Loans |
| 4. Changing Land Use | a. Choose Locations to Minimize Damage<br>b. Use Flood Plain for Playgrounds, Parking Lots, etc. | a. Land-Use Regulations to Encourage Open Uses<br>b. Prohibition of Highly Flood Hazard Uses<br>c. Condemnation and/or Urban Renewal | a. Flood Plain Information for Regulations<br>b. Require Flood Plain Regulations to Receive Aid Under Federal Programs<br>c. Federal Aid to Permanently Remove High-Risk Uses |
| 5. Controlling Floods | a. Request or Construct Levees, Channel Enlargements, Dams<br>b. Share in Costs of Flood Control Works | a. Request or Construct Flood Control Works<br>b. Share in Costs of Flood Control Works | a. Provide Flood Control – Levees, Dams, Channel Enlargement, Land Treatment, etc. |
| 6. Flood Insurance | a. Obtain a Policy if Available | a. Provide Information on Which to Base Rates<br>b. Share Costs of Subsidized Insurance<br>c. Supervision of Insurance Companies Issuing Policies<br>d. Conduct Studies to Develop Flood Plain Management Plans | a. Provide Information on Which to Base Rates<br>b. Subsidize an Insurance Program |

(adapted from Kates, 1962, pp. 6-7)

*modify the flood event* by affecting either precipitation (weather modification), runoff (watershed treatment), or streamflow (dams, levees, and channelization). Second, adjustments such as flood warnings, emergency actions, flood-proofing buildings, changing land usage, and planned unit development change the character of flood plain occupance and thereby *modify flood-loss susceptibility.* Third, future flood losses may be spread over time, area, or people by adjustments that *modify the flood-loss burden.* This can be accomplished through insurance, tax writeoffs, and disaster relief grants and loans (White, *et al.,* 1975).

A view of decision processes that surround the adoption or non-adoption of adjustments from an historical perspective, provides a core of "reality" from which paths towards alternative pasts and futures can be perhaps more effectively spun. At given points in time, levels of physically viable adoptions may be constrained by one, or a combination of, cultural restraints (political, social, economic, legal, and ecological) (White, 1961). Conversely, there may be certain factors that change these constraints thereby leading to changes in flood plain management.

One purpose of the historical review of the flood hazard system is to help identify constraints as they relate to individual, and, perhaps sets of, adjustments so that more meaningful and credible judgments affecting hypothetical progressions can be made. Those thought to be important are summarized in the checklist of constraints by adjustment-type in Table III-2. Although based upon an extensive review of the flood hazard literature, factors other than those listed may appear in specific sites (Ericksen, 1972; White, *et al.,* 1975). Factors that may be important in helping to alleviate these constraints are summarized in the checklist in Table III-3.

Typically, adjustments are evaluated singly and in a static fashion according to their benefits and costs in reducing property losses at the time of project evaluation. This way of handling adjustments neglects the dynamic aspects of flood hazard, including interactions between adjustments and their impact on other elements of the flood hazard system and its exogenous milieu over time. No direct consideration is given to the systemic effects caused when a social system is disrupted, nor of short- or long-term catastrophe potentials. Judgments in benefit-cost analyses as to effectiveness of adjustments are based on annual

## TABLE III-2

CONSTRAINTS ON ADOPTING ADJUSTMENTS

| MAJOR CONSTRAINTS | ADJUSTMENTS | | | | | |
|---|---|---|---|---|---|---|
| | Engineering works | Warning Systems | Flood Proofing | Land Use Management | Insurance | Relief and Rehabilitat'n |
| Budgetary limits: Federal agencies | X | | | X | | X |
| Community cost | X | X | X | X | X | |
| Individual Cost | | | X | X | X | X |
| Environmental opposition | X | | X | | | |
| Environmentally conscious | | | | X | | |
| Inadequate evaluative techniques | X | | | X | | |
| Lack of information on hazard | | X | X | X | X | |
| Lack of information on adjustment | | X | X | X | X | X |
| Lack of leadership and personnel (plg) | | X | X | X | | |
| Agency disorganization (poor planning) | | X | X | X | | |
| Biases of investigators on solutions | | X | X | X | | |
| Lack of financial incentives | | X | X | X | | |
| Reliance on other adjustments | | X | X | X | X | |
| Lack of legislation | | | X | X | X | |

## TABLE III-3

FACTORS INFLUENCING CONSTRAINTS

| FACTORS INFLUENCING CONSTRAINTS | ADJUSTMENTS | | | | | |
|---|---|---|---|---|---|---|
| | Engineering Works | Warning Systems | Flood Proofing | Land Use Management | Insurance | Relief and Rehabilitat'n |
| Recent experience or knowledge of flood | X | X | X | X | X | |
| Increased limits for expenditures | X | X | X | X | X | |
| New legislation | X | X | X | X | X | X |
| Growth of environmental consciousness | | | X | X | X | |
| Vigorous and able leadership | X | X | X | X | X | X |
| Provision of technical information on the hazard | X | X | X | X | X | |
| Provision of technical information on the adjustment | X | X | X | X | X | X |
| Broadened view of adjustment possibilities, including integrated plans | | X | X | X | X | |
| Improved evaluation techniques | X | | | X | | |
| Urban renewal and development | | | X | X | | |
| Establishing financial incentives | | X | X | X | | |
| Improved agency organization | | X | X | X | | |

average flood losses rather than catastrophe potential.

In a very general way, flood-loss potentials for major adjustment types derived from benefit-cost analyses are given in Figure III-2. These graphs are based on very little empirical evidence and are largely judgmental (White, 1964; White, *et al.*, 1975). Nevertheless, until more refined curves are developed they may serve as helpful guides in developing assumptions about the effectiveness of adjustments for use in scenario progressions, although the latter will depend largely on conditions unique to the study area.

The generalized curves in Figure III-2 are tempered by the fact that in terms of urban land uses, and therefore flood hazard potential, some adjustments are more effective than others for reducing losses. In Table III-4, levees, reservoirs, flood-proofing and emergency actions are shown to be the most applicable adjustments to all of the land use types noted (Sheaffer, *et al.*, 1970, pp. 51-52).

Ideally, the curves in Figure III-2 should be refined yet again since each adjustment is likely to have differential effects upon the main components of flood-loss. Basic relationships between principal adjustments and three classes of flood-loss (property damage, human casualties, and social disruption) are indicated in the matrix in Table III-5. There, positive and negative influences of adjustments upon the three flood-loss criteria, and in aggregate catastrophe potential, are qualitatively defined. These influences begin to express the dynamic nature of the flood hazard adjustment system. Significant is the pattern of ambiguity that levees, some types of land use management (such as planned unit development), and pre-disaster relief have on lessening flood losses. More obvious are the negative effects 'caused' by do-nothing, post-disaster relief, and insurance programs that lead to increases in catastrophe potentials.

In total, little is known about the dynamic relationships required to fill the cells in Table III-5. As with Figure III-2, Table III-5 is used as a guide in thinking about possible impacts of adjustments on losses as suggested by the circumstances of the community system in question. A similar matrix is found in Figure VIII-1 where it is accompanied by detailed discussion of impacts for flooding in the Boulder case-study (Chapter VIII).

With the growth in emphasis upon integrated flood plain management (Figure III-3), any strategy for reducing flood losses is

TABLE III-4

APPLICABILITY OF ADJUSTMENTS TO VARYING LAND USES

+ = Applicable
0 = Ambiguous
- = Not Applicable

| | LAND USES | | | | | |
|---|---|---|---|---|---|---|
| | Open Space Recreation | Public-Structural | Transportation | Intensive Industrial | Intensive Residential | Intensive Commercial |
| **MODIFY THE FLOOD** | | | | | | |
| Flood Protection | | | | | | |
| Levees and channel improvements | + | + | + | + | + | + |
| Reservoirs | + | + | + | + | + | + |
| Watershed Treatment | 0 | 0 | + | + | + | + |
| Weather Modification | 0 | + | + | + | + | + |
| **MODIFY THE DAMAGE SUSCEPTIBILITY** | | | | | | |
| Land Use Changes | | | | | | |
| Structural to Non-Structural | + | - | 0 | - | - | - |
| Structural to Structural | - | + | + | + | + | + |
| Flood Proofing | 0 | + | + | + | + | + |
| Planned Unit Development | 0 | + | 0 | + | + | + |
| **MODIFY THE LOSS BURDEN** | | | | | | |
| Flood Insurance | 0 | 0 | + | + | + | + |
| Tax Writeoffs | 0 | - | + | + | 0 | + |
| Disaster Relief | 0 | - | + | + | 0 | + |
| Emergency Measures | 0 | + | + | + | + | + |
| **DO NOTHING** | - | - | - | - | - | - |

(Sheaffer, *et al.*, 1970, p. 52)

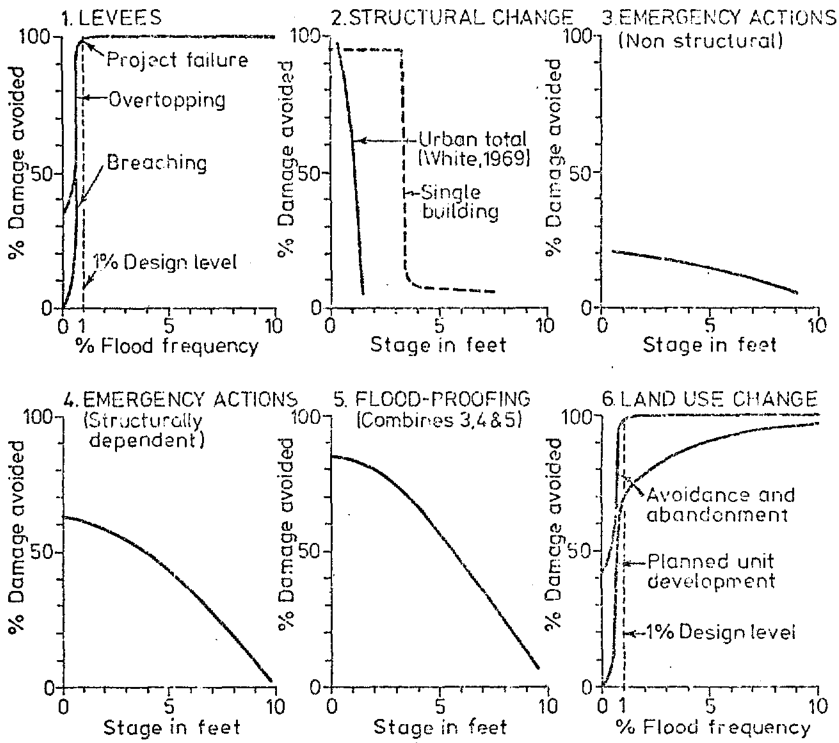
TABLE III-5

RELATIONSHIPS BETWEEN ADJUSTMENTS AND FLOOD LOSSES

+ = Increased flood losses
0 = Uncertain effects
- = Decreased flood losses

| | Property Loss | Human Casualties | Social Disruption | Catastrophe Potential |
|---|---|---|---|---|
| MODIFY THE FLOOD | | | | |
| Flood Protection | 0 | 0 | 0 | + |
| Levees and channel improvements | 0 | 0 | 0 | + |
| Reservoirs | - | - | - | + |
| Watershed treatment | 0 | 0 | 0 | + |
| Weather Modification | | | | |
| MODIFY THE DAMAGE SUSCEPTIBILITY | | | | |
| Land Use Changes | 0 | 0 | 0 | 0 |
| Structural to structural | - | + | 0 | 0 |
| Structural to non-structural | - | - | - | - |
| Flood-proofing | 0 | 0 | 0 | 0 |
| Planned Unit Development | 0 | 0 | 0 | 0 |
| MODIFY THE LOSS BURDEN | | | | |
| Flood Insurance | + | + | + | + |
| Tax Writeoffs | + | + | + | + |
| Disaster Relief | + | + | + | + |
| Emergency Measures | + | - | + | + |
| DO NOTHING | + | + | + | + |

## GENERAL FLOOD-LOSS REDUCTION CURVES FOR VARIOUS ADJUSTMENTS




1. Effect of project failure (overtopping and breaching) on levee protection against a 1% (100-year) flood. Under breaching conditions, damages could exceed pre-protection levels (zero) due to levee-induced flood plain development.
2. Up to 5 percent of damage is avoided by permanent structural changes to buildings (excluding elevation), but success depends on building type and flood stage (White, 1964).
3. Flood-loss reduction by warning-dependent, non-structural emergency actions range between 5 and 20 percent (Roman and Waybur, 1960; White, 1964). Effectiveness depends on flood stage and onset, nature of warnings, and human responsiveness.
4. Capacity of structurally based emergency actions to reduce flood-loss depends on flood stage and onset; warning systems and human response; and type of structure and building materials (White, 1964).
5. Flood-proofing (combines 2, 3 & 4) may reduce damages by up to 85 percent (White, 1964). Because of emergency actions, design failure of the structural change component need not result in pre-adjustment levels of loss.
6. Effect of 1% flood design exceedence on two programs of land use change: avoid and abandon the flood plain; and planned unit development, which would include flood-proofing along with land use management.

**FIGURE III-2**

likely to include more than one adjustment. Combining adjustments to obtain optimal outcomes will require examination of their compatibility. Compatibility of adjustments has been outlined previously by Sheaffer (Sheaffer, *et al.*, 1970, pp. 48-49).

Careful examination of the dynamics of these relationships yields a rather different set of patterns (Table III-6). For example, there is considerable evidence at hand to suggest that levees and channels are self-perpetuating; they positively influence themselves in that flood threats and accelerated urban growth encourage the continuing elevation of levees, excavation of channels, and lengthening of both. In addition, they appear to stifle the search for alternative forms of adjustment because less than design floods are seldom experienced. Levees and channels affect other forms of adjustment, such as land use management, negatively or adversely in spite of their apparent technical compatibility. Both influences (self-perpetuation and stifling alternatives) increase catastrophe potential since sooner or later a low probability event will occur that exceeds the design level of the engineering 'protection' works.

Unfortunately, the experience with adjustment interactions is so narrow and short that it is difficult to unravel the dynamics of compatibility and its effects on flood-loss reductions. Once again, the relationships noted in Table III-6 can be used as no more than a guide for thinking about and noting qualitatively the positive and negative relationships that could exist between adjustment types. It is important to note, however, that the positive relations shown in Table III-6 do not necessarily mean that flood-loss relationships will be beneficial nor a negative one detrimental, as the levee and channel example above shows. This and other examples are elaborated upon in Chapter VIII.

2. Environing Factors

Earlier sections briefly outlined factors of choice that related directly to the flood hazard system in the form of choices of adjustments to floods and factors constraining them. Since they are an integral part of the flood hazard system, they may be thought of as internal factors.

This section deals with choice factors that are considered external to the flood hazard system, yet whose outcomes may impinge

TABLE III-6

INTERACTIONS BETWEEN ADJUSTMENTS

+ = Positive influence

0 = Uncertain influence

- = Negative influence

N.B. + or - can be seen as beneficial or detrimental depending on adjustment type.

| | MODIFY THE FLOOD | Flood Protection | Levees and channel improvements | Reservoirs | Watershed Treatment | Weather Modification | MODIFY THE DAMAGE SUSCEPTIBILITY | Land Use Changes | Structural to structural | Structural to non-structural | Flood-proofing | Planned Unit Development | MODIFY THE LOSS BURDEN | Flood Insurance | Tax Writeoffs | Disaster Relief | Emergency Measures | DO NOTHING |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MODIFY THE FLOOD | | | | | | | | | | | | | | | | | | |
| Flood Protection | | + | + | + | - | - | | - | - | - | - | - | | - | | + | 0 | + |
| Levees and channel improvements | | + | + | + | - | - | | - | - | - | - | - | | - | | + | 0 | + |
| Reserviors | | + | + | + | 0 | - | | - | - | - | - | - | | - | | + | - | + |
| Watershed Treatment | | + | + | + | + | 0 | | - | - | - | - | - | | - | | + | - | + |
| Weather Modification | | | | | | | | | | | | | | | | | | |
| MODIFY THE DAMAGE SUSCEPTIBILITY | | | | | | | | | | | | | | | | | | |
| Land Use Changes | | - | - | - | - | | | + | + | + | + | + | | 0 | - | - | + | - |
| Structural to structural | | - | - | - | - | | | + | + | 0 | + | + | | - | 0 | 0 | + | - |
| Structural to non-structural | | - | - | - | - | | | + | - | + | - | 0 | | - | - | - | 0 | - |
| Flood-proofing | | 0 | 0 | 0 | 0 | | | 0 | + | - | + | + | | - | 0 | 0 | + | - |
| Planned Unit Development | | 0 | 0 | 0 | 0 | | | + | + | + | + | + | | - | 0 | 0 | + | - |
| MODIFY THE LOSS BURDEN | | | | | | | | | | | | | | | | | | |
| Flood Insurance | | | | | | | | | | | - | | | | 0 | 0 | 0 | 0 |
| Tax Writeoffs | | | | | | | | | | | | | | | | + | 0 | 0 |
| Disaster Relief | | + | | | | | | - | - | - | - | - | | | - | + | 0 | 0 |
| Emergency Measures | | | | | | | | 0 | | | + | + | | | - | - | + | - |
| DO NOTHING | | | | | | | | | | | | | | | | + | | |

upon it so as to influence catastrophe potentials. Two basic kinds of external factors are defined. First are those factors that change the urban system, but which are not directed at the natural hazard problem. For example, the development of a highway along a valley floor may provide the catalyst for building on the flood plain. Or, the establishment of building codes, land use ordinances, and comprehensive plans to regulate urban land usage for aesthetic reasons may have the unwitting effect of institutionalizing development on the flood plain, thereby increasing disaster potential. Second are those factors that change the urban system through policies generated outside of it, but which are not specifically directed at the natural hazard problem (as would, say, subsidized Federal flood insurance). For example, urban renewal and open space programs, state highway development and the like.

As with internal factors, these external factors of choice help bring about changes to the morphological and structural character of the urban system and, in so doing, influence hazard potentials--one way or another.

### 3. Progressions and Cross-Sections in Scenarios

The foregoing has been concerned with identifying key factors and informational sources relevant to the internal and external aspects of an existing flood hazard system in an urban community. Bridging the gap between this poorly understood past and an unknown (some would say unknowable) future is a difficult and speculative task. It is helped by utilizing understanding of forces and factors that have operated in creating the flood hazard system as it now is (as would be described under base conditions and environing factors), and by invoking forces that are perceived by the analyst as being important in changing the direction of the system's movement and in speculating about the consequences of such change.

In discussing methods in this section, it is perhaps best to begin with scenarios of current cross-sectional images since they relate more directly, in both time and space, to current real-world conditions than do either alternative pasts or futures, and are, therefore somewhat more easy to construct than the latter. But, even here, all that can be done is to indicate the steps that may be taken in gathering information from which a dramatic scenario may be written. Just how it is written is almost impossible to say in operational terms for therein lies the indefinable elements of imagination and creativity.

a. Cross-Sectional Images

The purpose of constructing a current cross-sectional scenario is to draw together elements of the urban flood hazard system in order to demonstrate the efficiency or inefficiency of the system's historical evolution, given the impact of an hypothetical flood under current conditions of development on the flood plain (Chapter V). The outcomes, expressed in life and property losses and the degree of social disruption, are then used as a benchmark against which scenario progressions of alternative pasts and futures may be judged (Chapters VI, VII, and VIII).

The first step in gaining information for use in creating a dramatic cross-sectional image is to secure from all relevant agencies as much material as possible on flood hazard and property damage estimates, and, if necessary, material from supplemental field surveys. (Refer to information needs and sources in the sections on physical and human aspects under base conditions.) Field surveys are also essential in order to provide the analyst with a sense of place and a feel for the conditions that could exist during an extreme flood event. Field surveys are, in turn, supplemented by the literature review synthesized in the historical analysis of flooding and flood plain management for the study area.

Second, as a check on the analyst's own evaluations about the hypothetical flood event and its damaging consequences, the opinions of people skilled in various aspects of the problem should be sought. This can be achieved through personal interviews and/or the convening of a panel of experts.

The panel of experts is required to consider the meteorological and hydrological circumstances under which an extreme flood event might occur, and its damaging and disruptive consequences. Informed consensus on the technical aspects of the scenario will strengthen its credibility and perhaps, too, its acceptability by decision-makers. Topics of discussion should include: the nature and location of the meteorological event; the hydrological response to such an event, including flood-to-peak intervals and levels, and velocities of flows; sources of debris and problems caused by debris, such as cloggage of bridge openings, deflection of flood flows, and increased levels of flow and property damage; the susceptibility of bridges above and within the urban area to debris cloggage and those considered likely to collapse; the liability of structural damage to principal buildings within the urban area; the expected level of effectiveness of community preparedness; human casualties; and social systems most vulnerable to disruption.

Personal interviews with personnel in city administration and private industry should be carried out to solicit opinions and factual information upon which evaluations on the extent to which principal service systems within the urban area might be disrupted by the extreme flood, and the approximate cost. Service systems would include, for example, water, sewage, communications, gas, electricity, and emergency preparedness services like hospitals, American Red Cross, Civil Defense, and police.

From this base of information, including objective facts and subjective opinions, dramatic cross-sectional images may be created (Chapter V).

b. Progressions in Scenarios

As employed here, scenario progressions are made to revolve around principal adjustment types and the effectiveness of each adjustment in reducing flood losses. But more than this, the scenarios would attempt to anticipate points of rapid and unexpected change in the flood hazard system's evolution.

Measures of effectiveness stem from estimates of flood losses (pecuniary, human casualties, and social disruption) at existing levels and rates of urban development, and from forces assumed to operate throughout the duration of the scenario progression. More complex scenario progressions draw out interactions between adjustment types and the implications these have for reducing flood losses (Tables III-2 to III-6).

Since the effectiveness of each progression is assessed in terms of its ability to reduce catastrophe potential for the flood hazard system, each past or future alternative or possibility derived from its respective progression is compared with the catastrophe potential inherent in current conditions of development: the benchmark provided in the current cross-sectional image.

Preceding sections have described how information on the base system of flood hazard can be obtained. This information is used to help create past and future possibilities in scenarios. As with the cross-sectional image, important additional input is gained by involving key decision-makers and flood hazard experts, familiar with the case study area, in speculations about possibilities for the evolution of the flood hazard system.

Take, for instance, scenario creations of alternative pasts. Progressions and outcomes from these alternatives are judged against a background of the actual history of flood plain management in the urban area and its consequences in the current cross-sectional image. To make credible the *time* at which each adjustment in an alternative past is to be adopted by the community, reference is made to Figure III-3. There, the rates at which principal adjustments have been adopted in the past

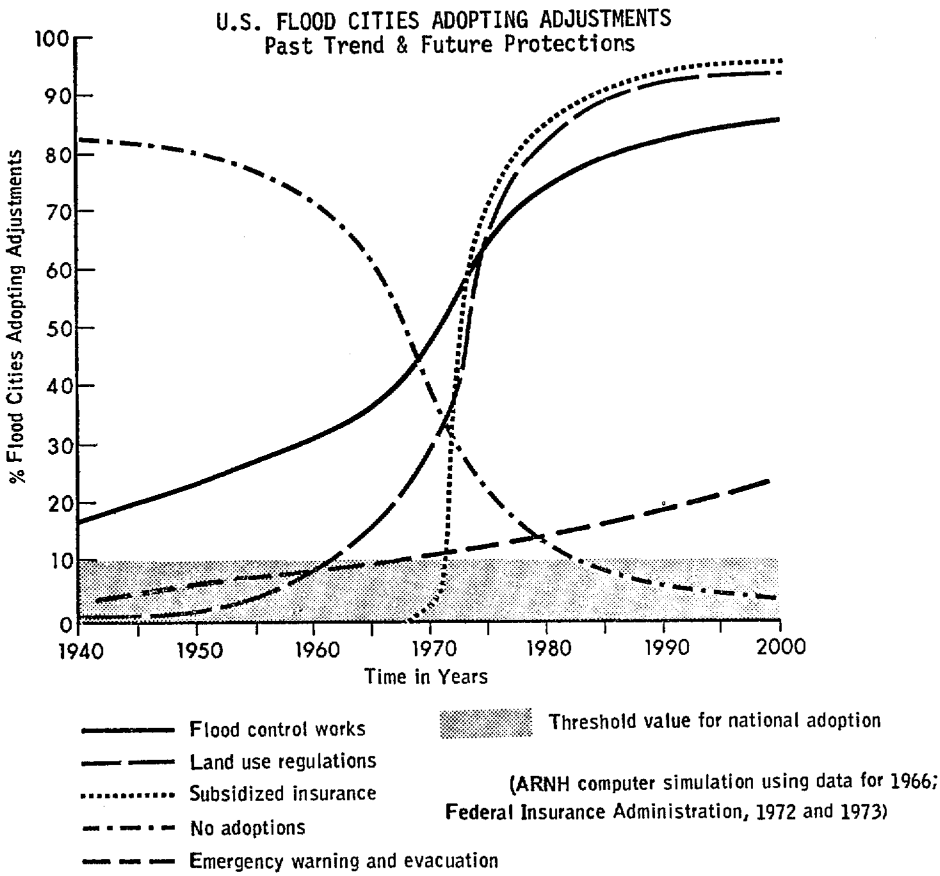



FIGURE III-3

by the nation's flood communities in general are defined. Using 10% of aggregate adoption as the threshold value, the point in time at which it was culturally feasible for a flood community to have adopted a given adjustment is determined. The threshold value equates to an inflection point on a rate of adoption curve following which adoptions increase rapidly. Literature on the diffusion of innovations suggests that a value of 10% of adoption approximates the take-off mark for more widespread and rapid use of an innovation. The curves also serve to reflect the changing emphasis in American society from approaching community flood-loss reduction through technological engineering solutions that primarily alter the physical environment, towards social regulations that influence human behavior. Moreover, the community placement upon each curve indicates the degree to which it is an innovator, laggard, or general adapter.

Given a starting point for an adjustment, extrapolations from the morphological and structural analyses made in the historical review provide information on conditions of flood plain development and the potential for losses from the hypothetical extreme flood event. Assumptions about the influence that each adjustment might have on flood plain development and its effects on reducing losses and averting catastrophe potential are then made (Table III-2 to III-6). The consequences are then traced in the scenario progression (Chapter VI).

Much the same method applies to scenarios of alternative futures only now the task of assessing the efficiency of the progressions and outcomes is made more difficult by the fact that there is no solid base of historical information to parallel and against which they can be compared. Instead, it is necessary to project into the future likely trends, or surprise-free scenarios, from existing information and to use these projections as a basis for judging alternative unexpected, but nontheless likely, possibilities (Chapter VII).

Having outlined the model and general procedure for developing scenarios, a demonstration of their employment in the evaluation of flood hazard futures in Boulder, Colorado, is given in detail in Part II. This begins with an historical evaluation of flood plain management in Boulder in Chapter IV, that is, specification of the base system; an assessment of the efficiency of the current flood hazard system in Boulder through use of the dramatic scenario in Chapter V; an evaluation of the effectiveness of adjustments to flood in scenarios of past and future progressions in Chapters VI and VII, respectively; and interactions between adjustments in Chapter VIII. Research implications for flood plain management in urban communities in general are specified in the final chapter.

The same general procedures noted in this chapter would apply as well to other natural hazards, such as hurricane, earthquake and drought. However, emphases on different elements of the model might very well differ. For example, it is apparent that exogenous factors play a much more important role in the drought hazard system than for flood (Warrick, *et al.*, 1975).

# PART II

# AN APPLICATION OF THE SCENARIO METHOD TO FLOOD HAZARD IN BOULDER, COLORADO

CHAPTER IV

# AN HISTORICAL EVALUATION OF FLOOD PLAIN MANAGEMENT IN BOULDER, COLORADO

In this chapter, flood plain management in Boulder is examined historically for the purpose of providing information about its flood hazard system that can be used in later chapters for developing scenarios on past and future flood plain alternatives. The analysis involves not only an attempt to determine changing patterns of risk, but to evaluate the processes of choice surrounding the evolution of Boulder's flood plain management policies.

## Early History: 1859-1940

The original square mile town of Boulder was platted in 1859 on the high plains some 800 feet north of Middle Boulder Creek and about one mile east of the mouth of Boulder Canyon. Its early growth waxed and waned in tandem with the vicissitudes of the gold and silver finds in the streams and rocks of the Rocky Mountain Front Range.

The coming of rail, both from the east and south in 1873, gave the young town a crossroads character. However, rather than emphasize industry, the community chose to make Boulder an education, health, and tourist center. To this end, the University of Colorado opened in 1877, Colorado Sanitarium in 1896, and Chautauqua Park in 1898.

Boulder entered the Twentieth Century on a wave of development. Population had doubled in the previous decade to 6,150 and would reach 10,000 by 1910 (Figure IV-1), and the original town was surrounded by increasing numbers of new additions. As the entrepôt for a prospering mining and agricultural hinterland, Boulder had sufficient size and admixture of activities by 1900 to take on distinct urban form (Figure IV-2).

The location of the principal land use types of Boulder evolved in response to strong geographical influences, principally topography. Ancient fluvio-glacial activity left Middle Boulder Creek embedded within a fourfold terrace system. The original town was located on the first and lowest terrace north of the river where a distinct commercial core evolved along Pearl Street, the main east-west artery of travel. Erosion

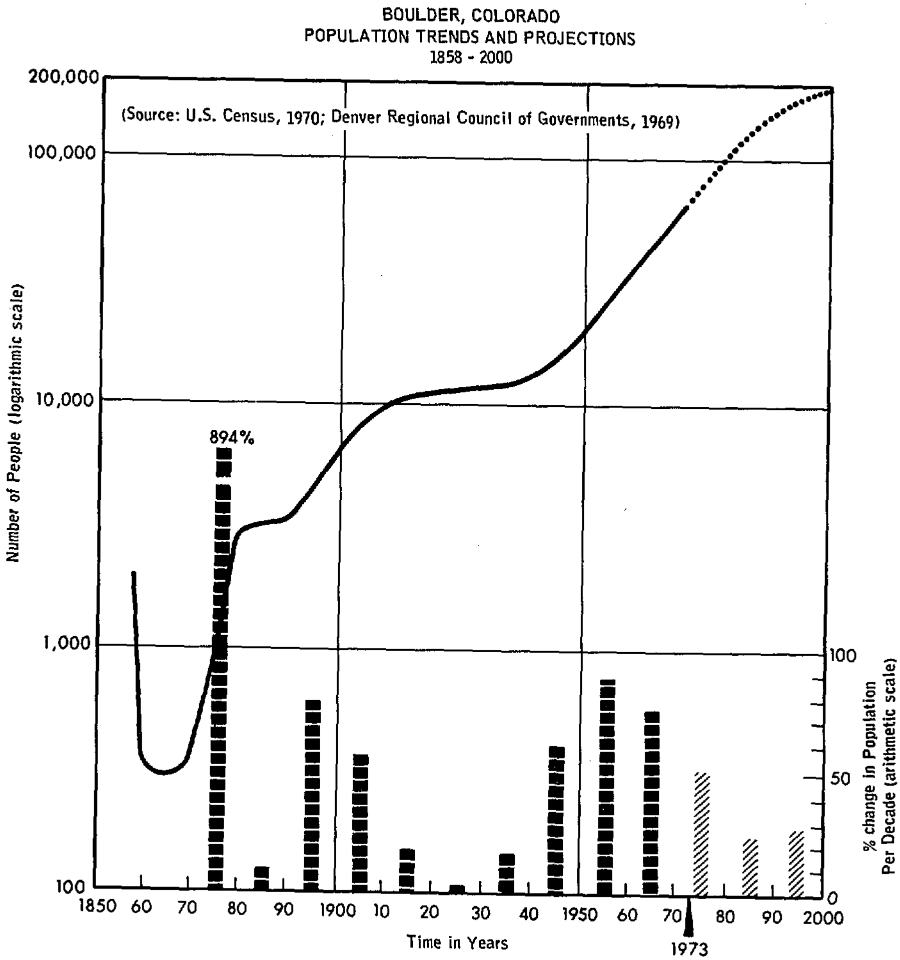

BOULDER, COLORADO
POPULATION TRENDS AND PROJECTIONS
1858 - 2000
(Source: U.S. Census, 1970; Denver Regional Council of Governments, 1969)
200,000
100,000
10,000
1,000
100
Number of People (logarithmic scale)
894%
100
50
0
% change in Population
Per Decade (arithmetic scale)
1850 60 70 80 90 1900 10 20 30 40 1950 60 70 80 90 2000
Time in Years
1973

FIGURE IV-1

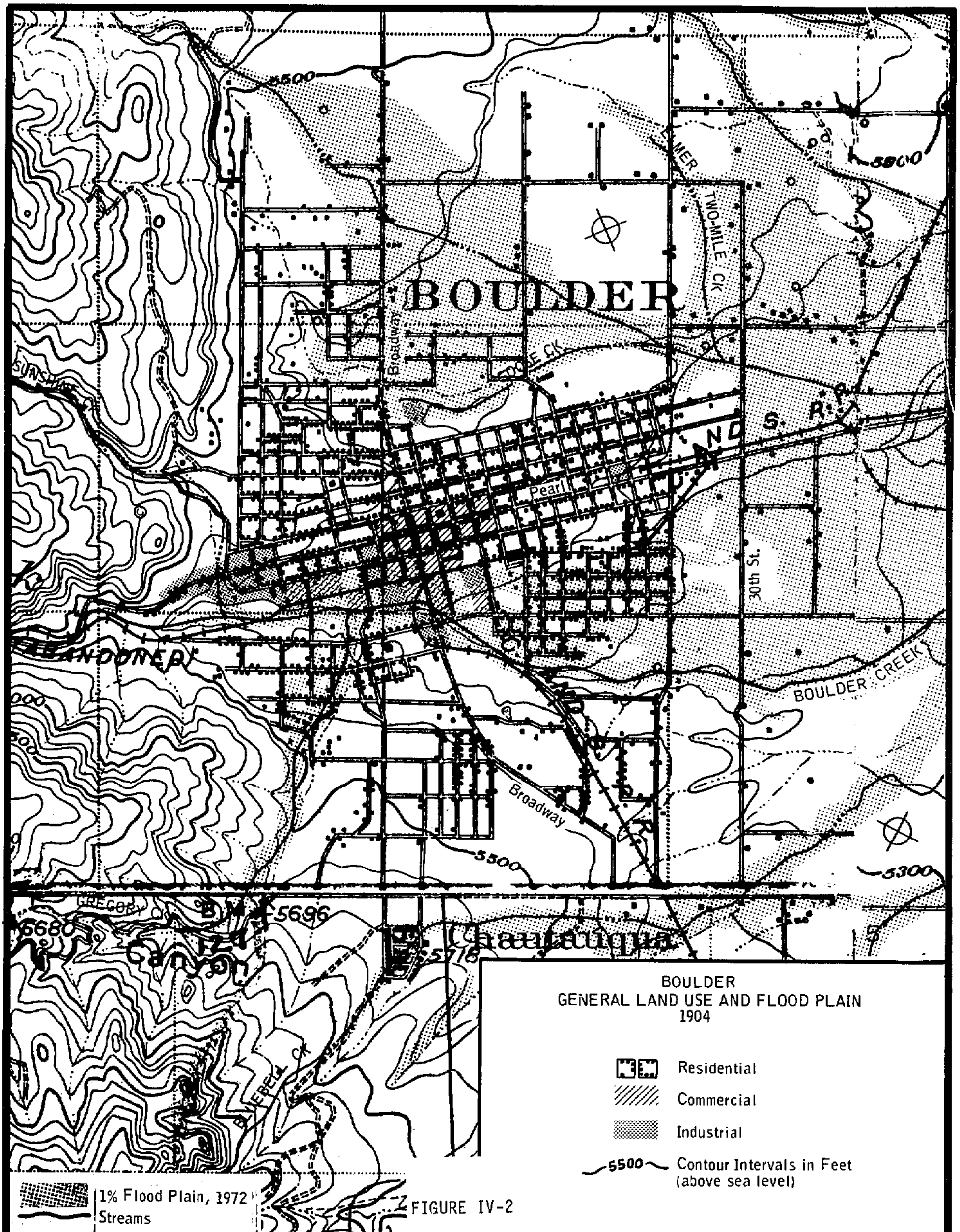

BOULDER
TWO-MILE CK
Broadway
Pearl
30th St.
BOULDER CREEK
Broadway
5500
5300
5696
5716
Canyon
Chautauqua
BOULDER
GENERAL LAND USE AND FLOOD PLAIN
1904
Residential
Commercial
Industrial
5500 Contour Intervals in Feet
(above sea level)
1% Flood Plain, 1972
Streams
Intermittent Streams

FIGURE IV-2

of the first terrace to the south of the creek caused abrupt relief less suited to town building.

Because of its low-lying and floodable nature, land nearer Middle Boulder Creek was not much utilized for commercial or residential use. But, being level and cheap, rail facilities were located there, and this in turn attracted industry.

Residential activity adjusted in the growing town in relation to landform, wind, and commercial and industrial activity. High-income housing located on the windward side of the second and third terraces, higher and to the northwest. Extending out from the commercial core, and along the inner periphery of high-income residential use, was a zone of middle-income housing. Finally, fringing more closely the commercial core, and inter-mixed with industrial uses along Water, Walnut, West Pearl, Middle Boulder Creek, and the rail track were the shanties of the poor (Stockley, 1938).

That parts of Boulder were exposed to flooding is implicit in the foregoing discussion. Indeed, by 1900, three floods, all serious in extent, had already occurred on Middle Boulder Creek. All three were the result of prolonged heavy rains and associated snowmelt in late May or early June.

The May 31-June 1, 1894, flood of record for Boulder occurred on receipt of some five inches of rainfall centered on the east slopes of the Front Range West of Boulder and about 10 miles from the Continental Divide. Most affected was the Fourmile Creek basin which reaches Middle Boulder Creek 1.4 miles upstream from the mouth of Boulder Canyon (Follansbee and Sawyer, 1948). Estimates place the discharge at 4th Street between 9,000 and 10,000 cubic feet per second (cfs.) (Metcalf and Eddy, 1912) and its return period at between 80 and 90 years (U.S. Geological Survey, 1961). Its spread and effects were described, in part in the *Boulder Camera* (31 May, 1894) as:

> A great flood came pouring down Boulder Creek at an early hour this morning. Every vestige of a bridge has been swept away, and railroad tracks torn from their moorings. From the Boulder Hotel to the University Hill was one vast lake with here and there a small patch of an island.

Yet, while serious, the flood "did not loom large in the proceedings of the City Council" (Perrigo, 1946, p. 246). After a lapse of four months, an ordinance was adopted and an appropriation of $10,000 made for the renewal of seven bridges and street repair (Perrigo, 1946, p. 246). Discussion to build barriers to reduce the "danger of another flow" occurred four times between March 1895 and March 1899, but such measures were never implemented.

Although floods of varying size were to occur six times during the first two decades of the century, Boulder continued to grow rapidly in size, population, and prosperity, based on tungsten mining (Figure IV-1). Yet, concomitant with growth was the concept of Boulder as a place of "beauty and quietude." In 1903, concerned citizens formed the Boulder City Improvement Association, and in 1907, the city's Office Park Board was established. At that time, the city adopted a policy of limited growth and prevented establishment of any new additions--an edict held good until 1941 (Goodwin, 1966).

In 1908, the Boulder City Improvement Association invited a nationally prominent landscape architect, Frederick L. Olmstead, to undertake a study for the physical improvement of Boulder including streets, waterways, sewage, and open spaces. In doing so, he produced a comprehensive, although conceptual, solution to the city's flood problem.

From his very perceptive observations Olmstead (1910) warned:

> If, lulled by the security of a few seasons of small storms, the community permits the channel to be encroached upon, it will inevitably pay the price in destructive floods. So with the channel of Sunshine Cañon and others....The fact that the lands nearest to the stream channel are so obviously subject to flooding has tended automatically to retard their occupation... but increasing land values are steadily increasing the inducements offered to the owner of any given parcel of these lands to fill it to a level above what he guesses the floods will reach and so build upon it....If this process goes on without...control for...maintaining an adequate channel, the cheap, unoccupied lowlands over which the flood-waters now pass harmlessly away will all be filled...and when a big flood comes, larger than the restricted channel can carry, the flood (will cause) immense damage.

Olmstead's suggestion for dealing with the flood problem was two-fold. First, a thorough evaluation of the flood hazard was to be conducted. This was acted upon by the Boulder City Improvement Society, and resulted in the Metcalf and Eddy Report of 1912. Second, he suggested a combination of channelization of the normal stream channel, floodwalls, parkways and parks. Where land values were high and the stream encroached (as around 12th Street, now Broadway), protective walls would be built. Downstream from there a floodway of varying width, stretching east at least one mile, would be maintained as natural parkland bound to the north and south by boulevards atop embankments or levees. This parkway concept applied as well to Sunshine Canyon, Beasley Ditch east of 24th Street, and two stretches on the south side of Boulder Creek west of 12th Street. Otherwise, exposed bottomlands on Farmer's Ditch, Beasley Ditch, and Boulder Creek would be retained in park.

Although the Metcalf and Eddy Report of 1912 directly utilized the Olmstead concept in a more detailed engineering survey, specific flood control action by the city did not ensue. Implementation would have required government action, but planning was still an unpopular policy, and financial resources were doubtful. Fortunately, however, under the city's park acquisition program, some of the land donated by philanthropic individuals was floodable and therefore removed from high loss-potential development. Thus, during the first three decades of the century, numerous tracts, especially railway land along Middle Boulder Creek, became available "for improvement in accord with the Olmstead plan," at least in terms of its open space recommendations (Perrigo, 1946, p. 219).

The period between the two world wars began and closed with moderate floods in 1921 and 1938. It was a period in which the rapid population growth of earlier times slowed to the point of stability (Figure IV-2). And, with its most basic material needs now satisfied, Boulder devoted more energy to more social programs, such as development of the University. This, in turn, attracted development on the terraces south of Boulder Creek and growth of a new business center on University Hill.

Not only did this invasion of a residential neighborhood by commercial uses lead to the passing of one of the first zoning ordinances in the American west (1928), but it brought about a change in the urban pattern. By linking the two commercial cores, 12th Street (Broadway) became an arterial route, and higher land values caused encroachment upon the creek from both north and south, in addition to invasion of dry gulches towards the city's northern and southern boundaries. Thus, whereas now the city not only had financial but also the legal (Home Rule, 1917) and institutional (Parks and Planning Commission, 1928) resources to implement a flood plain management program, the long absence of experience with serious flooding had dimmed the community's perception of threat and, therefore, the necessity for action.

By the 1940's Boulder had evolved into a quiet, cultural, semi-rural market town. There was little to indicate that the city was on the threshold of a period of rapid growth and development and that its potential flood problem would soon be magnified enormously.

## An Era of Rapid Growth: 1940-1973

For the period 1940 to 1973, Boulder's population increased over five and a half times, and the city area expanded by an almost equivalent amount (Figures IV-1 and IV-3). Factors accounting for this rapid growth are given below.

As in previous periods, the quality of the physical environment and the existence of a university played important roles in shaping Boulder's development. Soon after the Second World War, the Boulder Industrial Association of the Chamber of Commerce began a vigorous drive to attract industry to the docile community, using Boulder's low tax structure and attractive environment as enticements. At the same time, there was an almost three fold increase in university students to 8,866 (1950), as ex-servicemen took advantage of assistance offered in the G.I. Bill. The growth of scientific research and facilities in the University of Colorado, in turn, attracted not only industry, but other research institutions.

An additional factor in Boulder's growth was the construction of a multiple highway to Denver in 1952, making attractive Boulder an accessible dormitory center.

Consequent upon these factors, the city bought 200 acres of land on its southern boundary and sold it to the Federal government, on which it would locate the National Bureau of Standards in 1950. The Boulder Industrial Park was opened on Arapahoe Avenue east of 55th Street in 1955. The National Center for Atmospheric Research was opened in 1960. Beech Aircraft and Dow Chemical were located to the City's north and south, respectively, and many other industrial and research complexes followed. By 1973, fifty two manufacturing industries within the city had employment roles exceeding twenty.

Commensurate with this growth in population, industry, research and education, was the need for new public and commercial services, including housing.

Since no new additions had been annexed to the city between 1908 and 1940, much of the existing city had been filled in when the surge of development began in the 1950's. The consequence of this pressure upon all types of land uses was to force expansion outwards. For example, the National Bureau of Standards and the turnoff to the Denver-Boulder Turnpike served as foci for residential development to the south and southeast, respectively, which, in turn, attracted cores of commercial services. Similar development took place around the University as well as to the north of the city. But most commercial development came by way of planned expansion into a new regional core that, by the 1970's loosely covered a two square mile oblong that ran between 26th and 30th Streets, and from Iris Avenue in the north two miles to the banks of Middle Boulder Creek to the south.

The generalized land use pattern that has resulted from Boulder's transition from a semi-rural market town to a commercial, semi-industrial, research, educational city is illustrated later in Figure IV-7.

1. Sequent Occupance of Boulder's Flood Plains

One consequence of Boulder's growth has been a dramatic increase not only in the total area of city land that is floodable, but the city's proportion of it. This change in built-up areas at risk from the 1% flood is shown in the graph in Figure IV-3. Its spatial expression is illustrated in the graph in Figure IV-4 where growth is shown to have occurred in the north, east, and south.

Overall, the sequent occupance of Boulder's 1% flood plains, 1904 to 1972, is detailed for structural units by land use type in Table IV-1. Growth and change in Boulder since 1955 is shown in the graph in Figure IV-5 and more specifically for Middle Boulder Creek in Figure IV-6.

On Boulder's 1% flood plains aerial photo analyses of cross-sections in 1955 and 1973 show that building increased by nearly 130%, from around 1,270 to 2,930 units on some 2,500 acres (Figure IV-5). Most of the increase was due to residential invasion of dry gulches to the north and south and commercial and industrial development to the east. Although the older western sector shows minimal growth in number of units for all land uses, the graph disguises the fact that many old buildings have been recently replaced with new, high damage potential commercial and public units. (The rate of decay at about 2% per year involved some

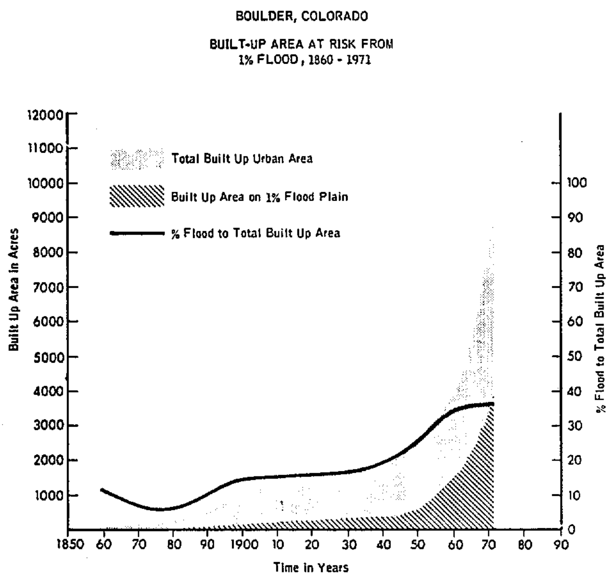



FIGURE IV-3

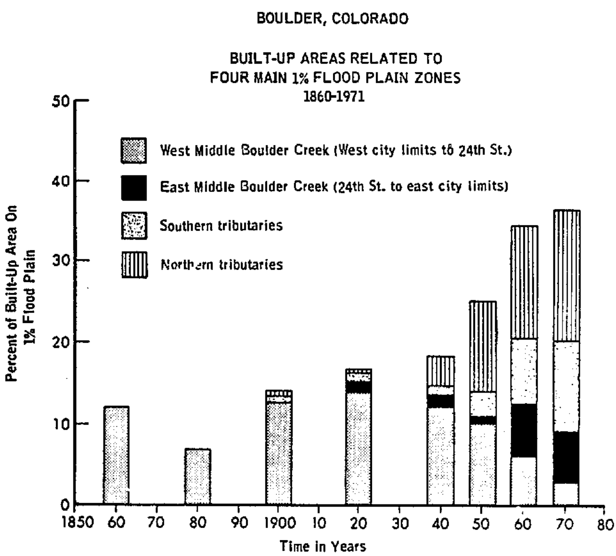



FIGURE IV-4

TABLE IV-1

SEQUENT OCCUPANCE OF BOULDER'S FLOOD PLAINS

| Occupance Type | Structural Units by Flood Plain Zones and Periods | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | West Middle Boulder Creek | | | | | East Middle Boulder Creek | | | | | Northern Tributaries | | | | | Southern Tributaries | | | | |
| | 1904 | 1955 | * % Change | 1973 | % Change | 1904 | 1955 | % Change | 1973 | % Change | 1904 | 1955 | % Change | 1973 | % Change | 1904 | 1955 | % Change | 1973 | % Change |
| Residential | 228 | 101 | -58 | 87 | -14 | 32 | 90 | 64 | 31 | -66 | 114 | 709 | 84 | 1571 | 55 | 67 | 308 | 78 | 1070 | 71 |
| Single Family | ? | 67 | 100 | 54 | | ? | 34 | ? | 10 | -67 | ? | 702 | ? | 855 | 18 | ? | 304 | ? | 989 | 69 |
| Multi-Family | ? | 19 | 100 | 24 | 21 | ? | 4 | ? | 4 | 0 | ? | 2 | ? | 74 | 97 | ? | - | - | 79 | 100 |
| Mobiles | - | 15 | 100 | 9 | | - | 52 | 100 | 17 | -67 | - | - | - | 642 | 100 | - | 4 | 100 | 2 | -50 |
| Commercial | 29 | 37 | 22 | 52 | 29 | - | 7 | 100 | 48 | 85 | 1 | 8 | 88 | 61 | 87 | 1 | - | -100 | 16 | 100 |
| Industrial | 12 | 2 | -83 | 2 | 0 | - | 4 | 100 | 54 | 93 | 1 | 1 | 0 | 23 | 96 | - | - | - | 5 | 100 |
| Public | 1 | 4 | 75 | 4 | 0 | - | - | - | 4 | 100 | - | 3 | 100 | 12 | 75 | - | 1 | 100 | 3 | 67 |
| Totals | 270 | 144 | | 145 | | 32 | 101 | | 137 | | 116 | 721 | | 1667 | | 68 | 309 | | 1094 | |

* That is, percent of structures added or lost over preceding period.

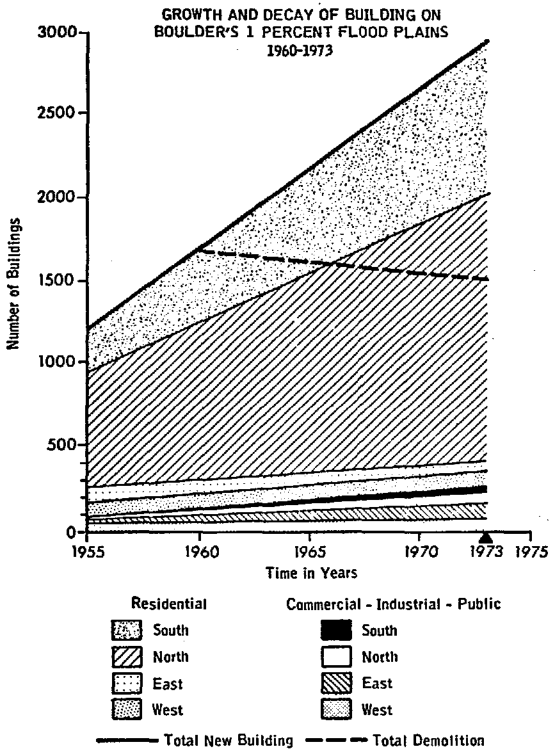



FIGURE IV-5

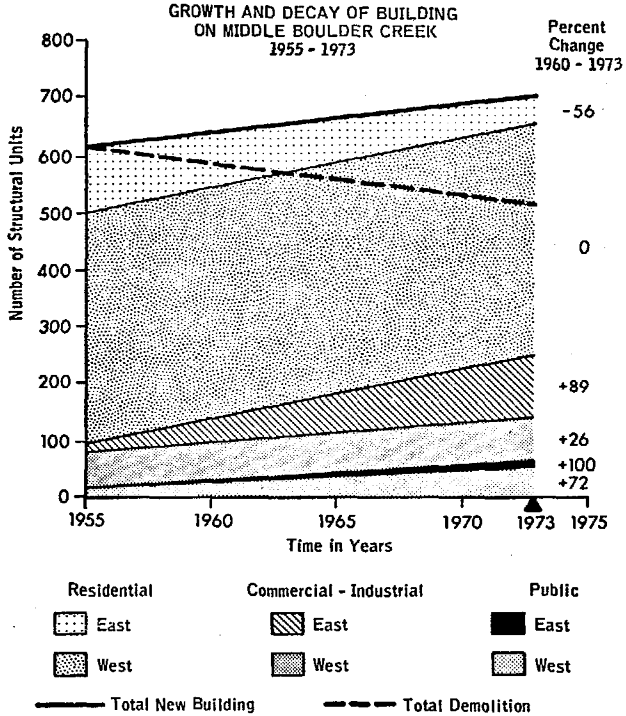



FIGURE IV-6

600 units over the 18 years to 1973.) This general trend in growth and decay of building on Boulder's flood plains is amplified for Middle Boulder Creek in Figure IV-6.

Between 1955 and 1973, the total number of buildings on the 1% flood plain of Middle Boulder Creek increased by 85 to around 700 units (Figure IV-6). But since 100 buildings were demolished during that time (with almost equal share east and west), the total number of new buildings was about 185.

Although residential building along Middle Boulder Creek decreased markedly in the eastern sector, the loss was more than compensated for by new, high value commercial and industrial development. Development in the older western sector was maintained at a steady level as new apartments and commercial units replaced old housing, businesses, and railway related buildings demolished when Canyon Boulevard replaced the rail track near the river in the mid-1960's.

As but one example of similar encroachment upon the smaller tributaries north and south of Middle Boulder Creek aerial photos show that on Gregory Creek at least thirty houses have been located on the 1% flood plain since 1955 when they totalled 55. Most of this new development has encroached closer and more dangerously upon the channel than pre-1955 housing.

Having examined briefly factors that have led to the systematic invasion of Boulder's flood plains, a statement of the city's current flood hazard position is now given.

## 2. Current Flood Hazard in Boulder

In Figure IV-7, an attempt is made to relate patterns of land use to topography and to the 1% or 100-year flood distribution. This is the planning flood adopted for use in flood plain management by Boulder in 1971. It is that flood which has a 1% chance of occurring in any one year; 18% in twenty years; and 63% in 100 years. The precision of spread is somewhat dubious for several reasons. The most accurate mapping has been done for Middle Boulder Creek--the major stream that runs through the city's center--by the Corps of Engineers (Corps of Engineers, 1972). But the flood flows and levels derived through flood frequency analyses are made under assumptions of natural hydraulic and physiographic conditions. That is, they take no account of obstructions to flow caused by bridges over channels and development on the flood

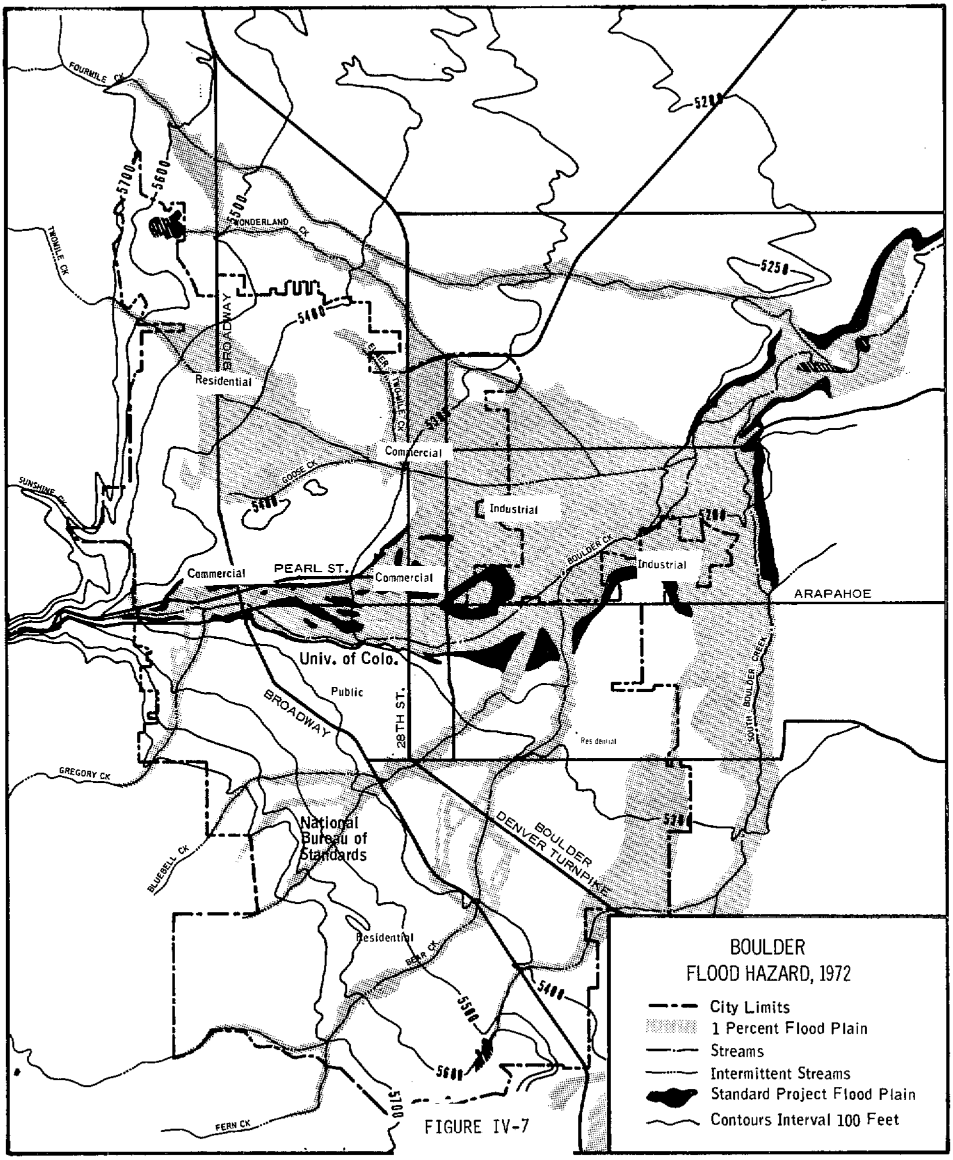

BOULDER
FLOOD HAZARD, 1972
City Limits
1 Percent Flood Plain
Streams
Intermittent Streams
Standard Project Flood Plain
Contours Interval 100 Feet
FOURMILE CK
TWOMILE CK
WONDERLAND CK
SUNSHINE CK
GOOSE CK
BOULDER CK
SOUTH BOULDER CREEK
GREGORY CK
BLUEBELL CK
BEAR CK
FERN CK
BROADWAY
PEARL ST.
28TH ST.
ARAPAHOE
BOULDER DENVER TURNPIKE
Residential
Commercial
Industrial
Public
Univ. of Colo.
National Bureau of Standards
5200
5250
5300
5400
5500
5600
5700

FIGURE IV-7

plain. These influences have never been measured, but are believed to affect flood levels in the manner shown in Figure IV-8.

EFFECT OF FLOOD PLAIN ENCROACHMENT
(INCLUDING FLOOD-PROOFED) ON FLOOD LEVELS

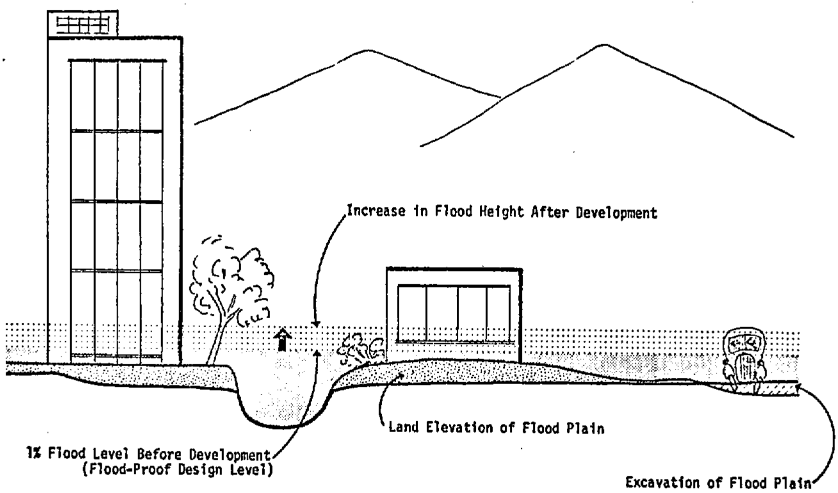



FIGURE IV-8

The mapping accuracy of flood spreads on tributary streams north and south of Middle Boulder Creek is less precise than for the latter, and could be subject to considerable error, but the distribution used is the best measure to date.

In addition to the 1% flood, the Standard Project Flood of the Corps of Engineers is shown in Figure IV-7. An accurate assessment of its probability of occurrence has not been made, but it could range between 0.05% and 0.025%, that is a 200-year to 400-year flood. Its estimate of areal spread on tributary streams is unknown at this time.

In terms of land use in relation to flood hazard, the significant feature in Figure IV-7 is the extent to which high cost commercial and industrial uses have occupied the lower terraces of Middle Boulder Creek and their extension to obviously vulnerable nodes on the tributary streams. (Compare the land use patterns in Figure IV-2 (1904) with those in Figure IV-7 (1972) as they relate to the 1% flood spread.) Important for human safety and welfare is the extent to which residential development has invaded the flood plains of the tributary streams. The land use patterns in Figure IV-7 suggest that, as in the past, there is currently a high level of vulnerability to flood loss in Boulder. The following sections deal with Boulder's efforts--often minimal--to cope with this problem.

3. Choice of Adjustment to Floods

Excluding several evaluations of flooding in Boulder County, at least twenty-two reports by ten agents have been made on the city's flood problem, 1945 to 1973 (Table IV-2). Three-quarters of them document the nature of flood risk and its growing potential for damage; two-thirds advocate engineering protection; but only one-fifth suggest social means for reducing the risk.

All except three reports were requested by the city. As in earlier periods, however, the number and degree of measures adopted for reducing flood-loss potentials have either lagged far behind or fallen far short of professional recommendations for action (Table IV-2).

The period opened with a detailed survey by the Corps of Engineers in 1945, reminiscent of the Olmstead recommendations made thirty-five years earlier:

> Local interests...expressed a desire for channel improvements through Boulder to provide protection against floods on Boulder and Sunshine Creeks. They...promised that such improvements be designed for incorporation in an overall plan for a boulevard-parkway along Boulder Creek being prepared for Boulder by consultant city planners.

The Corps' proposal called for protection against a flood the size of that which occurred in 1894. The project was authorized in the Flood Control Act of 1950 at a Federal cost of $515,000, and to non-Federal agencies, including Boulder, of $1.192 million. Boulder took no action due to costs that the city would have to bear and skepticism about negative consequences of inaction.

While these reasons may reflect the true outcome, it is important to note that the Corps' report was not accepted and taken under advisement by the city administration and council, and, therefore, its merits or demerits were not discussed by either city government or the public. Through an almost singularly personal decision of someone with the administration, the proposal was not afforded the "proper" or "usual" decision-making procedures. It is conceivable, then, that debate could have provided the proposal a different priority value.

Events of the 1950's, however, make it difficult to support

# TABLE IV-2

BOULDER CITY FLOOD HAZARD STUDIES: 1910--1973

| Date | Agent | Location | | | Study Type | | | Recommendations |
|---|---|---|---|---|---|---|---|---|
| | | Middle Boulder Creek | Northern Tributaries | Southern Tributaries | Hazard Evaluation | Engineering Control | Special Regulations | |
| 1910 | Olmstead | X | X | | | X | X | Hazard evaluation; channelization; levees; land use regulation. |
| 1912 | Metcalf & Eddy | X | | | X | X | | Channelization; levees; floodways |
| 1921 | Burns & McDonnel | X | X | | | X | | Enlarge bridge clearances; bank protection; channelization |
| 1945 | Corps of Engineers | X | | | X | X | | Floodwalls; levees; channelization |
| 1946 | De Boer | X | | | ? | ? | ? | ? |
| 1948 | U.S. Geological Survey | X | | X | X | | | - |
| 1955 | Debler | ? | ? | ? | ? | ? | ? | ? |
| 1957 | Soil Conservation Service | X | X | X | X | X | | Proposed Boulder Watershed Protection Project |
| 1958 | White | X | | | X | | | - |
| 1959 | Corps of Engineers | | | X | X | X | | Flood control dam |
| 1960 | U.S. Geological Survey | X | | | X | | | Flood control and land use regulation |
| 1961 | U.S. Geological Survey | X | | | X | | | Hydrological Investigation Atlas HA 41 |
| 1961 | U.S. Geological Survey | X | | | X | | | |
| 1961 | Plan Boulder | X | X | X | | | X | Land use regulation through cooperation |
| 1965 | Civil Defense | X | | | | | X | Emergency planning |
| 1966 | White | X | X | X | | | X | Land use regulations; warnings and preparedness; hazard evaluation of tributaries |
| 1969 | Corps of Engineers | X | | | X | | | Avoid hazardous locations |
| 1969 | Wright-McLaughlin | | X | | X | X | | Channelization and storage |
| 1969 | Wright-McLaughlin | X | | | X | X | | Channelization and storage |
| 1970 | Wright-McLaughlin | X | | | X | X | | Channelization and storage |
| 1970 | Wright-McLaughlin | | | X | X | X | | Channelization and storage |
| 1972 | Corps of Engineers | X | | | X | | | Flood plain information map for management purposes |
| 1973 | Wright-McLaughlin | | | X | | | | Channelization and storage |
| 1973 | CECEP* | X | | | | X | X | Multipurpose physical & social measures: in progress |
| 1973 | Corps of Engineers | X | | | X | X | | Channelization, levees, and floodwalls |

* Corps of Engineers Committee on Environmental Planning, Boulder Branch.

such contention. For example, within five years of the decision to reject the Corps' project, a social survey found that the "most prevalent attitudes" held by property owners, real estate operators, and government officials about Middle Boulder Creek was "the belief that while there may have been at some vaguely defined time in the past a flood hazard it no longer exists" (White, *et al.*, 1958). Many who were aware of the 1894 flood felt that construction in 1924 of Barker Dam 15 miles upstream from Boulder would prevent its recurrence. In fact, the Colorado Public Service power storage dam, had, and still has, negligible facility for reducing flood flows in Boulder, since most flood water is generated downstream from the dam. Yet, this belief was to persist among public and government alike until at least 1965 when council requested a report be made on the subject (Hallenbeck, 1965). The belief of many remains unchanged.

A "less prevalent attitude" held by owners of new development on the flood plain was that it was "a calculated risk well worth taking," especially for those in more speculative ventures (White, *et al.*, 1958, p. 99).*

Given the private managers' generally poor perception of the technical risk involved, such attitudes seemed warranted even in the absence of recourse to either insurance or a well-developed flood relief program.**

Yet, if one considers the long and eventually acrimonious debate that surrounded a proposal by the Boulder Mountain Valley Watershed Association to incorporate Boulder within a Flood Control District, such negative attitudes bear witness to the difficulties involved in short-term socioeconomic goals about the consequences of a likely, but rare catastrophic event. For example, between January, 1956 and December, 1957, at least forty seven articles relevant to flooding and the Flood Control District were printed in the *Boulder Daily Camera*. The original

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*The developer of a multi-storied apartment building which encroaches on the stream channel is reported to have said in 1957 that he bore little risk from flooding as he expected to sell within six months (personal communication between the author and G. F. White, 1973).

**Many cognitive studies since 1958 have provided evidence of the poor perception of technologic risks of flooding by individuals. See for example, Robert W. Kates, Hazard and Choice Perception of Flood Plain Managers in the United States. Department of Geography Research Paper No. 78 (Chicago: University of Chicago Press, 1962).

sponsors of the Boulder Mountain Valley Watershed Association were joined by two dozen interested groups at the Association's formative meeting in February, 1956. Subsequently, they lobbied Boulder City Council to petition the local district court to create a Flood Control District, establishment of which would ensure up to 75% Federal assistance in a works program under Public Law 566 (Watershed Flood Control Act, 1954). Assured that its Home Rule Charter would not be threatened (Dunbar, 1956), and having received no public opposition to the proposal (*Boulder Daily Camera,* 19 May 1958), the city petitioned the court in May, 1956. Within five months, the proposal was being labelled as "dangerous, unnecessary, and illegal" by a small, but effective opposition (*Boulder Daily Camera,* 21 December 1956). In spite of the lofty charge that a Flood Control District would constitute a "super power", and the more pragmatic one that "costs would exceed benefits",* the city's petition was defeated on two minor legal procedural technicalities, and never renewed. Renewal almost certainly would have led to its adoption.

The decade closed with publication in the *Boulder Daily Camera* of professional predictions of severe flood damages in Denver and Boulder, including the results of the social survey, and a request by the city to the U. S. Geological Survey for a flood hazard evaluation along Middle Boulder Creek (Mikesell, 1959). In agreeing to do the evaluation on a 50-50 cost-sharing basis--a cost to the city of about $9,000--Boulder was among the first group of communities in the United States to be included in the U. S. Geological Survey Hydrologic Investigations Atlas series (U. S. Geological Survey, 1961).

Although some consideration was given during the first half of the 1960's to possible development of flood plain regulations and a new Corps proposal to channelize and dam Skunk Creek (Corps of Engineers, 1959; Planning Staff, City of Boulder, 1966), the post-war pattern of opposition and inaction to flood plain management in Boulder persisted.

With so much planning expended on the flood problems of a single city, and with so many regionally and nationally prominent planners and agencies involved over so many years, the point is long past asking, "What factor or factors are necessary for the adoption of

*First estimates were that Boulder would pay $750,000 for a $3 million land treatment and flood control project.

flood plain management policies?" For Boulder, the answer seems to have lain in the actual occurrence of the damaging flood event, specifically, the regionally severe flooding of June 16-20, 1965 and the locally severe flooding of May 4-8, 1969 in which damage to city public facilities totalled $379,000 (Table IV-3). Consequently, for the seven years prior

TABLE IV-3

FLOOD DAMAGES IN BOULDER
MAY, 1969

| Nature of Costs | Costs ($) |
|---|---|
| Public Property | |
| Debris clearance | 1,880 |
| Sanitary sewers | 36,480 |
| Streets, roads, and bridges | 97,040 |
| Dike, drainage, and levee repairs | 188,500 |
| Public utilities | 55,100 |
| Private Property | |
| Commercial, industrial, and residential | 2,500,000 |
| Total Costs | 2,879,000 |

(Source: City of Boulder, 1973).

to 1973, there was increasing emphasis on developing comprehensive flood plain management plans for Boulder. By 1973, however, implementation of such plans was still far from complete.

Policy-wise, measures adopted since 1965 include an emergency warning and evacuation plan, flood plain regulations, storm-water retention requirements, flood insurance, and the establishment of a storm drainage and flood control utility with fee collecting powers.

a. Emergency Warning and Evacuation

The emergency warning and evacuation plan developed out of the 1965 flood experience and was revised after testing by the flood in 1969 (Director of Public Works, City of Boulder, 1965; 1970). In essence it calls for monitoring of the stream system by observers who maintain radio contact with the city's Director of Operations. Although directly responsible to the Coordinator of Public Facilities and ultimately the City Manager, the Director of Operations is responsible for informing all key personnel, including his superiors, of a deteriorating flood condition and for giving information directly through local radio to the public on flood operations and warning and evacuation procedures. The plan is appropriately linked to rural emergency centers and makes use of services and personnel of the American Red Cross, Police and Fire Departments, and the University Police for evacuation, search and rescue, and relief operations. The efficiency of the current plan has yet to be tested.

b. Flood Plain Regulations

Following the June, 1965 floods, efforts were directed at developing flood plain regulations. Professional advice was once again sought, and the recommendations given (White, 1966b) finally adopted in a flood plain ordinance (3505) three months after the May, 1969 flood (City of Boulder, 1969), but not without strong opposition, especially from land developers (*Boulder Daily Camera*, 5 July 1969).

The regulatory area is the equivalent of the 100-year or 1% flood spread which, following definition, was adopted by the city council on March 17, 1971. The flood plain ordinance requires the regulatory area to be divided into a floodway district--that area needed to convey the 1% flood safely--and a flood storage district which forms the remainder of the regulatory area. Definition of these two districts and their adoption by the city council had not, however, been made by late 1973.

The regulatory measures are flexible and do not exclude outright, building, and other high value uses from the flood plain. For instance, a variety of open-space uses are listed as the only permitted uses in the floodway. Yet, if special modifications as specifically required by the city administration are complied with, excluded uses--such as permanent structures--can be located in the floodway. Special modifications for buildings would include, for example, placement of structures parallel to the line of flow to minimize their obstruction, and flood-proofing measures including building and/or land elevation above the unobstructed 1% flood level. The variants allowed in the floodway are permitted uses in the flood storage district (City of Boulder, 1969).

In view of these regulations, the city's decision to link the old public library to a new addition by an over-stream corridor is reprehensible not only for the exposure to risk it causes, but for the poor example it sets. Similarly, although the proposed City and County Justice Center (near 6th Street) is for the most part outside of the 1% flood plain, its 700-foot length runs fully across the path of the Standard Project Flood. This seems sure to push flood waters further north into the old business district.

With regard to flood-proofing, no effort has been made to arrive at a permitted density of development, nor to assess the cumulative effects of variant uses upon the unobstructed 1% flood level. Obviously, it is the obstructed rather than unobstructed level that should be flood-proofed (Figure IV-8). Indeed, until the floodway and flood storage districts are defined, it is difficult to see how adequate adjustment to land use and buildings can be made. But more than this, those adjustments that are being made would appear to be in violation of existing law! It is instructive, therefore, to find that a Boulder councilman, formulator of the city's flood plain regulations and a principal in the firm of consulting engineers responsible for flood plain studies, has joined with concerned citizens in a suit against the City Council for violation of Ordinance 3505 (Kolwitz, *et al.*, vs. City of Boulder, *et al.*, 1973; City of Boulder, 1969; Wright-McLaughlin Engineers, 1969, 1969a, 1970, 1970a).

Be this as it may, in two years of operation, only seven parcels of land have been denied building permits for industrial or commercial purposes on Boulder's 1% flood plains (Dieffenderfer, 1973). For the same period about thirty buildings of that type were located within the 1% flood plain of Middle Boulder Creek (Figure IV-9). Field observations show many to be inadequately flood-proofed.

c. Flood Insurance

With the adoption of regulatory measures, Boulder was accepted into the subsidized insurance program of the Federal Flood Insurance Administration in early 1971. The degree of adoption and extent of coverage is relatively small as seen from figures in Table IV-4. This is due to the newness of the scheme; a low profit margin to the insurance companies (25%) which discourages vigorous selling; and high cost of premiums (in spite of a 90% Federal subsidy) that discourages public purchase.

4. Toward Comprehensive Flood Plain Management

The recent adoption of social measures to help ameliorate Boulder's growing flood problem presents not only a break in the long-term pattern of negative decisions by the city, but the first fruits of a more sophisticated unified approach to flood plain management than that offered through more

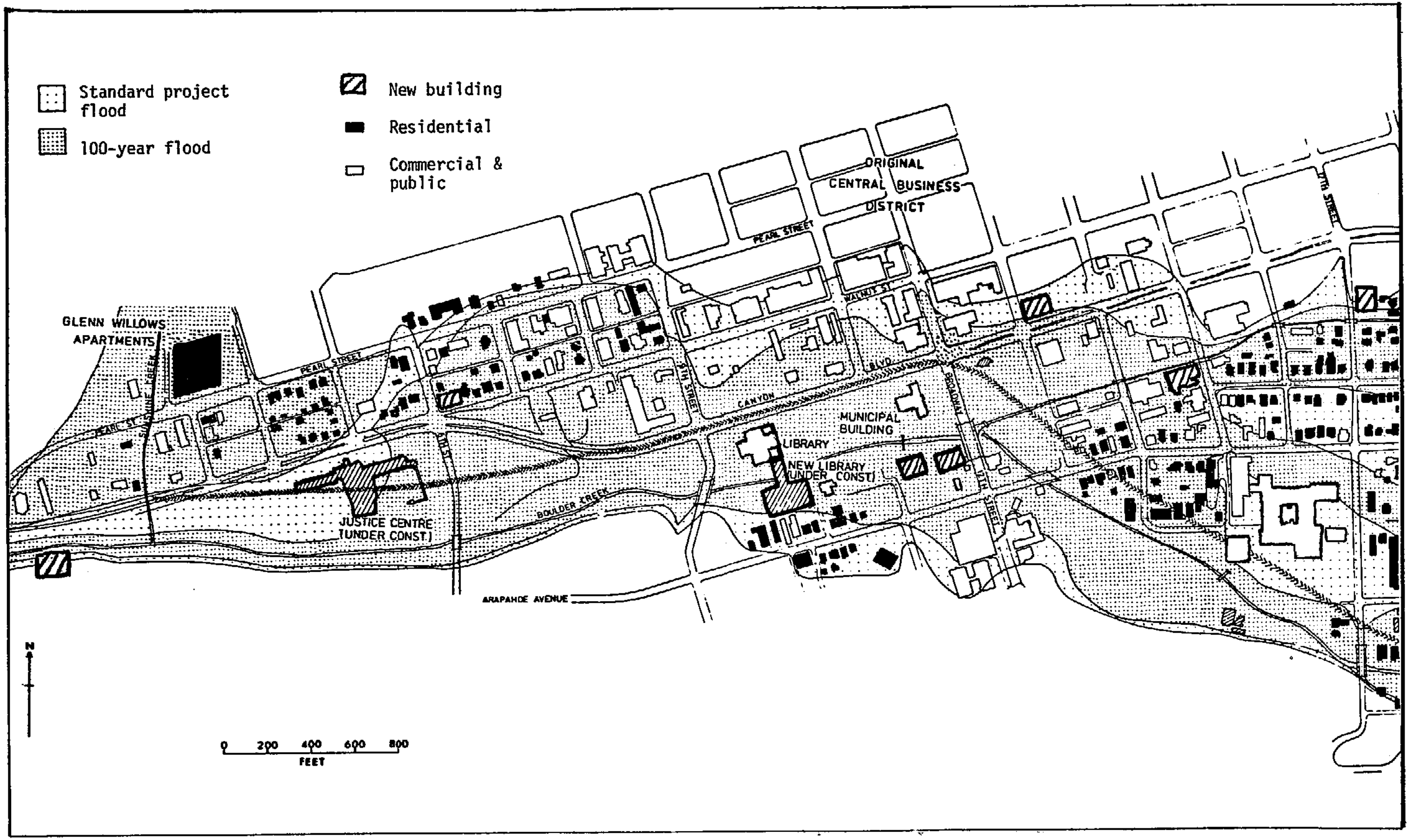



FIGURE IV-9 BUILDING ON THE FLOOD PLAIN OF MIDDLE BOULDER CREEK, 1971-1974

TABLE IV-4

ADOPTION OF FLOOD INSURANCE IN BOULDER [1]

| Land Use Type | Number of Permits Issued | | | Average Premiums Paid ($) | | | Average Value ($) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1971 | 1972 | 1973 | 1971 | 1972 | 1973 | 1971 | 1972 | 1973 |
| Residential | 17 | 26 | 88 | n.a.[2] | n.a | n.a | 14,647 | 12,769 | 14,886 |
| Commercial | 3 | 5 | 13 | n.a. | n.a | n.a | 27,333 | 17,400 | 35,000 |
| Industrial | - | - | - | - | - - | - | - | - | - |
| Public | - | - | - | - | - | - | - | - | - |
| Other | - | 1 | 13 | n.a | n.a | n.a | - | 35,000 | 20,230 |
| Total | 20 | 32 | 114 | 90.40 | 80.66 | 61.03 | 16,500 | 14,188 | 14,868 |

[1]As of the 30th of June each year.

[2]Not available.

(Federal Insurance Administration, 1973, unpublished)

narrow traditional engineering programs. To understand something of the true character of Boulder's current attempts at adopting additional elements of this unified approach, it is necessary to return once more to the widespread regional flooding of 1965.

Soon after the disastrous flooding in eastern Colorado, a group of concerned engineers from throughout the region approached the Denver Regional Council of Governments and requested that they become their formal advisory committee on urban storm drainage and flood control problems in the region. The initial outcome of the advisory committee, chaired by Boulder's representative who is now Director of Operations, was a criteria manual that defined not only hydrological and engineering aspects of urban storm drainage and flood control, but many social and institutional facets as well (Denver Regional Council of Governments, 1972). Second, to overcome the problem of multijurisdictions in a sprawling metropolitan region (over 200 jurisdictions), an Urban Drainage and Flood Control District was created by an act of the Colorado State Legislature in 1969. The Urban Drainage and Flood Control District was to coordinate planning and provide financial and technical assistance to participant political entities, such as Boulder, within the district. Third, under the Denver Regional Council of Governments, a Federally funded pilot study using elements of the new criteria manual was carried out on Boulder's northern tributaries in 1968 (Wright-McLaughlin Engineers, 1969). Although flooding had been serious in that area in 1965, the city had refused funds for research into the problem. However, impressed by the Denver Regional Council of Governments, Urban Drainage and Flood Control District's demonstration of the need for comprehensive master planning of stream systems--a need that was undoubtedly reinforced by the 1969 floods--the city helped fund similar studies of the remaining tributary areas (Wright-McLaughlin Engineers, 1969; 1969a; 1970; 1970a).

In addition to the hydro-engineering studies, a request was made by the Boulder City Council to the Corps of Engineers to once more evaluate the flood hazard on Middle Boulder Creek and alternative solutions for reducing it, including multiple adjustments (Corps of Engineers, 1972; 1973). Instrumental in prompting this new request and in drawing up alternatives for review was the Boulder Branch of the Corps of Engineers' Colorado Citizens' Coordinating Committee on Environmental Planning (CECEP). Boulders' CECEP began operating in May, 1970, and by the end of 1971 had co-sponsored several public hearings to air likely alternatives for reducing flood damage potentials on Middle Boulder Creek. The committee was composed of many who had strong academic interests in environmental management in general and flood hazard in particular. They in turn, were supported by public interest pressure groups such as Plan Boulder. Initially, the response by the Corps of Engineers towards consideration of alternatives other than traditional engineering works (that is, of social alternatives) was very favorable, but as new personnel replaced the old during evaluations, the final outcome revealed that the Corps of Engineers had returned to its traditional stance.

The alternatives recommended by CECEP for environmental, social, and economic review by the Corps of Engineers fell into two broad groups: structural--principally engineering works for controlling flood flows; and non-structural--principally social measures for reducing flood-loss potentials through social reorganization. The structural engineering alternatives included (see Figure IV-10):

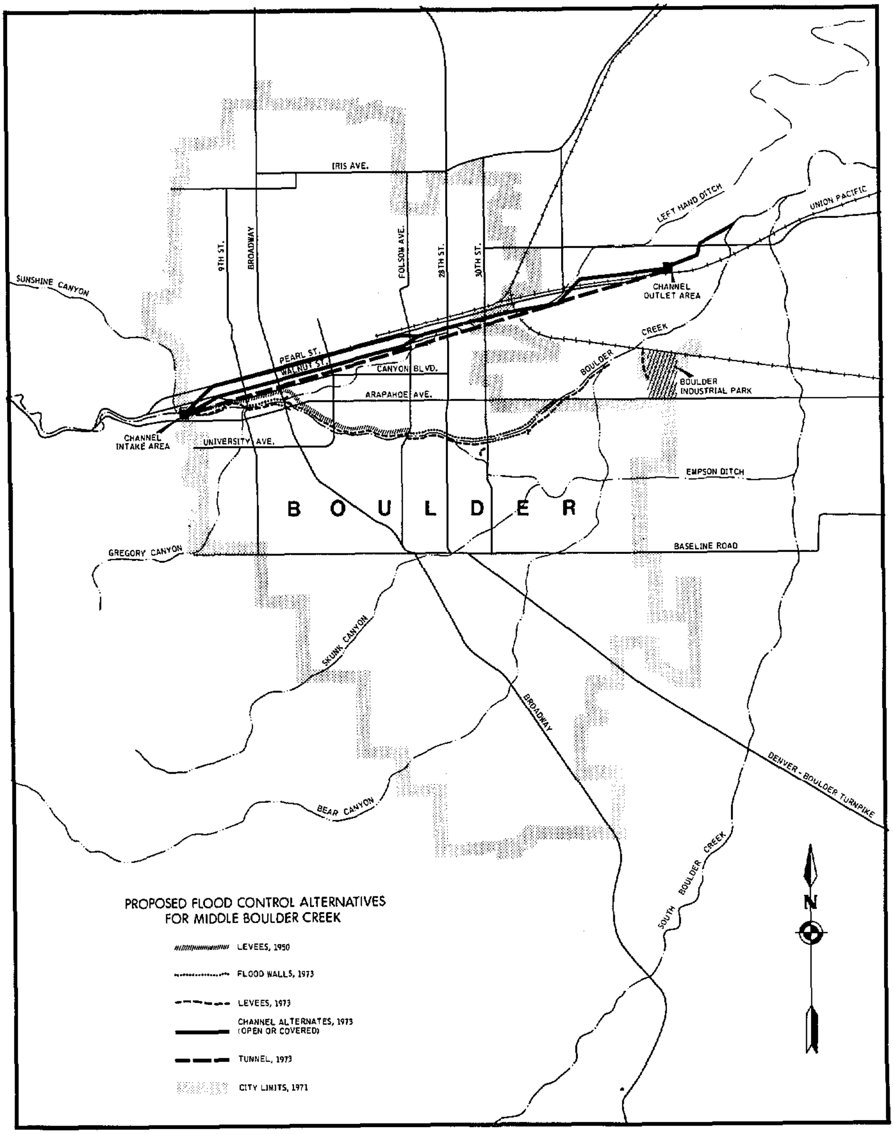

IRIS AVE.
9TH ST.
BROADWAY
FOLSOM AVE.
28TH ST.
30TH ST.
SUNSHINE CANYON
LEFT HAND DITCH
UNION PACIFIC
CHANNEL OUTLET AREA
PEARL ST.
WALNUT ST.
CANYON BLVD.
ARAPAHOE AVE.
CREEK
BOULDER
BOULDER INDUSTRIAL PARK
CHANNEL INTAKE AREA
UNIVERSITY AVE.
EMPSON DITCH
B O U L D E R
GREGORY CANYON
BASELINE ROAD
SKUNK CANYON
BROADWAY
DENVER - BOULDER TURNPIKE
BEAR CANYON
SOUTH BOULDER CREEK
N
PROPOSED FLOOD CONTROL ALTERNATIVES
FOR MIDDLE BOULDER CREEK
LEVEES, 1950
FLOOD WALLS, 1973
LEVEES, 1973
CHANNEL ALTERNATES, 1973 (OPEN OR COVERED)
TUNNEL, 1973
CITY LIMITS, 1971

FIGURE IV-10

(1) *Diversion Tunnel.* A flood control tunnel that would intercept flood waters near the mouth of Boulder Canyon and return the flows to Boulder Creek downstream from the city. A sediment and debris basin would be required to prevent clogging at the tunnel entrance and would necessitate relocation of some homes and highways in the basin area.

(2) *Diversion Channels.* A concrete-lined diversion channel down either Pearl, Walnut or Arapahoe Streets would also intercept flood waters at the Canyon mouth. The channel would be either a boxed-in culvert for flood control purposes only, or an open channel, aesthetically enhanced for open-space uses including hiking, biking and boating.

(3) *Upstream Impoundments.* The three types of upstream impoundments considered included: (a) a large flood control dam or multi-purpose dam near the mouth of Fourmile Creek only two miles upstream from Boulder which would inundate at least 800 acres of canyon and require re-routing four miles of highway and relocation of at least fifty houses; (b) three medium flood control dams on the three major tributaries of Boulder Creek upstream of the city; and (c) small flood control dams on more than eighty minor tributaries in the Boulder Creek basin.

(4) *Soft Channel Treatment.* The soft channel treatment concept featured modified bridges, set-back, aesthetically pleasing levees, and native stone flood walls, but little or no channelization.

(5) *Hard Channel Treatment.* This concept emphasized enlargement of the natural channel through deepening and widening, plus lining with concrete.

The non-structural alternatives offered by CECEP for consideration by the Corps of Engineers included:

(1) *Reforestation.* Land treatment through reforestation was suggested for the Boulder Creek basin as a means of retarding flood flows.

(2) *Permanent Flood Plain Evacuation.* This concept would have removed all damageable buildings from the flood plain so that a natural floodway could be maintained.

(3) *Flood Plain Zoning; Flood-Proofing; Flood Insurance; and Retarding Urban Runoff.* Each of these four non-structural measures was also to be considered, even though variants of each had been, or was subsequently, adopted by the city.

In addition to analyses of the physical feasibility and the benefits and costs associated with these alternatives, their ecological impacts upon both biological and social systems were to be assessed. The latter analysis would fulfill requirements of the Environmental Planning

Act, 1969 (Public Law 90-190, 1970), that all Federal agencies include environment impact statements on all projects that significantly influence the environment. The environmental analysis would also include a city-wide social survey to determine public reaction to the various alternatives proposed, and to assess public policy priority values.

The outcomes of these various analyses are summarized in Table IV-5. There it is shown that the most socially and environmentally acceptable solutions (diversion tunnel and channel) are the most costly ones and have negative benefit-cost ratios. Conversely, the socially and environmentally least attractive solutions (hard or soft channel treatment) are shown to have the more favorable benefit-cost ratios.

However, results of the social survey conducted by Hill (1972) show that:

> while the people of Boulder are looking for a multi-disciplined approach to a program which will reduce flood hazard, will provide protection at low cost, and will give environmental preservation and enhancement they regard life and limb to have top priority with economic considerations second.

As for the economic evaluation, benefits and costs are presented in terms of adopting a *single* alternative, rather than some optimally desirable mix of adjustments. But more than this, only the traditional engineering alternatives have been economically evaluated. The social alternatives were ignored. Since an engineering graduate has successfully carried out a benefit-cost analysis of social alternatives for flood plain management in Boulder (Hurst, 1973), this can only mean that the results of the Corps of Engineers' analyses in Table IV-5 reflects the traditional bias and inertia of that agency and its personnel. Recommendations by the Corps of Engineers that Middle Boulder Creek be channelized and leveed were ill-received by the Boulder City Council. Thus, a solution that not only has physical and economical relevance, but also ecological, social, and political operability, is still being sought by CECEP and city government (Corps of Engineers, 1973).

This search for a unified approach to flood plain management at the local community level fully reflects recently established guidelines at Federal and regional levels (Task Force on Flood Policy, 1966; U.S. Water Resources Council, 1972; Denver Regional Council of Governments, 1972). But planning for a comprehensive city-wide approach to flood plain

TABLE IV-5

FLOOD-LOSS REDUCTION ALTERNATIVES FOR
MIDDLE BOULDER CREEK
100-YEAR FLOOD

| Type of Adjustment | Cost of Alternative ($ millions) | Cost-Benefit Ratio | Federal to Non-Federal Funding Ratio | Environmental Impact* | |
|---|---|---|---|---|---|
| | | | | Social | Ecological |
| Structural | | | | | |
| Large flood control dam | 23.2 | 1 to 0.67 | 1 to 7 | 3 | 3 |
| Medium dams (3) | n.a | n.a | n.a | 1 | 2 |
| Small detention dams | n.a | n.a | n.a | 1 | 2 |
| Soft channel works including levees | 6.4 | 1 to 1.42 | 1 to 23 | 1 | 3 |
| Hard channel works | 7.7 | 1 to 1.40 | 1 to 29 | 3 | 3 |
| Diversion tunnel | 31.5 | 1 to 0.31 | 1 to 15 | 2 | 1 |
| Diversion channel flood control only | 21.9 | 1 to 0.45 | 1 to 10 | 2 | 1 |
| Diversion channel multi-purpose | 28.0 | 1 to 0.38 | n.a | 2 | 1 |
| Non-Structural | | | | | |
| Reforestation | n.a | n.a | n.a | 1 | 2 |
| Flood-proofing | 8.8 | n.a | n.a | 1 | 3 |
| Flood plain regulations | n.a | n.a | n.a | 2 | 3 |
| Urban storm runoff detention | n.a | n.a | n.a | 2 | 2 |
| Flood insurance | n.a | n.a | n.a | 3 | 3 |
| Permanent evacuation | n.a | n.a | n.a | 1 | 1 |
| Do nothing | 25.0 | n.a | n.a | 3 | 3 |

(U.S. Corps of Engineers, 1973, unpublished)

*Environmental Impact: 3 = Unfavourable; 1 = Favourable management in no way guarantees its adoption and subsequent implementation. Adoption is principally contingent upon social and political acceptability, which is in turn largely dependent upon economics.

On August 21, 1973, Boulder City Council went a long way towards adopting a unified flood plain management program when it passed Ordinance No. 3927, thereby establishing a storm drainage and flood control utility that would coordinate, design, construct, and manage the urban storm drainage and flood control system (City of Boulder, 1973). Perhaps more important, the utility has authority to collect fees on the basis of the amount of storm drainage generated by urban development in an equitable manner, but with property owners within the flood plain regulatory area contributing 40% more than owners outside of it.

The urban storm drainage and flood control plan is currently priced at $22 million and has an implementation horizon of twelve years. By far the largest single cost is Middle Boulder Creek at $7 million (Table IV-6). The city is hopeful that for Middle Boulder Creek, Corps of Engineers' funding can be used to supplement local funds for development of an integrated non-structural project, rather than for a single best benefit-cost alternative, such as a levee, as is customarily the case.* For the most part, the master plan has been presented to the public by city administration in a series of public meetings called for each of the tributary areas, where encroachment by building has necessitated primarily an engineering approach. These more detailed and precise engineering designs now being developed have good prospects of being adopted and eventually implemented.

## Factors of Change in the Flood Hazard System

Selecting strategies for reducing flood losses and carrying them out in an effective fashion can be inhibited in many ways. Decision processes are governed by many factors that affect the way in which a flood hazard system evolves. In this section an attempt is made at specifying those factors that appear to have had an important bearing on the way in which the flood hazard system of Boulder has undergone change. The influence of these factors on future change needs to be borne in mind when developing scenarios of alternative futures. Although the treatment is systematic, the overlapping of factors will be obvious.

*Since writing the original of this chapter, a new law has been passed which will allow use of Corps funds for non-engineering adjustments.

TABLE IV-6

ESTIMATED COST OF BOULDER'S STORM DRAINAGE AND FLOOD CONTROL MASTER PLAN, 1973

| Stream Systems | Drainage Area (miles$^2$) | Flood Protection Cost ($000's) |
|---|---|---|
| Northern Tributaries | | |
| Fourmile Creek | n.a. | n.a. |
| Wonderland Creek | 3.6 | 520 |
| Twomile Creek | 2.1 | 2,000 |
| Elmer's Twomile Creek | 0.8 | 310 |
| Goose Creek | 3.2 | 3,000 |
| Sunshine Creek | 1.0 | 1,000 |
| Sub-total | 10.7 | 6,830 |
| Middle Boulder Creek | | |
| West (west city limit to 24th Street) | | |
| East (24th Street to east city limit) | | |
| Sub-total | 4.3 | 7,000 |
| Southern Tributaries | | |
| Gregory Creek | 1.2 | 1,150 |
| Bluebell Creek | 1.6 | 1,550 |
| King Avenue Creek | 0.7 | 350 |
| Skunk Creek | 2.7 | 70 |
| Bear Creek | 4.2 | 4,650 |
| Viele Lake Channel | 1.4 | 1,270 |
| Anderson's Channel | 0.6 | 20 |
| David's Draw | 1.7 | 70 |
| South Boulder Creek | n.a. | n.a. |
| Sub-total | 14.1 | 9,130 |
| Total | 29.1 | 22,960 |

(Personal communication from Ted Dieffenderfer, Director of Flood Control and Storm Drainage Utility for the City of Boulder, to the author, 1973)

1. Changing Values

The flood hazard system is a subset of the larger community system. The community system develops in response to decisions that, in general, reflect the broader cultural values of the nation. In Boulder, a concern for environmental quality, earlier in the century, which held potential for sound flood plain management was drowned in the new surge of economic and urban growth that occurred nationally following the Second World War. Growth, based on the new technology, was, and in most communities still is, a respectable goal. Its emphasis in Boulder in the 1940's and 1950's led to the rapid and largely unquestioned development of vulnerable flood plain land.

During the 1960's the adverse effects of technologically based growth have become increasingly apparent throughout the nation. A new environmental consciousness has developed to challenge the old growth ethic. Thus, Boulder, perhaps more readily than most cities, has been more concerned with developing policies that reflect concern for environmental quality, including limits to its growth and wiser use of its flood plain lands (Boulder Area Growth Study Commission, 1973; City of Boulder, 1973).

Nationally, a more cautious view of technological solutions coupled with increased environmental planning is reflected in development, through the 1960's, of comprehensive and integrated flood plain management that makes use of a range of social means for modifying flood-loss potentials--such as insurance, regulations, and community preparedness.

This trend is reflected in Boulder where dams and levees have been rejected on primarily aesthetic grounds in favor of less ostentatious channel improvements and social solutions.

2. Decision Levels

A system's evolution is affected by decisions made at varying levels in the social structure. For flood plain management, as well as other management areas, these levels include: 1) public managers at Federal, state, and local levels who have legal and administrative responsibilities for taking action on the public domain; 2) private managers at individual (householder) or group level (industrial complex) whose decisions affect flood plain management; 3) general public action which influences decisions through voting, contact with government agencies (CECEP), and pressure groups (Plan Boulder); 4) technical experts in a variety of academic disciplines; and 5) specialized officials in government agencies, such as the Army Corps of Engineers, Federal Insurance Administration, and Geological Survey.

The private manager is generally motivated by the notions of free choice and profit based on growth. Hitherto in Boulder these goals were compatible with public management, as reflected in decisions by the city that resulted in a prolonged period of flood plain invasion. More recently, public management has been moving toward environmentally conscious policies, while the investment philosophies of private management remain essentially unchanged. Thus, efforts are continually being made by private managers to circumvent or otherwise negate the regulatory instruments of the city by exerting economic and political pressure on city management.

Re-emergence within the community of an environmental conscience has resulted in more successful action by citizen pressure groups concerned about environmental quality than in the 1950's when the growth ethic was in command. The success of groups such as Plan Boulder and CECEP has been aided by technical input from academic personnel operating either within or outside of the pressure groups.

The interplay between levels of public management has an important bearing on system change. Although a policy of flood plain management has been slowly emerging in Boulder throughout the 1960's elements of its adoption were hastened by policies developed at state (Urban Storm Drainage and Flood Control District) and Federal (National Flood Insurance Act of 1968) levels. Thus, constraint imposed external to the community can significantly alter the pattern of flood plain evolution within the community.

3. Changing Actors

A change in actors may be seen to influence system change in two main ways. First, as cultural values undergo change, community leaders emerge who are sympathetic toward new public goals. Thus, within both Boulder's administration and city council, there are people who have a strong interest in pursuing a program of comprehensive flood plain management. This leads directly to the second way in which changed actors can influence system change. A sound flood plain management policy can become ineffectual simply because people responsible for its application interpret the policy differently from its formulators. In Boulder, implementation of the flood plain zoning ordinance (no. 3505) is at such variance with what was intended by its formulators, that the latter have filed suit against the city for violation of its own regulations (Kolwitz, *et al.*, vs. City of Boulder, *et al.*, 1973).

In a related way, a turnover of staff within that branch of the Corps of Engineers responsible for evaluating alternative solutions to flooding on Middle Boulder Creek changed the branch's emphasis from more contemporary non-structural adjustments to traditional engineering works.

4. Acceptable Level of Risk

In spite of numerous reports and partial reports on the flood hazard and solutions to it, Boulder remained largely inactive in flood plain management until the late 1960's. Inaction is in part explained by the fact that a large flood discharge had not occurred since 1894. Without serious exposure to the physical event, decision-makers simply ignored or misunderstood technical advice, and channelled concern into more obvious, everyday social programs (streets, sewerage, water).

In one sense, this says something about the cognitive inabilities of lay people to handle probabilistic situations. This is reflected in two statements often heard by the author in Boulder: "The 100-year flood occurs only once every hundred years or so"; and "We haven't had a flood for a long time and are due for a whopper." The first statement is not only more prevalent, but more inhibitive to development of a flood plain management program, since it suggests that the present is safe and there is ample time left in which to look after the future.

When poor understanding of the risk involved is coupled with the 10 to 20-year investment philosophies of the entrepreneurial private managers, it becomes obvious why there has been so much invasion of Boulder's flood plains.

It is significant, therefore, that first moves towards comprehensive flood plain management followed closely the small, yet very damaging, floods of 1965 and 1969. The difficulty in the future will be to sustain this experience of flood threat, and to build images of even greater threats in the future. The chances of doing so are enhanced by the fact that many flood-loss reduction measures have now become institutionalized. The degree to which these measures are properly sanctioned and implemented will largely determine their success, and that will most likely depend on the decision-makers' view of flood threat.

In spite of the current city council's concern for environmental quality, they have yet to demonstrate sympathy towards the flood hazard views of the hydrological expert who is their fellow-member on the council. Lack of sympathy appears due to imperfect knowledge of the flood problem, rather than management *per se*. This can be specifically illustrated by the statement of one councilman to the author at the conclusion of a Corps of Engineers presentation of flood risk and the benefits and costs of alternative solutions, "I didn't understand what they (the Corps of Engineers) were talking about."

5. Systemic Effects

As Boulder community extended its increasingly complex structure onto flood plain lands, small and moderate floods produced increasingly serious losses. But, just as increased social complexity has led to increased potential for losses beyond points of physical damage, it has also produced sufficient specialization of social activity to support an institutionalized flood plain management policy. This contrasts earlier periods when in spite of sympathy towards environmental quality in the early part of this century, when the potential for damage was less marked, the city lacked the resources necessary for development of any flood policy. Later, as the resource base increased, flood events were small enough that they did not arouse sufficient concern to implement flood control measures.

6. Uncertainty and the Future

A large flood has not occurred in Boulder for 80 years; yet specialists in hydrology continually point to the danger of its repetition and the probability of its doing so. Yet, the range of estimates for the 1% flood on the western margin of the city runs from a discharge of 4,500 cfs. to 11,000 cfs. In little more than a decade, the discharge value as computed by two Federal agencies principally involved in flood frequency analyses has fallen from 10,000 cfs. to 7,400 cfs. In addition, the precision with which flows have been mapped leaves much room for doubt in the minds of the local land use planners.

Given the degree of uncertainty that surrounds the level of acceptable risk, the community's managers appear to minimize failure and maximize success. Thus, even though flood plain regulations have been adopted, they are currently being applied in a piecemeal, case-by-case way, thereby obscuring long-run aggregate outcomes, which may be far less efficient than current management is prepared to concede. On the other hand, if a too idealistic land use management program, such as avoidance and abandonment of the 1% flood plain, is pushed for, it may fail to deal sufficiently with existing problems. More important, by not being adopted, it could lead to more limited action on the flood problem.

## Boulder: Retrospect and Prospect

Although Boulder has not experienced a major flood discharge for almost eighty years, recent encroachment of its flood plain lands makes relatively minor flood discharges a serious flood hazard problem. By the time Boulder had developed an economic base and institutions capable of supporting a flood protection program, repeated, though minor, flooding at exposed locations during the three decades ending about 1955 was not sufficient to arouse feelings of threat in spite of repeated studies to the contrary. Not until the damaging floods of the latter 1960's--by which time development had obliterated the dry gulches and seriously encroached Middle Boulder Creek's flood plain--did the community become sufficiently concerned to act. Consequently, several elements of a unified approach to flood plain management have been adopted, including flood plain regulations and an urban storm drainage and flood control utility and fee collection system.

The future of Boulder's flood plains is, however, far from certain. Uncertainty surrounds not only the decisions that will be made, but their possible outcomes. In the fluid conditions that currently obtain, many questions regarding the management of Boulder's flood plains arise. For instance, if the master plan is finally accepted and adopted, to what extent will it remain true to the concept of a unified flood plain management approach? Will it happen, as a former Public Works Director suggested, that, "once the master plan has been completed, restrictions on development within the 100-year flood plain would be drastically reduced"? What would be the consequences of a decision to drastically reduce the regulatory requirements of development? Will there be, as one professional water resource researcher believes, a negative decision on Middle Boulder Creek similar to that of the early 1950's? What might be the consequences of inaction or inadequate action in the 1970's, 1980's or later?

These are questions that can be used to help probe the future. In exploring the future, interest is in examining the consequences of adopting given policies or the effect that changes in policy will have on future outcomes. Interest is also in delimiting research opportunities that if applied could help facilitate achieving more desirable paths and goals.

Before exploring the future, however, two supplementary analyses are carried out. The first is a cross-sectional account of Boulder's reaction to a flood hypothesized to occur in 1973. This account describes deficiencies in the existing system. Second, ways are explored in which the outcomes of the historical progression of flood plain management in

Boulder (as described in the cross-sectional scenario) could have been different had different types of policies been adopted by Boulder earlier in its history. This is done in an analysis of alternative pasts.

As with alternative futures, alternative pasts are used to explore questions about the impact of different policy and research applications. For example, Boulder does not seem to have lacked information in the past (Table IV-2), but was it the right kind in the right form? If the Corps of Engineers had had CECEP groups in the early 1950's, would it have ensured public discussion of levee protection and its adoption?

Before examining either alternative pasts or alternative futures, the present is explored in a cross-sectional image, for this will not only provide a summary of the current flood hazard system's efficiency, or inefficiency, but it can be used as a marker against which outcomes from alternative progressions (past and future) can be qualitatively measured.

## CHAPTER V

### EXPERIENCING THE UNEXPECTABLE: A SCENARIO OF THE ONE PERCENT FLOOD IN BOULDER IN 1973

In the previous chapter, the existing conditions of development on Boulder's flood plains were described, together with the current level of social adjustment to potential flood events. In this chapter, the capacity of Boulder's current social organization to absorb the shock of a severe flood is explored in a cross-sectional image through a synchronic analysis.

In the analysis, three interrelated objectives have been kept in mind: first, to simulate the nature, magnitude and geographical distribution of property damages, human casualties, and disruption to social systems that would be likely to occur in Boulder in a 1% flood in 1973; second, to indicate the capacity that existing adjustments have for reducing the flood's impact; and, third, to give some feel for those factors that would create stress in the social system of Boulder during a disaster.

To meet these objectives, the general method for constructing current cross-sectional scenarios, outlined in Chapter III, was adapted for Boulder's conditions in the following way. First, information was gathered upon which judgments about the socio-economic consequences of a 1% flood in Boulder could be made. The gathering of information involved acquisition of data from the U. S. Army Corps of Engineers; field surveys; and opinions from a panel of experts and supplementary personal interviews. Second, these analyses and opinions were then used to help develop a technical scenario of the problem. And, third, the technical scenario provided the basis and principal justification for judgements made in writing a more speculative, dramatic scenario.

Because of unavoidable repetition of information in the technical and dramatic scenarios, only the dramatic scenario is included here. In order to provide some credence or plausibility to the fictional dramatic scenario that follows, however, some indication of actual data and expert opinion used in it is given in footnotes, and in tables and illustrations at the end of this chapter.

## Dramatic Scenario

With convective storms boiling over the mountains, Saturday, the 31st of August, seemed certain to end as the days before it had done. The week had been more humid than usual, but the hot summer days had closed with cooling rains from towering thunderheads pushed out from the mountains by persistent westerlies. Only the stillness of the day seemed different. By 5 p.m., the thunderheads still hung over the mountains and the sky had darkened ominously to leaden gray.

A massive stationary cell of cumulonimbus clouds stretched west from Boulder eight miles to beyond Sugarloaf Mountain. Its thirty square mile base centered over Bummer's Gulch and Fourmile Creek, tributaries of the Middle Boulder. By 5:30 p.m., torrential rains were falling along a ridge between Mounts Arkansas and Sugarloaf, about one and one half miles south of the old mining settlement of Salina (Figure V-2). At 7:00 p.m. the storm was in the midst of releasing its full fury, and the Director of Operations for Boulder became concerned about the possibility of flooding within the city. Upstream, normally dry gulches filled with gushing waters which became more ferociously destructive as they sped downslope with ever-increasing volume as tributaries spilled into ever-larger channels.

Within two hours of the storm's beginning, the first crashing debris-filled crest of water smashed through Wallstreet and Salina, splintering numerous small bridges and flooding fifteen buildings. The complete destruction of nine old buildings added to the debris of trees being torn from the stream banks by the raging waters. Five persons were swept to their deaths.[1]

The flood wave momentarily halted as it spread over the tiny Crisman flood plain one and one third miles downstream from Salina, destroyed eight houses and two bridges, and then crashed on through the steep-walled canyon four and one half miles to its confluence with Middle Boulder Creek at Orodell, a little over two miles upstream from Boulder.

In the premature dusk, residents perched high on the canyon's rim heard the booming roar of the water and scanned its rapid descent toward Orodell. Aware of imminent disaster, several spectators of the awesome flood wave phoned a hasty warning to the flood plain dwellers below.

In its final rush to Orodell, eleven houses and a motel of relatively recent construction were wrenched from their foundations by the force of the water or splintered by the charging debris. Twelve other homes were inundated to varying depths.

Three hundred yards upstream from the confluence, the Public Service Company's transmission line from the Boulder Hydro Plant was cut as debris-filled water travelling at fifteen miles per hour smashed down a pylon, causing temporary outages within Boulder and its environs.

The Orodell debris added to the clogging of the conduit under Boulder Canyon Road. The highway itself formed a fifteen-foot dam that caused water to back up a quarter of a mile upstream, and temporarily halted Fourmile Creek's devastating contribution to the already raging Middle Boulder Creek.

Without adequate warning of impending disaster, many residents at Orodell perished. First count of the missing totalled thirty-one.

As Fourmile Creek gouged at the man-made barrier at Orodell, the first wall of water from Middle Boulder Creek crashed into the Arapahoe Avenue bridges on the west side of the city. The surging, debris-filled wave had already snapped the city's water supply line that slung low across the stream one mile to the west. For a while, water poured around the bridge ends, travelled a short distance over the very narrow flood plain, then sloughed back into the incised channel. But then, under the weight of scouring waters, the debris-plugged bridges burst to release the volume of muddied waters on its rampage through the city's heart.[2]

A two-inch gas line tied to one of the bridges snapped like a twig; the first of many breakages that would be repeated downstream.

Hasty evacuations had been made from eight homes in Cañon Park subdivision, which clings precariously to a narrow bench on the left bank immediately upstream from the west Arapahoe bridges.

Meanwhile, the full force of flooding from two small tributary streams--Sunshine Canyon to the north, and Gregory Canyon to the south--had already been felt in the city with devastating and tragic consequences. The intensity of rain was such that their less than two square mile catchment basins and very steep gradients caused volumes of high velocity water to wreak unbelievable damage in little more than one hour.

By 8:00 p.m., the force of water from Gregory Canyon was so great that boulders up to three feet across were being hurtled down-slope, smashing trees, houses, and other obstacles that stood in their paths. A fifty-yard swath of destruction ran a dozen blocks from the corner of

Baseline and Flagstaff roads to Middle Boulder Creek between 6th and 9th Streets. The normally placid and tiny channel held no bounds. Ten houses were completely demolished and fourteen others substantially damaged. In all, sixty-eight homes were inundated.

Twenty-one persons lost their lives from Gregory Canyon waters, including three picnickers who had taken shelter from the sudden storm under a large boulder near the stream bed in the upper catchment. Many survivors would describe narrow escapes from death. Cars parked in the mouth of Gregory Canyon south of Baseline Road were swept downslope.

To the north of Boulder Creek the progress of flood waters down Sunshine Canyon was delayed by frequent blocked road crossings which formed small dams. But the sequential collapse of these obstacles created an ever-greater volume of water near the canyon's mouth. As water gushed past Memorial Hospital, it catapulted into Knollwood--a new subdivision of high-income housing that reaches down from Red Rocks into the creek bed below. With no warning at all, the hurtling waters smashed into several low-lying homes in a deafening roar. Persons above the creek, not fifty yards distant, watched in horror as neighbors were swept to their watery doom. Time would show that four persons had lost their lives in this normally enchanting locale. As with Gregory Canyon, the waters receded almost as quickly as they had come.

The destructive flow sped on engulfing the new Glenn Willow Apartments and Cañon Park Liquors on Pearl Street astride the stream, and older buildings immediately below. Muddy, debris-laden waters fanned out west to Red Rocks Motel and east down Pearl Street and Canyon Boulevard as far as 8th Street, throwing residents in low-value homes into frenetic action. After inundating residential, commercial, and light manufacturing property, the broadened front of water dove south across vacant city land into Middle Boulder Creek.

Shortly thereafter, the overflow from Middle Boulder Creek had swept around the Arapahoe bridges at the canyon mouth to be followed some twenty minutes later by the first great wave caused by the bridges' collapse. The narrow flood plain between 3rd and 9th Streets quickly became a confused and maddened mass of converging waters from north, south, and west. New apartments built on the stream's south bank just east of Eben G. Fine Park near the city's upstream boundary were inundated and severely damaged. Further east and north of the river, waters swashed into the ruins of the old and incompleted Park Allen Hotel.[3] The time was 8:15 p.m., and the tempestuous rains had already ceased. (Major land uses and emergency services affected are shown in Figure V-1.)

In the murk of that flooded night, Boulder struggled to make effective its emergency preparedness plan.

As the Director of Operations was seeking information about the severity of the storm from the National Weather Service office at Stapleton Airport, thirty miles distant, the first flood warning calls from residents upcanyon were being received in the city.[4] In accord with the Emergency Plan for Floods (1970), an alert went out to all departments and agencies responsible for its execution. However, by the time the County Sheriff had received the alert, shortly after 7:15 p.m., Salina had already been ravaged and the flood wave was thundering toward Orodell.

Within the city, the police and fire departments and campus police were instructed by the Director of Operations to commence simultaneous warning and evacuation proceedings for all of Middle Boulder Creek's 1% flood plain. Emergency crews from the city's Street, Water, and Sewage Department were dispersed from the Emergency Operations Headquarters in the City Service Center at 5050 Pearl Street to pre-arranged quadrants of the city to help move evacuees to higher ground in city radio-equipped vehicles.[5] At that time, flood surveillance personnel, quick to the sources of trouble, were radioing in reports of major flooding at Orodell. A citizen alarmed at the sudden surge of waters down Gregory Creek reported his concern to the authorities at 7:40 p.m. Around that time, the American Red Cross, at its basement headquarters in 920 Pearl Street, was beginning to prepare for the shelter and care of evacuees.[6] Contact was being maintained with the Emergency Operations Center through a city-lent radio vehicle.

Boulder at 8 p.m. was a frantic hive of activity, with mobile sirens sounding, bull-horns blaring, and emergency crews racing among the people imploring their immediate retreat. For two city areas of less conspicuous risk, Gregory and Sunshine, disaster had already struck. For them, the warning messages being beamed over Radio KBOL-KBVL and TV-9 and 4 were cruelly redundant.

At 8:00 p.m., the Arapahoe Avenue bridges had burst and flood waters rushed east toward the city center. Within the next hour, the 6th, 9th and 12th Street (Broadway) bridges would in their turn hold briefly and then collapse as those upstream had done. Each failure caused a new wave of water to spread out across the broadening flood plain north

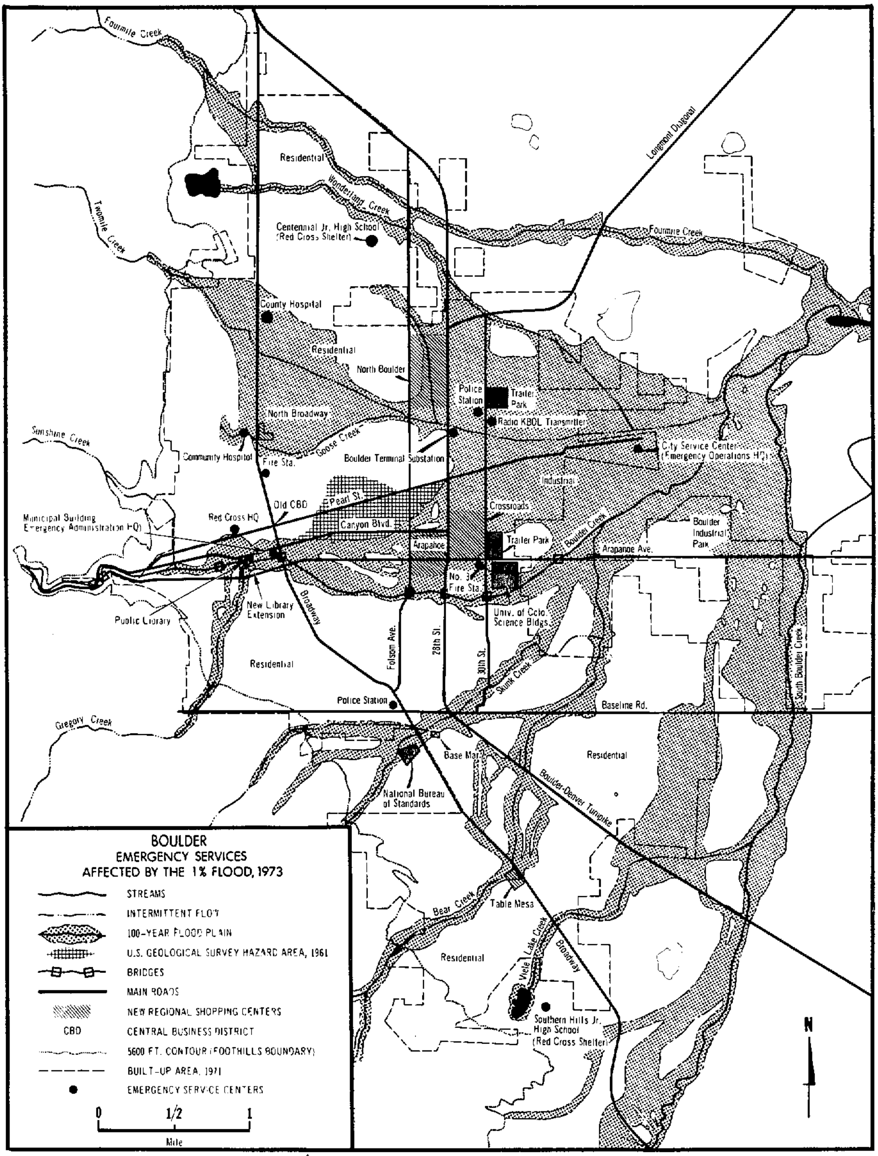

BOULDER
EMERGENCY SERVICES
AFFECTED BY THE 1% FLOOD, 1973
STREAMS
INTERMITTENT FLOW
100-YEAR FLOOD PLAIN
U.S. GEOLOGICAL SURVEY HAZARD AREA, 1961
BRIDGES
MAIN ROADS
NEW REGIONAL SHOPPING CENTERS
CBD
CENTRAL BUSINESS DISTRICT
5600 FT. CONTOUR (FOOTHILLS BOUNDARY)
BUILT-UP AREA, 1971
EMERGENCY SERVICE CENTERS
0
1/2
1
Mile
N
Fourmile Creek
Twomile Creek
Wonderland Creek
Longmont Diagonal
Residential
Centennial Jr. High School (Red Cross Shelter)
County Hospital
North Boulder
Police Station
Trailer Park
Radio KBOL Transmitter
North Broadway
Goose Creek
Sunshine Creek
Community Hospital
Fire Sta.
Boulder Terminal Substation
City Service Center (Emergency Operations HQ)
Industrial
Pearl St.
Old CBD
Crossroads
Municipal Building Emergency Administration HQ)
Red Cross HQ
Canyon Blvd.
Arapahoe
Trailer Park
Boulder Creek
Arapahoe Ave.
Boulder Industrial Park
No. 3 Fire Sta.
New Library Extension
Public Library
Broadway
Univ. of Colo. Science Bldgs.
Folsom Ave.
28th St.
30th St.
Skunk Creek
South Boulder Creek
Police Station
Baseline Rd.
Gregory Creek
Base Mar
National Bureau of Standards
Boulder-Denver Turnpike
Table Mesa
Bear Creek
Viele Lake Creek
Southern Hills Jr. High School (Red Cross Shelter)

FIGURE V-1

beyond Pearl Street. From 6th Street east, Canyon Boulevard and Walnut Street were transformed to raging causeways whose waters tore up curbing and pavement as if it were paper. Between these temporary channels, the offices and workshop of Arnold Motors (in blocks eight and nine) were immersed and dozens of vehicles tumbled like toys in the flow. Further east, the partial collapse of both the Chamber of Commerce and Canyon Inn buildings occurred soon after the destruction of the 9th Street bridge. The latter's rupture caused a great surge of debris to ram into the western wall of the Public Library located thirty yards downstream on the creek's left bank.[7] The impact caved in the western wall. Water gushed inside of the building to tear away much of the structural supports and cause its collapse. The newly erected beams and piles for the over-stream connection to the partially constructed addition to the Public Library were torn down also. Downstream, where Broadway crosses the creek, water and debris had smashed ground level windows in the Municipal Building, causing some structural damage, extensive loss of contents, including records, and forcing closure of the Flood Emergency Administration Headquarters. Similar losses were experienced across the street at the Public Service Company offices and First National Bank. By about 9:15 p.m., floodwaters had left the creek all the way east to the city's limits and beyond.

As the flood spread and became more shallow, its speed was lessened.[8] Nevertheless, its damaging impact upon the contents of buildings of all kinds was phenomenal.

The collapse of the Broadway bridge only served to create further blockage of the natural stream channel--which at that point bends southeast--and to hasten the escape of water towards Canyon Boulevard, down Left Hand Ditch, and various other ancient stream channels. Near the creek and in the temporary channels, velocities were high and waters deep.

Beyond Broadway (12th Street), numerous structural losses had occurred as the flood deepened towards its peak shortly after 10 p.m. Never an area of high-income homes, numerous unsubstantial old buildings were moved from foundations in a wedge of flood plain between Canyon Boulevard and the creek. Many commercial invaders were likewise affected.

Closer to the main channel, buildings of recent construction suffered severe structural damage. At 14th Street, part of a three-story apartment building--Terrace View Manor--collapsed, as did ten houses in a depression near 17th Street. In that vicinity, the complex of University of Colorado apartments (Athens Court and Marine Family Housing) were flooded, as was Boulder High School.[9] Road-works at the corner of 14th and Marine Streets near Terrace View Manor were completely eroded away several hundred feet. On the eastern campus east of 30th Street between Arapahoe Avenue and the creek, expensive equipment in several University buildings was damaged. These included the three Physical Science Research buildings, the Life-Sciences Research and Behavioral Genetics Laboratories, and the Cyclotron building. Upstream, between 30th and 24th Streets, new commercial development was severely hit. Worst affected was that portion at the Arapahoe Shopping Center south of Arapahoe Avenue, where flood depths reached six feet in Neustetters[10] (although units to the north were also affected), and the large Harvest House Motor Hotel complex adjacent to the creek. Four guest houses on the stream's banks were completely demolished. Across the stream, the new Columbine student accommodation was inundated. North of the creek, between 28th and 30th Streets, several dozen middle-income homes and apartments in the Cordry Crescent subdivision were flooded, many moving off their bases. Immediately north, at the eastern end of Canyon Boulevard, the Crossroads Shopping Center was flooded to varying depths, but less severely than the Arapahoe Center immediately west. Numerous cars left stranded in the hasty retreat of Saturday-night shoppers and theater-goers were swept east in a shambles.[11]

At flood peak, between 10 p.m. and 10:30 p.m., central Boulder had become a vicious torrent of water which severed the city in two.

Several fires caused by electrical short circuits and gas leakages raged over the city, adding to the horror of people trapped by the rapid rise of flood waters.[12] Fire-fighting was carried out at two-thirds capacity by units from the north and south, as Fire Station No. 3 at 30th and Arapahoe had been made inoperable by invading flood waters.

Communication between emergency squads was being maintained by radio-telephone, or, when overloaded, and in the absence of such units, by runners. Services had been cut when scouring flood waters disrupted major telephone cables along Middle Boulder Creek.[13]

Similar disruption occurred to other public service systems. The transmission and receipt of electricity was cut at several places. Boulder Hydro Plant, five miles upstream from Boulder, shut down under pressure of extreme discharges.[14] The main transmission line from the Hydro Plant to the Boulder Terminal Substation located at 28th Street and Mapleton Avenue was broken above Orodell, and the receiving station itself was inundated by water from Twomile and Goose Creeks. Transmission to the NCAR Substation from Boulder Hydro was likewise cut, forcing the city to rely upon the redistribution of overtaxed supplies from its remaining substations to the east and south. The lack of power and communication services caused rapid breakdown of coordination between various emergency groups and points of operation. This added to an already highly confused situation, and hindered evacuation and rescue efforts.

Water pressure dropped quickly following the rupture of the main line from the Boulder Filtration Plant across Middle Boulder Creek and other pipes downstream to 17th Street. Raw sewage flowed out of the overtaxed disposal system.[15]

The convergence of a curious public upon the stricken city center created chaotic tie-ups of traffic which further hampered evacuation and rescue efforts.[16]

In spite of prompt action by city and volunteer emergency crews that was initially reasonably coordinated, much of the affected public skeptically refused to heed initial warnings of flood.[17] Some of those who did heed the warnings moved to areas that became equally vulnerable as the seemingly capricious waters sought out new channels of flow blocks from the normal creek. Many caught in the onrushing waters were students and itinerants new to Boulder and, therefore, less familiar with its terrain.[18] Still others remained in homes or business premises in an attempt to stem invading waters or to lift movable contents to higher locations. Although such measures proved successful in some suitable structures and in areas of shallow flow, they failed in others where waters grew swift and deep. For some, the delay meant death.

Anticipating the need for beds, blankets, medical and feeding units, the American Red Cross telephoned an immediate request for supplies from its regional center in Denver at 7:45 p.m. Shelters were opened up in predetermined schools to the city's north and south, and medical and school health volunteers contacted for duty.[19] The arrival of supplies from Denver was delayed several hours because the southern and eastern highways were made impassable by flooding from Skunk and Bear Creeks, and Middle Boulder Creek, respectively.

In the city's north, Twomile Creek left its channel and made its way south along Broadway to join Goose Creek where it was turned east near Balsam Avenue. There it flooded residences, the North Boulder Shopping Center, and Boulder Community Hospital, forcing hasty evacuation of 140 patients to the safety of Longmont, fifteen miles north.[20] With nearly all of the city's medical service located in the north, isolation of the southern sector by flood waters forced its populace to rely upon the strained services of only one medical center, Wardenburg.

Although flooding on the peripheral tributaries was less severe than that across the city's center, it was, nonetheless, serious.

By the dawn of day, the silty waters had receded and were once more confined to the natural channels. Large ponds of water remained caught within the numerous swales that run parallel to the channels. The coming of daylight revealed something of the magnitude of devastation and disruption within the city. Cars, trees, and pieces of houses were piled up all around. The search for bodies continued, but was hampered by the great tangle of debris and deep oozing mud. A threat to health was immediately apparent.

To absorb the shock of this devastating event, Boulder has had to channel much of its physical and human resources into a lengthy cleanup and rehabilitation program. In its struggle to regain social order, the city has been aided by numerous Federal, state, and private agencies quick to the scene of tragedy.

Numerous meetings between affected and assisting agencies have been held to help determine strategy for the city's recovery and to prevent the disaster's recurrence. One month after the disastrous flood a report has been prepared and submitted to the Boulder City Council. It is, in essence, the basis of an application to the United States Department of Housing and Urban Development for a grant of $25 million to help rebuild destroyed areas of the city within the framework of integrated flood plain management.

Basically, the report to Boulder City Council described the flood event and damages caused by it. In essence, it stated that the flood was caused by a convective storm which resulted in 4.5 inches of rain falling near Mounts Arkansas and Sugarloaf in a three-hour period (Figure V-2). The average three-hour rainfall over the affected area of 40 square miles was estimated at 1.5 inches (Figure V-3). The rain storm had drenched about 30% of Middle Boulder Creek's 140 square mile catchment area upstream of Boulder. Runoff resulting from the August 31st storm produced peak discharges on Fourmile and Middle Boulder Creeks comparable to those of 1894 (Figure V-3). Record 1% peaks were discharged from Sunshine and Gregory Creeks, but flooding on Twomile, Bear, and Skunk Creeks compared to the 5% flooding of 1969. Travel rates of the flood

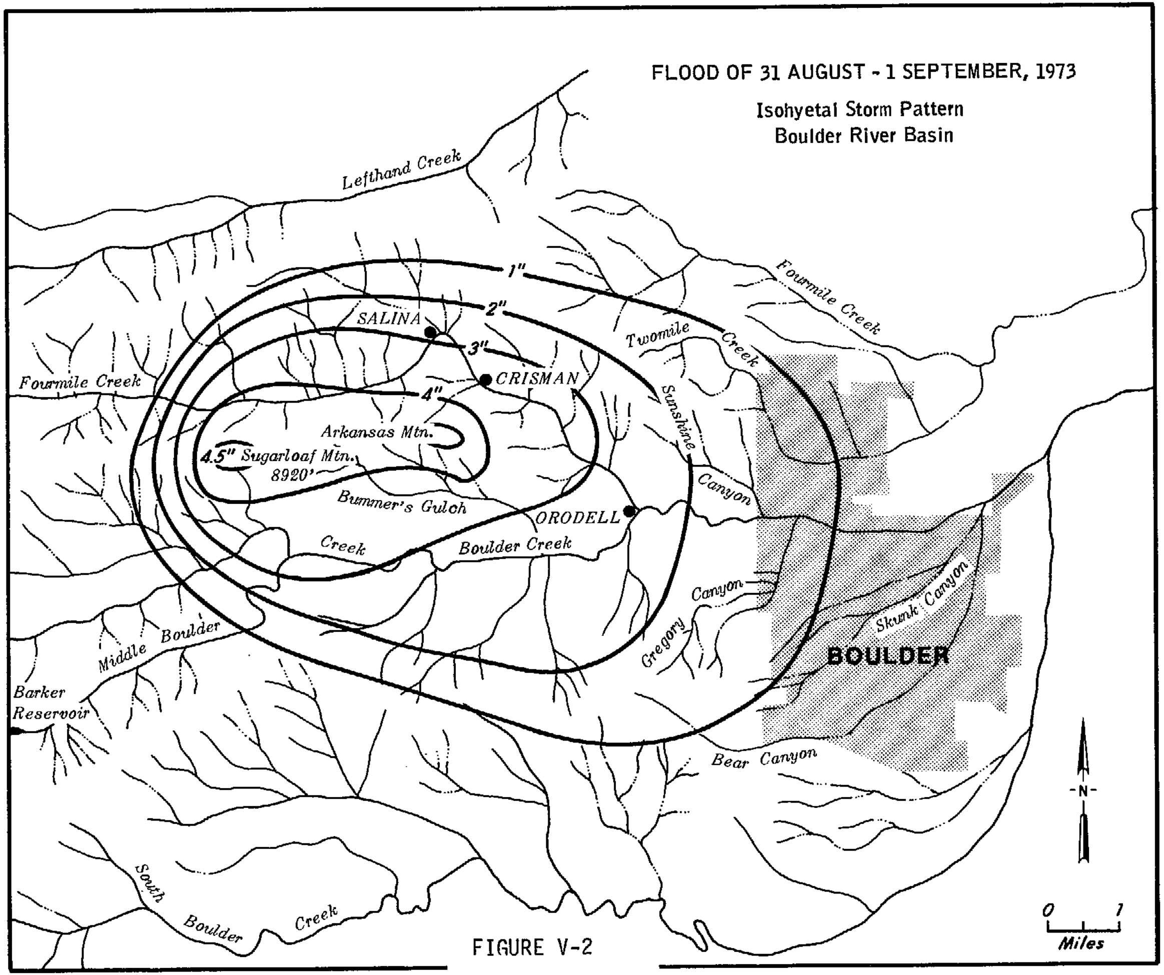

FLOOD OF 31 AUGUST - 1 SEPTEMBER, 1973
Isohyetal Storm Pattern
Boulder River Basin
Lefthand Creek
Fourmile Creek
Twomile Creek
SALINA
CRISMAN
1"
2"
3"
4"
4.5"
Arkansas Mtn.
Sugarloaf Mtn.
8920'
Bummer's Gulch
ORODELL
Boulder Creek
Creek
Sunshine Canyon
Gregory Canyon
Skunk Canyon
BOULDER
Middle Boulder
Barker Reservoir
Bear Canyon
South Boulder Creek
N
0 1
Miles

FIGURE V-2

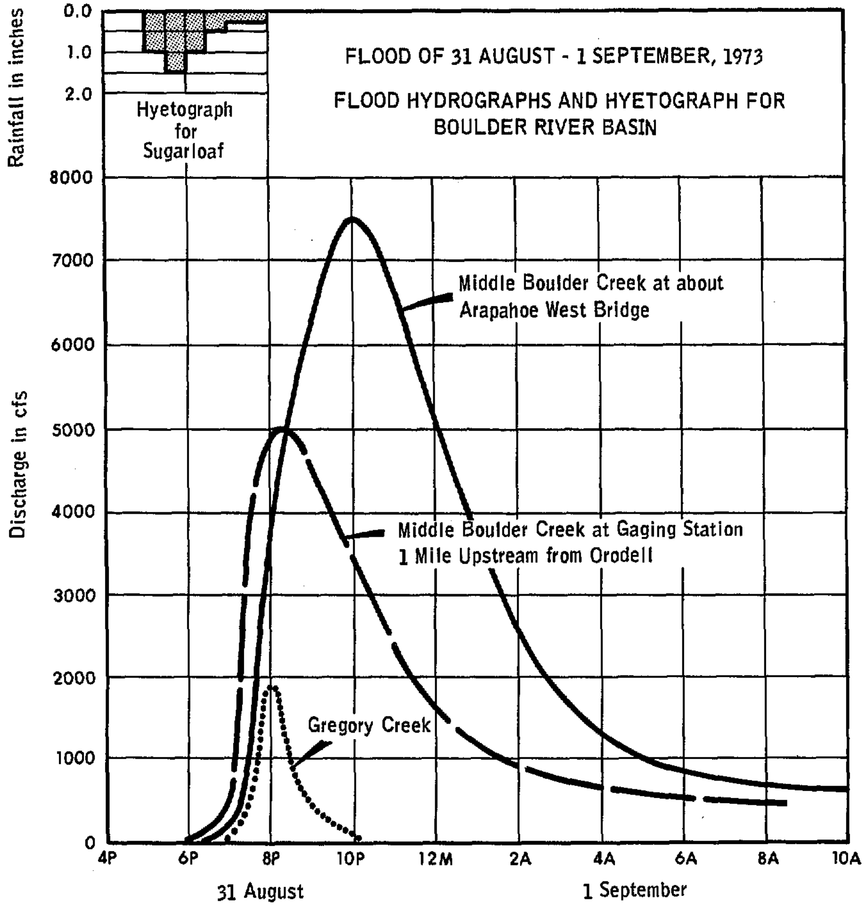

Rainfall in inches
0.0
1.0
2.0
Hyetograph for Sugarloaf
FLOOD OF 31 AUGUST - 1 SEPTEMBER, 1973
FLOOD HYDROGRAPHS AND HYETOGRAPH FOR BOULDER RIVER BASIN
Discharge in cfs
8000
7000
6000
5000
4000
3000
2000
1000
0
Middle Boulder Creek at about Arapahoe West Bridge
Middle Boulder Creek at Gaging Station 1 Mile Upstream from Orodell
Gregory Creek
4P
6P
8P
10P
12M
2A
4A
6A
8A
10A
31 August
1 September

FIGURE V-3

crest on Middle Boulder Creek within Boulder varied from four to eight miles per hour over a flood plain with a gradient of 70 feet per mile. In the mountains, and on Gregory and Sunshine Creeks velocities had been much higher.

Within Boulder, 2,600 acres were flooded. This represented about 18% of the city's total area and about 50% of the total 1% flood plain within the city. Preliminary estimates of total damaged within the city, direct and indirect, exceeded $38 million. Damages to county property, mainly residential and transportational, were about $5 million. Categories of damages and costs from the Federal report to Boulder City Council are summarized in Table V-1. Damages to structures by type within the city on the flood plains of Middle Boulder Creek and the tributary streams are given in Tables V-2 and V-3, respectively.

Reiterating an already painfully known fact, the Report noted that the flood had claimed 95 lives, 50 from within the city. The Report concluded:

> The great irony of this tragedy is that after eighty years of a do-nothing attitude, the city was in the process of developing policies that would have, if properly implemented, brought about integrated flood plain management so that such a disaster would not occur in the future.

## Experiencing the Unexpectable: Decision-Maker Reaction

The cross-sectional scenario, "Experiencing the Unexpectable", dramatizes the impact of the 1% planning flood upon existing conditions of development on Boulder's flood plains. In so doing, it provides a benchmark against which the outcomes of alternative pasts and futures in Chapters VI and VII may be generally assessed by both analysts and community decision-makers.

It seems reasonable to assume that the usefulness of scenario progressions (past and future) will very much depend upon how the decision-maker views the current cross-sectional scenario, "Experiencing the Unexpectable: A Scenario of the One Percent Flood in Boulder in 1973".

To get at this and related questions, the thirty-six key Boulder decision-makers listed in Table V-4 were asked to read the dramatic scenario, and were then later questioned about its usefulness.

The key questions asked and the distribution of answers given are shown in Figure V-4. It is encouraging to note that for three of the

TABLE V-1

ESTIMATED COST OF THE HYPOTHETICAL FLOOD OF 31 AUGUST-SEPTEMBER 1, 1973, IN BOULDER, COLORADO*

| Types | Units | Costs ($000's) | Totals ($000's) |
|---|---|---|---|
| Structures Flooded | | | 28,000 |
| Residential | 620 | 2,000 | |
| Commercial-Industrial | 300 | 23,000 | |
| Public (city, schools, hospitals) | 55 | 3,000 | |
| Public service systems | | | 3,620 |
| Transportation | | | |
| Bridges and culverts | 15 | 400 | |
| Roads | 9 mi. | 600 | |
| Vehicles | 1,200 | 2,000 | |
| Mountain Bell Telephone | | 150 | |
| Public Service Company | | | |
| Gas | | 100 | |
| Electricity | | 100 | |
| City Water System | | 70 | |
| City Sewer System | | 200 | |
| Associated Economic Costs | | | 790 |
| National Guard | | 80 | |
| Red Cross | | 110 | |
| Salvation Army | | 75 | |
| Corps of Engineers--contracts, debris removal | | 250 | |
| City debris removal | | 100 | |
| USDA food stamp program | | 160 | |
| Insect spraying | | 5 | |
| Typhoid and tetanus shots | | 10 | |
| Some Secondary Economic Costs | | | 6,000 |
| Freight delayed and traffic re-routing | | 1,000 | |
| Estimated interest costs for reconstruction loans--Small Business Administration | | 1,500 | |
| Loss of Income | | | |
| Personal | | 500 | |
| Business | | 3,000 | |
| Total City Flood Cost | | | 38,410 |
| Total Flood Cost to Boulder County mainly residential and transport | | 5,000 | 5,000 |
| Lives Lost | | | |
| City | 50 | | |
| County | 45 | | |
| Total Boulder City and County | 95 | | 43,410 |

*Detailed analyses were not carried out to determine Associated and Secondary Costs. Rather figures were arrived at by comparing the likely experience in Boulder with the experience of other flood disaster cities. For example, the 1972 flood in Rapid City, S. Dakota, directly affected about 10,000 flood plain occupants and similar land uses to those described for Boulder, where 3,000 people were assumed flooded. Secondary and associated costs in Rapid City totalled over $40 million (75% of it tourism), structural damages over 35 million, and utilities about $10 million.

TABLE V-2

ESTIMATED PROPERTY DAMAGE FROM A 1% FLOOD
ON MIDDLE BOULDER CREEK, BOULDER, 1972

| | Type of Structure | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Commercial-Industrial | | Residential[1] | | Public | | Total | |
| | Number | Damages $ (000's) | Number | Damages $ (000's) | Number | Damages $ (000's) | Number | Damages $ (000's) |
| North Bank | | | | | | | | |
| 3rd to 13th Streets | 37 | 2,988 | 58 | 229 | 3 | 1,100 | 98 | 4,317 |
| 13th to 24th Streets | 49 | 2,572 | 262 | 522 | 34 | 480 | 345 | 3,574 |
| 24th to 28th Streets | 35 | 4,314 | 1 | 1 | - | - | 36 | 4,315 |
| 28th to 30th Streets | 44 | 3,600 | 39 | 200 | 2 | 5 | 85 | 3,805 |
| 30th to east city limits | 51 | 2,050 | - | - | - | - | 51 | 2,050 |
| Sub-total | 216 | 15,524 | 360 | 952 | 39 | 1,585 | 615 | 18,061 |
| South Bank | | | | | | | | |
| 3rd to 13th Streets | 14 | 2,034 | 13 | 146 | 2 | 30 | 29 | 2,210 |
| 13th to 24th Streets | - | - | 4 | 32 | 4 | 66 | 8 | 98 |
| 24th to 28th Streets | 4 | 40 | - | - | 1 | 220 | 5 | 260 |
| 28th to 30th Streets | - | - | - | - | - | - | - | - |
| 30th to east city limits | 7 | 470 | 21 | 42 | 1 | 6 | 29 | 518 |
| Sub-total | 25 | 2,544 | 38 | 220 | 8 | 322 | 71 | 3,086 |
| | 241 | 18,068 | 398 | 1,172 | 47 | 1,907 | 686 | 21,147 |

[1]Residential units include 264 single-family dwellings and 133 ground level apartments in 38 multi-dwelling units. (Source: Corps of Engineers' damage data by block per land use type; field surveys.)

TABLE V-3

AN ESTIMATE OF PROPERTY AFFECTED BY 1% FLOODING[1]
ON INTERMITTENT TRIBUTARY STREAMS, 1973

| Location | Type of Structure[2] | | | | | | |
|---|---|---|---|---|---|---|---|
| | Public | Commercial | Industrial | Residential | | | Total Units |
| | | | | Single | Multi | Mobile | |
| Northern streams | 12 | 61 | 23 | 855 | 74 | 642 | 1,667 |
| Southern streams | 3 | 16 | 5 | 989 | 79 | 2 | 1,094 |
| Total | 15 | 77 | 28 | 1,844 | 153 | 644 | 2,761 |

[1]Information from aerial photograph interpretation using air photo maps flown May, 1973 on which was superimposed the City of Boulder 100-year flood plain map, 1971. The 1% flood has been used for the tributary streams because smaller flood spreads have not yet been defined for them.

[2]Only structural buildings are summarized so that, for example, while there are 153 multi-family residential buildings, this does not include the number of ground level units within each building. The same applies to commercial structures.

characteristics measured, over 75% of the respondents accorded a favorable scale-value of four or five on a five point scale. The measures were of the scenario's effectiveness in *communicating information* about the flood problem; the extent to which it would be useful in *making decisions* about the flood problem; and whether or not the scenario was found to be *more meaningful* than other forms of information they may have received about the flood problem. These results are even more encouraging in view of the wide range of information available to the decision-makers, as shown in Table III-1, and public meetings with the Corps of Engineers officers in 1972 and 1973.

TABLE V-4

DECISION-MAKERS QUESTIONED ON THE SCENARIO, "EXPERIENCING THE UNEXPECTABLE..."

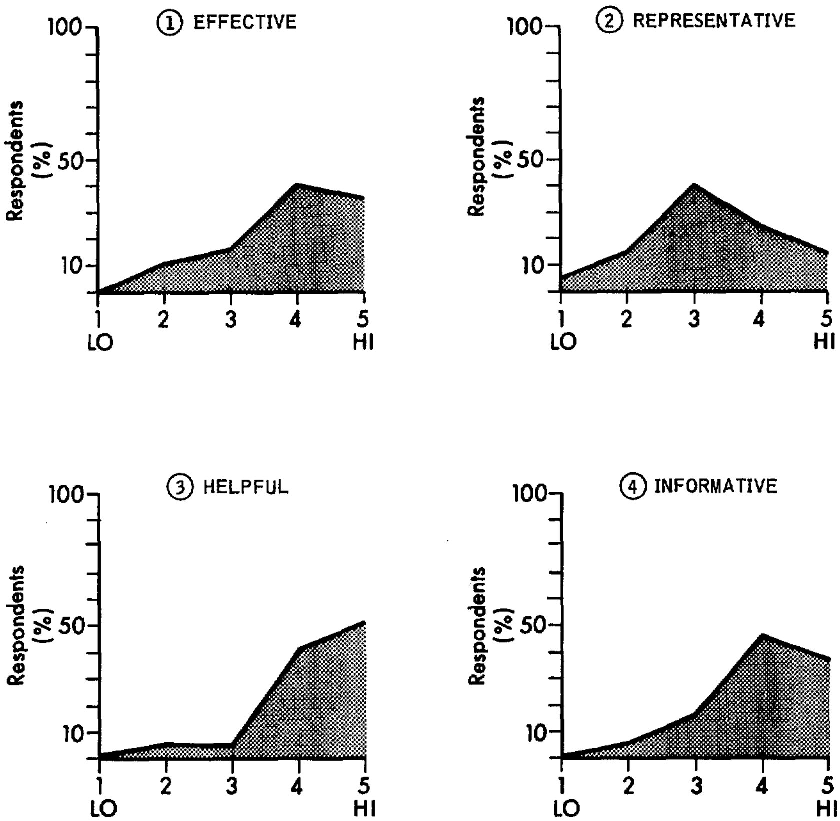
| DECISION-MAKERS | | |
|---|---|---|
| Decision-Making Group | Number Sampled | Number of Respondents |
| Boulder County Commissioner | 3 | 2 |
| Boulder City Councillors | | |
| (i) Current | 9 | 6 |
| (ii) Immediate Past | 3 | 2 |
| Key City Administrators | 3 | 2 |
| Boulder Planning Board | 7 | 2 |
| Heads of Emergency Services | 4 | 2 |
| Chairpersons of Citizen Groups | 2 | 2 |
| News Media | 5 | 2 |
| | 36 | 20 |

(Field Survey, 1974)

As to the extent to which the dramatic scenario was likely to *represent reality*, only 40% of the decision-makers fell on the four or five end of the scale (Figure V-4). About 80% of respondents clustered around the center of the scale. The principal reason given for this by about half of the respondents was that they thought the scenario, in aggregate, somewhat exaggerated the problem. Yet, fortunately, this criticism does not appear to have detracted from the dramatic scenario's potential usefulness as a guide to making decisions that will help reduce deleterious flood impacts.

Having created an image of what could happen if the 100-year flood were to occur in Boulder under current conditions of flood plain development, the work now proceeds with the creation of scenarios that explore the consequences of adopting various adjustments in outcomes of alternative pasts.

UTILITY OF DRAMATIC SCENARIO
"EXPERIENCING THE UNEXPECTABLE IN BOULDER IN 1973"




QUESTION:

① How effective do you think the flood scenarios are in communicating to you information about the flood problem in Boulder?

② How well do you think the dramatic scenario of the 100-year flood in Boulder by itself represents reality?

③ Do you think that information dramatized in scenario fashion is of help in making decisions that would reduce the flood hazard in Boulder?

④ Have you found the scenarios more meaningful as a means of providing information about the flood hazard than other information you have received (and/or heard) about the flood hazard?

FIGURE V-4

## NOTES

[1]The meteorological conditions for a 100-year flood were reviewed by Waltraud Brinkmann, climatologist, University of Colorado and Ed Zipser, National Center for Atmospheric Research, Boulder.

The hydrological conditions of the 1% flood and its damaging and disruptive consequences were discussed in a meeting with a panel of experts consisting of: Kenneth Wright, Councilman, City of Boulder and past Chairman, Surface and Water Hydrology Committee, American Society of Civil Engineers; William Taggart and Robert McGregor, hydrologists, Wright-McLaughlin Engineering Consultants; Ted Dieffenderfer, Director of Operations, City of Boulder; John Stewart, hydrologist, City of Boulder; Ernest Flack, hydrologist, University of Colorado, and Ruth Wright, member of Corps of Engineers Citizens' Committee on Environmental Planning, Boulder Branch.

Information on specific elements of social disruption were provided in interviews with Colonel Burford, Director of Civil Defense; Rick Rolland, American Red Cross; Ken Fuller, Henry Hermose, Electricity Division and E. Todd, Gas Division, Public Service Company of Colorado; Dick Weathers, Acting Manager, Boulder Hydro Plant (Public Service Companies); Bob Bruger, Mountain Bell Telephone Company; Radio KBOL-KBVL engineers; Charles P. Phillips, Operations Manager, Boulder Community Hospital; Andy Hollar and Peter Peterson, Water and Sewer Utility, City of Boulder; Don Douglas, Transportation Utility, City of Boulder.

[2]As with most of the city's bridges, the Arapahoe west bridges are poorly anchored. Some panelists believed that they were almost washed out by the 4-5% flood of 1969.

[3]These ruins are currently being resurrected into the Boulder City and County Justice Center.

[4]In spite of a new weather tracking radar station at Limon, Ted Dieffenderfer, Director of Operations, Boulder, reports that he, not the NWS, has always been the initiator for information about flood threats to Boulder. Examples cited included the floods of 1965 and 1969, and the minor 1973 spring flood. Yet each of these floods was caused by regional low pressure systems that had produced rains over several days. It is assumed, therefore, that the opportunity for the D.O. to initiate action would be far less for a short-duration convective storm.

[5]The plan provides for the evacuation of 1500 people in approximately 50 city-owned vehicles.

[6]The Red Cross Headquarters is on the edge of the 1% flood spread as shown in the Corps of Engineers, Special Flood Hazards Information Report, May, 1972. It is possible that higher levels and changed directions of flow caused by debris blockages could flood out the basement headquarters. Similarly, shallow flooding could be expected to affect the city's Emergency Operations Headquarters at 5050 Pearl Street, if overflows from Twomile Creek are very large (Figure V-1).

[7]The western wall of the Public Library is constructed of brick veneered hollow concrete block which could collapse under the pressure of water alone at about a five-foot depth. In 1894, the force of water was

so great that a locomotive was pushed off its tracks near 12th Street.

[8]Building in relation to the 100-year flood spread is clearly shown in Corps of Engineers, Special Flood Hazard Information Report, May, 1972. Stage-damage estimates for flood plain buildings were carried out by the Corps of Engineers in 1972 and made available for use by the author upon his request in August, 1973.

[9]Evaluations of University of Colorado property exposed to flood risk are available in two recent unpublished graduate student reports. Flood Hazard on University of Colorado Property (Boulder: University of Colorado, Department of Geography, 1972); Flood Hazard Assessment of University of Colorado Property Along Boulder Creek (Boulder: University of Colorado, Departments of Civil Engineering and Economics, 1972 ).

[10]Field Survey by the author.

[11]At about 7:30 p.m. on Saturday, August 31st, roughly 2,500 vehicles were parked in streets and ground level parking lots in the 100-year flood plain. In the Arapahoe and Crossroads Shopping Centers there were 725 vehicles. Arnold Motors held about 240 vehicles.

[12]It is expected that small feeder lines, especially those attached to destructed bridges, would rupture. Gas explosions would occur some distance from the rupture since natural gas requires a mix with between 84% and 94% of oxygen to explode.

There is no provision in the existing Emergency Plan for Floods to contact private companies such as the Public Service Company or Mountain Bell Telephone, of impending flood damages. Thus, gas and electricity would be disrupted before the company could take preventive or protective action. While the Public Service Company could be expected to quickly tie off supplies to the destroyed areas and to divert resources to areas affected by, but outside of, the flooded area, there would be periods of disruption over large areas of the city, especially in electrical supply.

[13]The cable vault and generators are in the basement. Two doors to the basement are considered water-tight. Deep water in the basement would cause $10 million in damages. Replacement costs for cable on Middle Boulder Creek would amount to $135,000. Cables were replaced at three points in 1969 flooding.

[14]In 1965, sandbags were necessary to prevent flood waters entering Boulder Hydro Plant. If the two 12,000 kw generators were shut down before being flooded, it would require up to 6 months to make them operational at a considerable cost. If still in operation when flooded, the generators would probably have to be replaced at a cost of about $500,000 plus labor cost.

[15]In the minor spring flood of 1973, raw sewage flowed in flood waters from Bear Creek, as man-hole covers floated off. Really serious flooding would make the waste treatment plants inoperable.

[16]Convergence behavior in disaster is a common and well documented phenomena. See Allen H. Barton, Communities in Disaster. Anchor Books, 1970.

[17]There have been few studies of individual response to warnings. The most recent and comprehensive analysis was for Rapid City and shows that only 20% of the sampled population acted upon receipt of first warning message; 25% on the second; 26% on the third; and 24% on the fourth. See Dennis S. Mileti, "Drowning: A Communicable Disease." Paper presented before the Annual Meetings of the American Sociological Association, New York. Boulder: University of Colorado Institute of Behavioral Science, 1973. Table 1, 22.

[18]Boulder has a high itinerant population during summer months. Central Park on the corner of Broadway and Canyon Boulevard adjacent to the creek is favored as a meeting area. On Saturday, the 31st of August, a two-hour free rock bank concert between 7 and 9 p.m. attracted a crowd of several score young people to Central Park. Such concerts are commonly held. The Geography Graduate Student Report assessed that 1652 University of Colorado students, staff and dependents would be exposed to risk from the 100-year flood, Nov., 1972.

[19]The two shelters would most probably be Centennial Junior High School and Southern Hills Junior High School to the north and south, respectively. Although Burbank Junior High School had been scheduled as an emergency shelter, it would not be used as it is now realized that it is on the 1% flood plain of Viele Lake Creek.

[20]A new extension to the Boulder Community Hospital was inundated by moderate flooding from Twomile Creek in 1954. All basic service facilities would be rendered inoperable in a serious flood since they are located in the basement floor which would receive 8-9 feet of water. It is possible that water would also enter the first floor. Damages would amount to at least $1 million and operations would be curtailed several months. The hospital is not linked to the Emergency Flood Plan. The chances of boilers exploding are high.

# CHAPTER VI

## SCENARIOS OF ALTERNATIVE PASTS

The cross-sectional scenario of the previous chapter indicates how inefficiently the actual flood hazard system in Boulder has evolved. To divert this trend and avert possible disaster in future, the city will need to make positive decisions and take appropriate action. In looking for clues as to how Boulder might proceed, the historical evolution of Boulder's flood hazard system is re-examined under a series of different initiating decisions.

In retrospect, the historical analysis of flood plain management in Boulder suggests many points in time at which the adoption of adjustments could have resulted in far different levels of flood losses, casualties, and disruption of societal systems than those described in the cross-sectional scenario of the August, 1973 flood. In this section, then, the historical consequences of adopting various flood-loss reducing measures, when culturally feasible, are explored.

The national curves of aggregate adoptibility depicted in Figure III-3 have been used to help delimit historical starting points for adopting major flood adjustments in Boulder. The scenarios in this chapter are, however, selectively illustrative rather than comprehensively definitive. Thus, instead of writing scenario progressions for each adjustment in turn from point of adoption to the present, or various combinations thereof, only two scenario types are employed. The first scenario explores the potential flood-loss reduction capacity of a *single* alternative: engineering protection works. The second scenario employs *multiple* adjustments, adopted sequentially, but which by 1973 combine to form an integrated flood plain management strategy. Basic assumptions used in estimating the flood-loss reducing capacities of alternative adjustments derive from Chapter III and the outcomes are illustrated graphically in Figure VI-2.

### Scenario One: Engineering Protection Works

For some time, adoption of the Crops of Engineers' 1952 plan for flood control works along Middle Boulder Creek was stalled by the Boulder Government because it could not see that flood threat was sufficient to warrant the project's cost. A subsequent change in attitude towards the Corps' plan was attributable to two main factors. First, frequent flooding culminating in the spring flood of 1954 caused serious damages on northern tributaries and raised fears that much worse could stem from extreme discharges along the Middle Boulder. Second, suggestions that a region-wide Flood Control District be set up were becoming increasingly serious and were seen to pose a threat to the autonomy of some aspects of city government. These factors, together with some changes in city government personnel, led to the decision to adopt the Corps of Engineers' flood control project.

West of 13th Street a boulevard-levee was set back from the channel, replacing the railway line west to 3rd Street. East of 13th Street, where the stream makes a turn to southeast, the levee-boulevard was constructed close to the channel as far as 24th Street where it terminated. With the floodway created by the levee north of the stream, and channel widening and straightening between 9th and 17th Streets, the increased flow capacity of Middle Boulder Creek was such that levees to the south were not needed (Figure VI-1). Sunshine Creek was excavated and its banks revetted.

Much of the new floodway land west of 13th Street was city-owned open-space acquired from the railway company decades earlier. But old commercial and residential buildings north of the rail track along Water Street had to be removed. Similarly, east of 13th Street a large number of vintage homes and commercial structures were removed. Seven bridges were modified or made redundant.

Throughout the 1950's and early 1960's, Boulder expanded rapidly, especially east of 24th Street where agricultural lands gave way to the construction of supermarkets, motels, retail businesses, manufacturing complexes, and houses.

Floods on tributary streams continued to occur, and in 1959 the city agreed to adopt the Corps' plan to channelize and dam Skunk Creek as a way of protecting property of the National Bureau of Standards, and the Highland Park-Martin Acres subdivisions that had symbiotically developed nearby.

In June, 1965, Middle Boulder Creek swelled with a 5% flood that was easily contained within the designed floodway. East of the protection

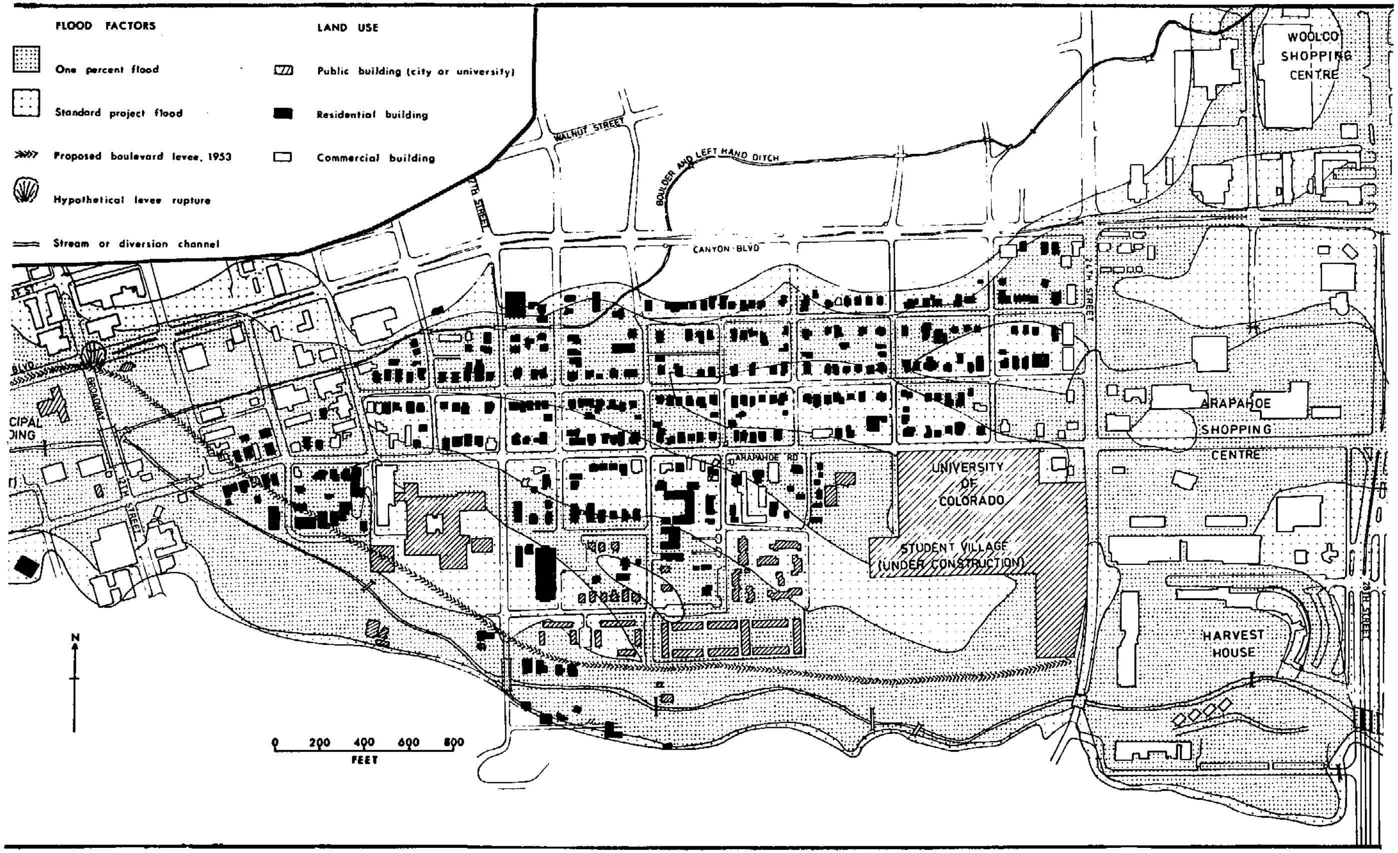



FIGURE VI-1 BOULDER LAND USES AFFECTED BY HYPOTHETICAL LEVEE RUPTURE (Corps of Engineers, 1972;1973) works, however, newly encroached flood plains were severely affected. Damages to property were magnified by the constricting effects of the control works upstream which caused higher levels of flow downstream from them.

With damages approaching $1 million, pressure mounted for extension of the levee system eastward since its success had been demonstrated upstream. Suggestions for flood plain regulations were ill-received, and plans for an emergency warning and evacuation system waned as levee construction once more got underway.

Although the levee extensions were completed by 1969, flooding on southern tributaries, especially Bear Creek, in May of that year caused damages exceeding $1.5 million. Once again, public pressure mounted for structural protection.

Boulder faced the threat of flood on the afternoon of 31 August 1973 with confidence, safe in the knowledge that her twice tested levees now extended the full length of the built-up river bank.

As flood discharges flowed towards peak, high levels of loss were registered in unprotected up-canyon areas and on small unprotected streams within the city including Gregory, Goose and Two-mile. The all but defunct flood warning and emergency evacuation system was of little value in saving life and property in these areas, and was found completely wanting for the unexpected events that followed.

Where the Middle Boulder bent southeast at Broadway, the levees had constricted the floodway to the extent that fast-flowing debris-laden waters were funnelled into the levee's side. The erosion caused by this process was exacerbated by waters that began overtopping the levee as discharge approached peak. Around 8:00 p.m., the levee burst and flood waters rushed into the city's heart (Figure VI-1).

Fortunately, the flood control measures on Sunshine Creek proved adequate. This, together with the fact that the relatively steep slope of the Middle Boulder flood plain allowed water escaping through the levee-rupture at Broadway to flow east, left the area upstream of Broadway on the north bank relatively flood-free (Figure VI-1). In spite of this, damages on Middle Boulder Creek within the city were enormous, exceeding $14 million (Table VI-1). Throughout the city and county, losses approached $30 million and 60 lives were lost. In addition, the ponding effects of waters trapped behind the levees caused not only increased flood levels, but velocities of flow to slow thereby increasing the amount of silt to be dropped and with it the burden of clean-up.

TABLE VI-1

ESTIMATES OF DAMAGES RESULTING FROM
RUPTURE OF A 1950's BOULEVARD LEVEE
BY THE 1% FLOOD IN 1973[1]

| Location | Number and Value of Structures on 1% Flood Plain | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Undamaged structures | | Damaged structures | | | | | |
| | 3rd to 13th Streets | | 13th to 24th Streets | | 24th Street to city limit east | | Total Damages | |
| | No. | $000's | No. | $000's | No. | $000's | No. | $000's |
| North Bank | 96 | 2,917[2] | 316 | 3,374[2] | 172 | 10,169 | 488 | 13,543 |
| South Bank | 29 | 1,918 | 8 | 98 | 34 | 778 | 42 | 876 |
| Total | 125 | 4,835 | 324 | 3,472 | 206 | 10,947 | 530 | 14,419 |

[1]These estimates assume a spread and depth of flooding similar to the unobstructed flood-flow. It also assumes that development of the Middle Boulder Creek flood plain would be similar to that described in the historical review with the notable exception that structures in the floodway would not be located there (Figure VI-1). Dollar values of damage are derived from data supplied by the U.S. Army Corps of Engineers, 1973; the number of structures from field surveys.

[2]Excludes structures actually built on the floodway zone proposed in the 1950 Corps of Engineers protection scheme: 31 structures with a 1% flood-loss potential of $1.6 million, of which $1.4 million is city owned.

## Scenario Two: Integrated Flood Plain Management

Aware of the need to plan its new surge in post-war growth and development, Boulder created a Department of Planning in the city administration. In 1951 the old Planning and Parks Commission set up in 1928 was changed to a Planning Board whose functions included: preparation and recommendation of a general plan to City Council; preparation of a zoning plan and subdivision regulations; control over platting and subdivisions; and encouragement of proper planning by all departments of the city. A separate Board of Zoning adjustment was created to take over the appeals cases of the former Planning and Parks Commission (Goodwin, 1966).

Meanwhile, from the time of the Corps of Engineers' field surveys in the early 1940's until the rejection of its proposed flood control project for Middle Boulder Creek around 1954, seven floods had occurred on tributary streams. Much of the flooding was, however, outside of the built-up city, especially to the north, although minor flooding had occurred on Middle Boulder Creek in 1942. On August 3, 1951, Fourmile Creek north of the city destroyed rail track near Valmont (6.5 miles northeast of the city center) and burst Buckhorn Dam. Four weeks later a convective storm caused Goose Creek to flood north Broadway within the city. In 1954, Goose Creek (swelled with additional waters from Twomile Creek) flooded the new extension to Boulder Community Hospital, while at the same time Sunshine Creek flooded houses and businesses along west Pearl and Water Streets.

By the mid-1950's it became obvious to planners in the new Department of Planning that recent subdivisions and commercial developments--such as the Highland Park-Martin Acres housing on Skunk Creek--were encroaching upon dry gulches known to carry potentially devastating floods periodically and, that many other areas within the city, both developed and developable, were exposed to serious risk. In the next five years, regulations were developed that caused the city's zoning ordinances, subdivision regulations, and building codes to reflect the hazards of flooding. After lengthy debate, and spurred on by the findings of a social survey that predicted catastrophic future losses, the new flood plain regulations were adopted in 1960 following completion of hazard evaluations of Middle Boulder Creek and its tributaries by the U. S. Geological Survey.

In its detail, this socio-structural plan for flood plain management first called for the tracing of encroachment lines to delimit floodways within which buildings and other flow impeding structures would not be permitted. Beyond the floodway limits, existing land use zoning ordinances, subdivision regulations, and building codes were extended to control the type, density, siting, and nature of structures within the 1% planning flood plain.

Regulations were also developed that would cause managers of social service systems, such as water and telephone, both public and private, to develop and renovate their systems with regard to the extreme flood event. These systems were to be integrated into a new emergency preparedness plan.

The community preparedness plan was developed to help reduce the chances of human casualties should severe flooding occur before substantial change had been generated by the new flood plain regulations. The need to establish an early warning system and an emergency evacuation plan became more apparent after serious flooding in 1965. These floods also hastened the search for means to integrate the city's flood program with that under development for the county which had responsibility for managing the upstream catchments and channels.

Because large dams, levees, and hard channelization were considered aesthetically and environmentally unpleasant, especially along the Middle Boulder, engineering flood control works were restricted to small levee-type structures or swales incorporated into the street and park system and located so as to divert overflows back towards the channel.

Long-term objectives for reducing flood-losses up to the 1% flood were established and "acceptable" levels of flood-losses defined. Reducing current (1960) flood-loss potentials by 80% over 20 years was adopted as a practical objective. In effect, this objective indicated the speed with which various elements of land use management were to be implemented, including the relocation from, acquisition and razing, and tie-down and flood-proofing of buildings and other structures on the 1% flood plain.

The long-term prognosis by the Flood Plain Management Division of the Town Planning Department for the main elements of the city's new integrated flood plain management program, were carefully outlined and summarized in graphical form (Figure VI-2). There, the flood-loss reducing capacity of each component was compared with the historical record and its projected future based on an essentially do-nothing policy. Combined, it was seen that the integrated components of the flood plain management program could reduce potential losses from $16 million in 1960 to $3 million in 1980. Stated another way, it was shown that continuation of the historical trend in flood plain encorachment would create a 1% flood-loss potential of around $36 million by 1970 whereas integrated flood plain management could reduce such losses by two-thirds to about $12 million. Those who wished to impose flood control works upon the natural stream system were shown how such schemes would only serve to encourage, if not accelerate the flood-loss potential from an initial "protected" value of around $4 million to as much as $35 million by 1980 or some $20

BOULDER, COLORADO: POTENTIAL FLOOD-LOSS REDUCTION CURVES FOR ALTERNATIVE ADJUSTMENTS

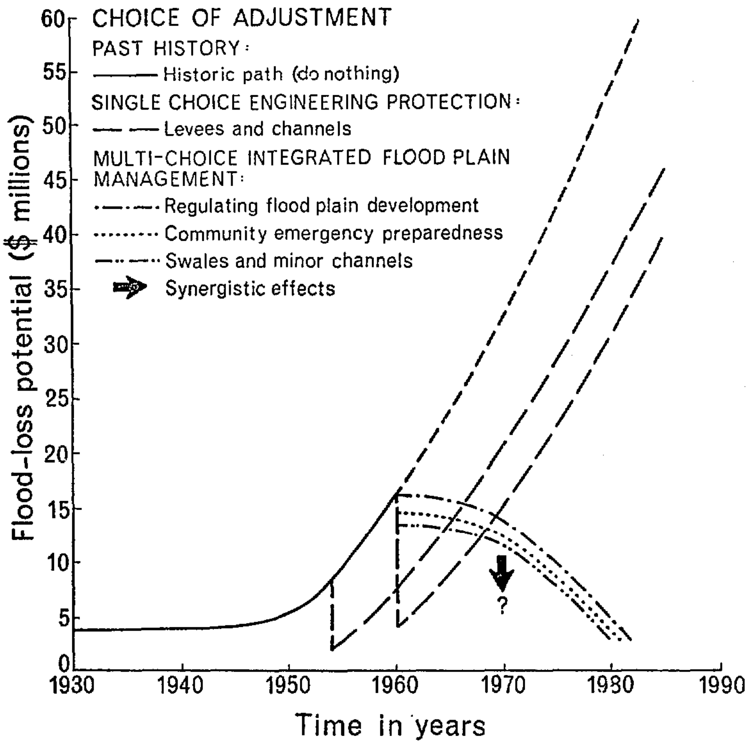



FIGURE VI-2

million less than under a do nothing policy. In addition, it was noted that interaction between each component in the integrated flood plain management program could have beneficial effects to the extent that the overall flood-loss reducing program could amount to consideraby more than the sum of the component parts. The dimensions of these expected synergistic effects were, however, unknown (Figure VI-2).

To ensure implementation of measures for regulating flood plain development, various sanctions were created. These included the integration of land use management for flooding purposes with related city programs, such as open space and urban renewal; the generation of low cost loans and subsidies to help property owners relocate outside the 1% flood plain using funds from relevant Federal and state agencies and a small sales tax on all property owners within the city; and the foundation of an independent Review Board to assess all land use variances to reduce vested interest pressures on city administrators responsible for implementing flood plain adjustments. To increase citizen awareness of potential flood-losses, information about flood-risk and means for reducing it (by way of redirected investments, permanent flood-proofing of buildings, and emergency actions) was provided through the mass-media, postal brochures, and flood plain identity markers. Personnel responsible for urban development in the private sector, such as builders, developers, and bankers, were made prime targets in the city's education towards a new flood plain management philosophy.

In accord with this flood plain management program, no new building had located within Boulder's floodways between 1960 and 1973, and only under special conditions was it permitted on the flood plain outside the floodway limits, where it was flood-proofed. Buildings located within floodways prior to 1960 were slowly phased out by either relocation or acquisition by the city at the first change of ownership or through voluntary moves by individuals receiving governmental subsidies for doing so. Those that remained were flood-proofed wherever possible.

The most vulnerable nodes in the public utility systems had been identified and flood-damage prevention measures effected. Particular attention was paid to several low-slung, unstable bridges upstream from 17th Street to which had been attached service lines for telephone, gas, electricity, and water supply.

Public service systems were carefully integrated into the city's well-developed community preparedness plan which was based on a flood-forecasting and warning dissemination system, and a program of public information and education on what to do should severe flooding ever occur.

The coming of the floods on the evening of August 31, 1973 were met by concerned, but efficient, responses from well prepared officials and an informed public. Alerted to the flood's progress by its newly installed flood-forecasting system, the city swung into operation the emergency warning and evacuation plan at 5:45 p.m. As impending danger became more apparent, general "flood alerts" gave way to specific "flood warnings" at 6:15 p.m. At 6:45 p.m. the public was informed of the decision to evacuate the flood plains through blasts on strategically placed air raid sirens. Evacuation orders--who should evacuate to where and how--were clearly and concisely broadcast over radio and T.V. where, for the latter, visual aids, such as maps and other models, were used to help enhance the sense of seriousness, urgency, and specificity of the situation. Flood simulations and earlier routine practices under the city's flood information and education program ensured smooth operation of evacuation procedures. By the time flood waters breached the banks of Middle Boulder Creek near 8 p.m., few people remained within the designated danger zones.

At the dawn of day, people looked out incredulously upon the mud-lined swath that the gouging waters had cut through the city's heart. Numerous low-lying buildings which had not yet been flood-proofed were inundated and those that remained on the floodways, completely destroyed. One bridge, not yet raised and strengthened, had collapsed and added to the tangle of trees and other debris uprooted from the parks that had been established in some of the floodways. Fortunately, the city's relocation and removal program had advanced to the stage where no residences were affected within the floodways and only a few dozen were inundated outside of them.

First estimates of the flood's cost within the city were placed at $8 to $10 million. Four persons were listed as missing.

## Synergistic Aspects of Flood Plain Management: Some Concluding Remarks

Research from a long period of experience with flood protection works indicates that between 1903 and 1958, some 30% of catastrophic floods in U.S.A. were the result of engineering failures through either design exceedence, rupture, or both (Holmes, 1961). Thus, the catastrophic image drawn in Scenario One has a sound empirical base. In addition, research has shown that the disruptive effects of a burst levee or dam are exacerbated by the synergistic effects engineering works have in that they encourage continued, and in many cases accelerated, encroachment of the "protected" flood plain and even adjacent unprotected areas. This effect is amply illustrated in Scenario One to the extent that it has been unnecessary to postulate accelerated encroachment, such has been the natural historical rate of development onto Boulder's flood plains.

It is not difficult to envisage scenarios that explore the effects of technology on community systems for natural hazards other than floods. From a base of historical data, the effects of weather modification technology could be traced in scenarios of alternative pasts for, say, hurricanes in Florida or droughts on the High Plains, while urban areas of California might be used as sites for examining the effects of the technology of earthquake prediction or of earthquake-proofed buildings.

It is the potential for catastrophe under engineering flood protection works that has led to the adoption of integrated flood plain management policies by Federal agencies and encouragement for their use in local communities. Efforts to extend these policies to other natural hazards are well under way. Scenario Two takes the main elements of such a program and illustrates in a dramatic, yet surprise-free way, how it can lead to reduced flood-loss potentials. Intuitively, such effects seem obvious, and it is on an essentially intuitive basis that the positive and beneficial synergistic effects of integrated flood plain management have been accepted into the new Federal flood policies. Given rigorous implementation, such reductions could become reality. But there's the rub. Will these programs be rigorously applied? If they are not, what might be the effects? Does there lurk within integrated flood plain management strategies the negative perversities, the detrimental synergistic effects, identified *post hoc* for engineering flood protection works?

These are the questions that should be borne in mind as the analysis moves on to consider flood plain management strategies in scenarios of alternative futures.

# CHAPTER VII

# SCENARIOS OF ALTERNATIVE FUTURES

The application of adjustments to Boulder's flood problem portrayed in the scenarios of past alternatives indicates how changes in flood plain policies could have resulted in different outcomes for the hypothetical 1% flood of 1973. In this chapter, these, and additional policies, are assumed to be adopted under varying current conditions of flood plain development, and speculations about possible future outcomes--desirable and undesirable--are made. Progressions are explored through major adjustments to flooding both in integrated programs and through the systematic treatment of land use management, engineering protection works, community preparedness, insurance, and relief and rehabilitation. The scenarios attempt to indicate interactions not only between an adjustment and other elements of the urban flood hazard system, but between other adjustments as well, and to identify points of rapid change in the system and factors responsible for them.

## Scenario One: Current Program

Expectations for a prosperous beginning to the new millenium were shattered by a catastrophe of disastrous proportions. The floods that came in the year 2000 wrought great destruction upon development on the flood plains of Middle Boulder Creek and some of its tributaries.

But how could it be? Had not Boulder subscribed to a policy of comprehensive flood plain management for more than a quarter century? What had gone wrong?

Little more than twenty-five years ago, it had been predicted that, unless otherwise directed, the historical forces of land use development, together with existing policy emphases--including flood plain management as then practiced--would create a pattern of land use in which severe encroachment of Boulder's flood plain land would result by 1990.

And so it happened. Rapid urbanization of the city to the east and south in the 1950's was quickly followed by county urbanization east of Boulder along the flood plain of South Boulder Creek. Early in 1970 Boulder was annexing industrially developed land on the flood plain formed by the confluence of Middle and South Boulder Creeks and by that decade's end, residential and commercial property on the flood plains of Wonderland and Gunbarrel to the northwest and northeast, respectively. Flagrant violations of the city's flood plain regulations also occurred within older portions of the city as developers continued to redevelop and fill in land along Middle Boulder Creek throughout the 1970's. But then, private development was simply following the pattern set by both the city and university through their locating such structures as the library, justice center, and university housing on the flood plain (Chapter IV).

Perhaps far less damage would have resulted in 2000 had the city stuck to its green-belt plan which included generous strips of flood plain land along the river banks (Figure VII-1). But no sooner had the long-term pattern of open-space been established back in the early 1970's, than variances involving both green-belt and flood plain lands began to emerge. The precedent was set in 1973 when the city annexed Flatiron Industrial Park, one-fifth of which cut into green-belt along South Boulder Creek.

Originally, about 45% of the total 3,600 acres of 1% flood plain expected to fall within urbanized Boulder by 1990 was earmarked for open-space use, but nearly 30 years of indifferent management permitted more damage-prone uses to encroach thereon.

In spite of the green-belt plan, the establishment of flood plain management policies in the early 1970's should have held far better prospects than those that emerged in 2000. For instance, by 1973, some 1,200 acres along Middle Boulder Creek, or almost two-thirds of its 1% flood plain seven miles east from the canyon mouth, had not been encroached upon by development with high loss potential. Ranged against this, however, was the fact that of the 600 acres that had been developed by 1973, almost 62% occurred east of 24th Street between the years 1961 and 1973, at a rate of almost 40 acres per year. What is more, over the last two years of that period, thirty commercial structures were located along Middle Boulder Creek in spite of existing flood plain regulations. Most were inadequately flood-proofed (Chapter IV). Thus, very powerful forces were moving Boulder toward continuing development of its flood plains. To stem these forces it was not sufficient merely to create the comprehensive flood plain management policies of the 1970's; they had also to be rigorously sanctioned.

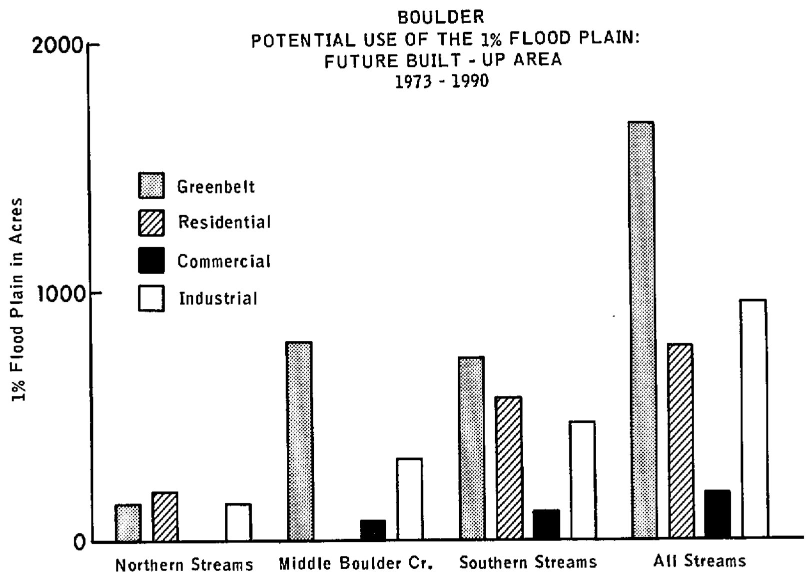



FIGURE VII-1

Perhaps had serious flooding occurred in the period soon after their creation, the regulations may have been more strictly observed and applied. Instead, the last quarter of the century had witnessed little flooding of serious consequence. Some of the tributaries were moderately affected by floods in 1977, 1979, 1983, 1989, and 1993, but in each instance the flood plain and storm drainage engineering schemes had been completed in time to handle the excess discharge. A serious flood along one tributary in 1988 simply served to hasten the completion of the final phase in the engineering program. But what is more important for the disaster of 2000 was that in each instance, completion of the engineering schemes was followed by further relaxation of flood plain regulations and therby closer encroachment by buildings upon the stream channel, thus adding to the damage potential as seen in this extreme flood event.

The outcome was similar along Middle Boulder Creek, only for different reasons. There it was decided not to levee and channel the stream, but to manage the flood plain through land use regulations--regulations which, as already described, were inadequately applied in the years that followed.

Fortunately for human life, most of the variance from regulations along Middle Boulder Creek were for commerical and especially industrial property to the east. Thus, relatively few houses were affected in the disaster and human casualties were, in that area, minimal. Not so on Gregory and Sunshine Creeks where residential settlement was densely established and where flood waters had exceeded the capacity of the flood protection works.

In a city of 130,000 this one flood event, rare though it may be, had caused in excess of $65 million (1973 dollars) in damage to building property and lots along the Middle Boulder from the canyon mouth seven miles to Gunbarrel. More than 70% of this damage was to post-1973 building. But in addition, by severing the city in two, the flood exacted a heavy toll through its disruption of the city's social fabric, causing the city's total burden of loss to approach $90 million (Figure VII-2).

In the absence of experience with recent damaging floods, and public education about them, the reaction of Boulderites to confused warnings of impending disaster was predictable, if tragic. Comparisons were quickly drawn between this and the flash-flood disaster in Rapid City, S.D., 28 years before.

The promising programs of disaster preparedness that had emerged during the 1970's, did not evolve to meet the challenge of the city's increasing catastrophe potential. As the reins of responsibility slipped from the knowing and able hands of the program's originators into those of the less-aware, disaster preparedness waned to the point of extinction; made inevitable, perhaps, by the lack of sensitizing damaging flood events.

In spite of its comprehensive flood plain management program, Boulder required massive infusions of state and Federal aid for its rehabilitation. Less than 15% of all property holders affected by the flood held insurance.

Historically, the creation of the now decrepit National Flood Insurance Program in the Act of 1968 was as much a means for encouraging local communities to adopt land use management and flood control measures as it was for providing subsidies to individuals within communities who joined the program. That is, unless a community had adopted and had had approved by the Federal Insurance Administration land use and/or flood control measures, it could not become a member of the Federal insurance program. And, in order for old policies to be renewed and new ones issued, it was necessary for the community to have made a special rate-making survey by 1974, a date continually set back as communities failed to meet new targets. In addition, new construction within the 1% flood plain was to be ineligible for subsidized insurance unless made "compatible" with levels of risk through flood-proofing.

Inadequate flood plain management within Boulder made this last aspect of the Federal flood insurance program of little consequence since relatively few buildings were flood-proofed. And for those persons who did go to the considerable expense of flood-proofing their property, they saw little need for insurance since they felt already "protected" against flooding in compliance with city regulations.

The insurance program got under way in Boulder in 1971. Within 2 years, over 3% of potential adopters had taken out policies; 12% had done so by 1980. Adoption had been stimulated by the flurry of flood control activity in the early 1970's which coincided with the national flood disasters of hurricane Agnes and Rapid City in 1972. A similar burst of policy purchase followed the extensive floods along the Platte River in Colorado in 1988. But the initial growth in adoptions levelled off throughout the 1980's as the engineering projects came on line and in response to the lack of damaging local floods. An additional constraint upon the extensive purchase of flood insurance was the fact that in spite of the 90% Federal subsidy, it still cost a homeowner almost twice as much to insure his home against a dimly perceived flood event as it did to insure his family for medical purposes.

Although the Federal flood insurance program had for long stipulated that unless individuals within communities had taken out insurance by 1975 they would be denied Federal relief in future flooding, it had little impact on the purchase of policies since it had been demonstrated often elsewhere that when a community suffered disaster, it was politically and humanely impossible not to provide relief in spite of existing legislation, local imprudence in flood plain management, and other circumstances.

With aid programs totalling $75 million, Boulder in the year 2000 proved to be no exception.

## Scenario Two: Planned Unit Development, Boon or Bane?

The historical review described Boulder's efforts to institute a policy of flood plain regulations. Experience has shown an alarming degree of ineffectiveness in the policy's implementation due to administrative procrastination in defining and adhering to key elements of the regulations. Scenario One has, in part, speculated on the possible negative consequences of continuing the policy in that form. This second scenario focuses on the more beneficially positive historical forces in Boulder's existing flood plain management program. It outlines a possible catalyst for more rigorous definition and therefore implementation of existing land use regulations, and the possible long-term consequences of such action--both expected and unexpected.

Tabled before council was an application to annex and zone forty acres of industrial land that lay within the apex formed by the confluence of Middle Boulder and South Boulder Creeks. The land was shown to be indisputably within the 1% flood plain. Although it was obvious for city administrators to require the industrial developers to reduce potential flood damages through land and building regulations, the question was raised as to the prudence and even legality of doing so *before* the city's floodway and flood storage districts had been defined and adopted by the city council (Chapter IV). Accordingly, council members were not prepared to accept that the city would not be assuming responsibility for costly protection measures and rehabilitation for the proposed annexation in the event of a severe flood. It was decided, therefore, to hold the proposed annexation in abeyance until such time as problems of definition and implementation had been properly researched. It was also agreed that an examination should be made of the feasibility of placing a moratorium on all development within the 1% flood plain until the definitional questions had been resolved.*

This decision reflected fully the intent of the flood plain regulations--that definition and management should proceed from at least a city-wide case, and not in an *ad hoc* piecemeal manner at micro-scale.

The council directive made personnel in the new Flood Control Utility immediately aware of the inadequacy of existing data on which to carry out a city-wide evaluation and definition of the flood hazard. The Corps of Engineers' *Special Flood Hazard Information Report* (1972) was little more than a brief resume of the problem. An outline in blue of the 100-year and Standard Project Floods on an aerial photo mosaic at a scale of one inch to 400 feet was found to be completely inadequate

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*Subsequent to this scenario being written, the council did in fact vote to annex the land in question. No decision was made to ensure proper compliance with Ordinance No. 3505 in the manner described. The decisions were opposed by only one council member, himself an expert in the field of hydrology and flood plain management.

for purposes of planning land use management. Consequently, as a prelude to flood hazard definition, a data inventory was prepared, collated, and analyzed. This meant obtaining all relevant data on Middle Boulder Creek from the Corps of Engineers including, for example, hydrologic and hydraulic analyses, topographic maps at two-foot contour intervals or less, aerial photos, areas of building with greatest damage potential, and damage estimates. It also required information on upstream damage and debris potential (which would affect flows within the city), and preparation of a file on all flood plain buildings and structures as to their potentials for structural and content damage, obstruction of flows, flotation, and flood-proofing. The wash-out and debris-cloggage potential of bridges within the city was also assessed (CECEP, 1973). From this pool of information and careful field-surveys, flood-flows, depths, and velocities were derived and related to existing and *desired future densities of development* on the flood plain. The ensuing flood levels were adopted as the design levels for the 1% flood, and the floodway and flood-storage districts accordingly defined.

After one year of concentrated effort, the new definitions were presented to and accepted by the council in mid-1974 as the basis upon which criteria for the management of flood plain development would be set. In essence, this meant detailing measures that would be needed to achieve an agreed upon objective for reducing life losses to near zero; reducing property losses to about 30% that of existing 1% flood potential; and taking all practical steps necessary for preventing serious disruption of social systems by 1994. Specific measures included public acquisition of open-space and of buildings for relocation and/or razing, and flood-proofing measures, including elevation of buildings and land where appropriate.

To achieve these objectives, seven basic measures were adopted:

(1) All residential development would be phased off the 1% flood plain along Middle Boulder Creek.

(2) All structures on the 1% flood plain between the canyon mouth and 15th Street would be acquired and the land given over to public open-space since it was this area that would receive the worst flood velocities.

(3) That area on the 1% flood plain east of 15th Street and currently zoned residential would be rezoned for commercial use, but commercial use would be excluded from areas where dangerous levels and velocities of flow had been determined to occur during a 1% flood.

(4) All building to be permitted on the 1% flood plain should be flood-proofed.

(5) Financial incentives and relief would be sought and provided for acquisition, relocation, and property modification--including public service systems--through appropriate local, state and Federal aids.

(6) Where necessary, all bridges on Middle Boulder Creek in the city would be raised and/or strengthened to pass the 1% flood and to minimize debris cloggage.

(7) The Boulder Greenbelt Program would be adhered to strictly.

1. Outcome 1: According to Plan

The planners estimated that acquisition of pre-1974 structures west of 15th Street for open-space purposes, and all residential structures on the remainder of the 1% flood plain of Middle Boulder Creek would involve some 190 units: 90 private single family dwellings; 12 private multi-dwelling structures with about 80 ground level units; 10 University of Colorado multi-dwelling structures; and 75 commercial-industrial structures.

The 1% flood damage potential prevented through this acquisition program was calculated to be $10.2 million--$1.7 million residential, $1.4 million public, and $8.1 million commercial-industrial.

The program for flood-proofing pre-1974 commercial-industrial structures east of 15th Street over the planning period was thought to reduce building property damage potential from 1% flooding by 85%, from $11 million to around $1.75 million.*

Thus, under pre-1974 conditions of development it was estimated that the planned unit program could reduce building property loss by about 90%, from just over $21 million to around $1.75 million.

It was realized, however, that permitted filling in of vacant land with new buildings east of 15th Street within the pre-1974 built-up area would increase the $1.75 million damage potential up to and beyond the planning target date of 1994. Aerial photo analysis suggested a development potential of 25%. If flood-proofed, it was estimated that this development could incur about $0.5 million in losses from the 1% flood.

Similar provisions and evaluations were made for flood-proofed development that would progressively extend the boundary of the built-up

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*The original building damage potential for 1973 was given as $22 million. Acquisition of property could reduce the total by $10.2 million to $11.8 million. Flood-proofing the remaining buildings could reduce the $11.8 million potential losses by 85% to $1.92 million.

area eastwards along the flood plain of Middle Boulder Creek. The 1% flood cost was calculated as being $3.5 million by the end of 1993.

Given these assumptions, the planners felt that total building property losses along Middle Boulder Creek from a 1% flood would be under $6.0 million--$1.75 million for pre-1974 property and $4 million for property developed between 1974 and 1994--or between 10 and 15% of the unprotected value.

Since the planned unit program also took account of reducing the disruptiveness that flooding would have on social organization, including the public service systems, the planners estimated that no more than $2 million in damages would occur to that sector from a 1994 1% flood.

Important to the success of the flood-proofing program was a community preparedness plan that would provide sufficient advance warning of a major flood for property owners to enact emergency and contingent flood-proofing measures. These warning dependent actions would include emergency actions that depend on structural modifications to buildings, such as temporary bulwarks across permanent or breachable openings (doors and display windows, for example); pulleys from which display counters may be suspended above flood levels; and seepage control using pumps, sealing compounds, and polyethylene sheathing. Other emergency actions that would not require structural alterations would include the removal of goods and equipment to flood-free locations either within or outside of the flood zone; temporary protection of equipment (for examples, disconnection of electrical apparatus and coating of machinery with grease); and flood fighting through sand-bagging and other means.

Given this program of planned unit development that included land use and structural change and warning contingent emergency action, advocates argued that by the year 2000, a 1% flood would cost the city between $5 and $10 million. They pointed out that this would be an average 80% less than the $38 million loss that such a flood would have caused in 1973, and compared it with an estimate of $90 million as the price Boulder would pay for continuing mismanagement of its flood plains (Figure VII-2).

2. Outcome 2: Capricious Nature

Encouraged by estimates that a rigorous program of planned unit development along Middle Boulder Creek would reduce flood losses to around 20% of existing 1973 levels by the year 2000 the Boulder administration pressed ahead with its implementation.

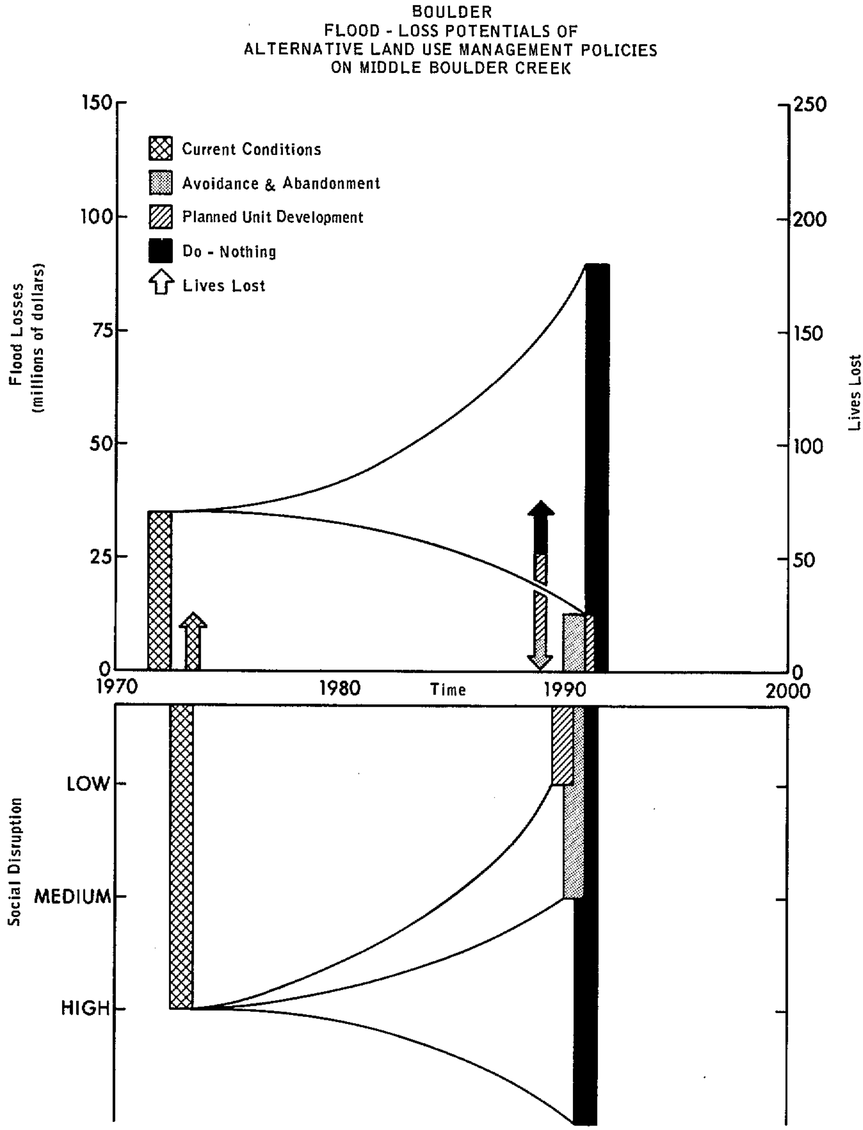
BOULDER
FLOOD - LOSS POTENTIALS OF
ALTERNATIVE LAND USE MANAGEMENT POLICIES
ON MIDDLE BOULDER CREEK
Current Conditions
Avoidance & Abandonment
Planned Unit Development
Do - Nothing
Lives Lost
Flood Losses (millions of dollars)
Lives Lost
150
100
75
50
25
0
250
200
150
100
50
0
1970
1980
Time
1990
2000
Social Disruption
LOW
MEDIUM
HIGH

FIGURE VII-2

The flash-floods of 1984 came quickly with little lead-time in which the city could execute its emergency preparedness plan. An early report of the disaster in the *Denver Post* in part read:

> The flash-flood along Middle Boulder Creek last evening severly damaged buildings and property across the center of Boulder and is likely to curtail business and service activities for many days. Early estimates of loss approach $30 million. At least one dozen persons are listed missing.
>
> The disaster appears more tragic when viewed against the background of efforts that have gone into preventing just such an event ever happening.
>
> For several decades, Federal agencies have repeatedly warned of the danger posed to the city by Middle Boulder Creek. In the early 1950's and again in 1972, the Corps of Engineers recommended that levees be constructed along Middle Boulder Creek to protect existing property. But Boulder declined these subsidized engineering schemes on the grounds that they would adversely affect the natural beauty and ecology of the stream and that the levees themselves could encourage increased use of the flood plain and thereby the long-term danger of a major disaster. Instead, over the last 10 years, Boulder has energetically applied land use regulations in a program of planned unit development that would reduce the flood-loss potential from the 100 year flood by over 70% by 1994, that is, over a 20 year planning period.
>
> In view of the events just witnessed, however, it would seem that, until fully implemented, such a program holds massive dangers since a flood may occur at any time during the planning phase when flood-loss potentials are high.
>
> As Professor Retaw, hydrologist, Department of Engineering, University of Colorado, observes: "The size of flood to which Boulder has planned its flood plain regulations is called the 100 year flood. A flood of this size has a 1 in 100 or 1% chance of occurring in any one year, but could occur more than once in one year, and therefore, several times during 100 years. When one computes the probability of this very same size flood occurring over the 20 year planning period (1974 to 1994), the value increases to 18% or nearly 1 in 5. For the 10 years just gone (1974 to 1984), the chance of the 100 year planning flood happening was almost 10% or 1 in 10. It might well be asked that when such an enormous amount of property and life is at risk, is it reasonable for planners to take a 1 in 5 gamble that the flood won't come before completion of the 20 year regulatory program? To the extent that it is surely far better to regulate than to do nothing but allow the potential for losses to grow, the planning program is justified, but on first impressions it might well appear as though, in this instance a levee system could have prevented Boulder's demise."

3. Outcome 3: A Lot Like Levees

In the year 2000, the Boulder Flood Control Utility could look back with satisfaction on nearly 30 years of fruitful activity. Not only was its program of flood control works on tributary streams complete, but several floods throughout the 1980's and 1990's had been successfully contained by it. What is more, the program of planned unit development along Middle Boulder Creek was well ahead of its planned objective to reduce 1973 levels of flood-loss potential of $38 million for the 100 year flood by 70% by 1994.

In spite of these planning achievements, the flash flood disaster in Boulder in May, 2000 was the worst the nation had experienced for the decade at a cost of $40 million (1973 dollars).

Post-disaster evaluations by an interagency team revealed the high levels of loss to be caused by the widespread design exceedence of flood-proofed property. Most property had been flood-proofed against the 100 year planning flood. But the May, 2000 flood was estimated to have a recurrence interval of 200 years. As such, it approached the size of the Corps of Engineers' estimates for the Standard Project Flood. In general, the 200-year flood exceeded the 1% flood design levels by between 1 and 2 feet.

Fortunately, under the planned unit development program almost all residential building that could be affected by the 100 year flood had been removed. Of the commercial-industrial property developed on the 1% flood plain, it was estimated that close to 5.6 million square feet of first floor space and 1.4 million square feet of basement space was affected by the May, 2000 flood. Approximately 60% of the space affected was post-1973 property. Structural and content damages associated with this property were estimated at $16 million.

In addition, losses residual to the flood-proofed component of buildings and lots were estimated at $6.5 million and associated and secondary costs at $5.5 million (Outcome 1). As well, some $12 million in losses occurred to property located between the 1% and 0.5% flood zones that did not fall under the planned unit development program.*

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*The Corps of Engineers' study of 1972 indicates that the damage potential to building property along Middle Boulder Creek between the 1% flood limit and the Standard Project Flood limit was $6 million. In general the level of the Standard Project Flood is two to three feet above the 1% flood.

Defenders of the regulatory program pointed out that without it, Boulder's losses would have approached $90 million, more than double the existing cost. Antagonists pointed to expected savings from a flood control scheme of dams or levees.

Scenario Three: Avoid and Abandon the Flood Plain

> It has been repeatedly stated that flood hazard is the result of human activity being located in flood-prone areas. It would seem obvious, therefore, that the most effective way of reducing flood-loss potentials would be to abandon the flood plain to its more natural functions, or at least to abandon it to more flood compatible human endeavors such as range and parkland. While small portions of flood plain land can often be given over to such uses, it would seem socially impossible to abandon a heavily urbanized flood plain like Middle Boulder Creek unless the area had been demolished first by an extraordinarily severe flood, as happened in Rapid City, S.D., after the June, 1972 disaster. Nevertheless, there should be some heuristic value in developing a scenario of flood plain avoidance and abandonment. At the very least, its outcome should provide the outside limit to flood-loss reduction possibilities for Boulder.

In order to provide a lower limit against which its integrated flood plain policy could be judged, the Flood Control Utility assessed the impact that a program of avoidance and abandonment would have on flood-loss potentials along the 1% flood plain of Middle Boulder Creek over its 20-year planning period.

It was assumed that after 1973 no new development would take place in this area and that existing building would be abandoned with obsolescence. Development was dichotomized by age into two areas west and east of 24th Street. To the west many buildings were observed to be aged to the extent that most could be expected to be razed and given over to open space uses by the mid-1990's. In addition, it was found that 85% of flood-prone residential units were in the western sector (Figure VI-1). Their abandonment would, therefore, drastically reduce casualty potential in time of severe flood although it would not have much effect on total property loss, since residential property made up only 5% of the 1975 total (Tables V-1 and V-2).

To the east of 24th Street most development in 1973 was new and could not be expected to become obsolete during this century. Thus, not only would damage potential remain high in this area, but social disruption would still be moderately severe as a good proportion of current commercial, industrial, and public units would still be operating on the flood plain in the 1990's. It seemed reasonable to expect, however, that the more vulnerable elements in public utility systems (such as sewage, gas, electricity, and communications) would have been modified or relocated under the avoidance-abandonment policy by the end of the planning period. And, also, that some of the more vulnerable structures, such as in the Cordry Crescent residential area at 28th Street, would be prematurely razed or relocated.

Even without being flood-proofed, and given that no more than 15% of the 1973 building property damage potential was removed east of 24th Street by 1993, it was estimated that this sector would result in about $8.5 million in damages in a 1% flood at the end of the planning period. It was further assumed, that if such a program resulted in loss-reductions of around 50% of existing potentials to public service systems and associated and secondary costs, then the total flood losses in 1993 would fall to around $12-13 million, or about 13% of that estimated for an essentially do nothing policy (Scenario One).

## Scenario Four: An Integrated Community Preparedness Plan

> The cross-sectional image of flooding in Boulder in 1973 revealed the deficiencies in the city's historical attempts at improving its community preparedness plan. These deficiencies were carried over into the alternative future for Boulder's comprehensive flood plain management program in Scenario One. In this scenario, the implications of improving Boulder's existing *Emergency Plan for Floods* (1970) are considered. And, once again, an attempt is made to establish a structure and anticipate factors that might enter into the decision processes that lead to change.

The new Flood Control Utility saw as one of its high priority tasks elaboration and integration of its community preparedness plan so that human casualties would be minimized in an extreme flood event. This meant integration of data collection on potential flooding, dissemination of information, and emergency evacuation procedures. This task seemed especially important since it appeared likely that the city would not adopt the Corps' proposed levee system, but would rely on a non-structural, essentially land use management approach along Middle Boulder Creek that would take many years to become sufficiently effective for reducing human casualties.

Central to the new plan was the purchase and installation by the National Weather Service, of automatic flash flood warning devices on the three major tributaries above Boulder. These water-level sensors would automatically relay messages about critical flood-levels to the community alarm station in Boulder. The system would reduce the burden of reliance upon the climatic sensibilities of the Director of the Flood Control Utility who, under the old system, had to visually interpret the meteoro-hydrological conditions of flash-flooding. Manual monitoring of the stream systems during critical flood periods would, however, continue as a backup and supplementary data gathering system. Contacts with the National Weather Service Office in Denver would be maintained and strengthened.

From their hazard evaluations, the Flood Control Utility staff developed a plan for the long-term ongoing supply of information about the potential for serious flooding in Boulder and actions that would be necessary should the event occur. Three fundamental characteristics were recognised and met head-on. First, the Flood Control Utility isolated several difficulties that would emerge if warning-contingent emergency actions were to be formally fostered. In a flash-flood with little warning time implementation of property-saving emergency actions could delay the evacuation of personnel and so increase casualty potential. Movements of people onto the flood plain to effect property-saving measures would congest and confuse evacuation efforts. There was also the pervasive problem of efforts being rendered useless in a larger than expected flood. Given these factors, the Flood Control Utility decided against adopting a formal program for educating the public about warning-contingent flood-proofing and emergency actions and instead focused upon reducing human casualties through emergency evacuation measures. Second, the city decided that it would use, when necessary, the power vested in it through its Home Rule Charter to compel evacuation of occupants from flood threatened areas. And third, the staff accepted at face value research results that the public does not generally panic when told the truth about disaster potential. Thus, it was decided from the outset that the truth and consequences of the flood problem and community leadership's responsibility in time of crisis would be clearly articulated to the public.

Ongoing dissemination of information was achieved in a number of different ways.

A half-hour television program was produced and shown on local stations describing the past history of flooding in Boulder; why the possibility for disaster had rapidly increased in recent years; what was being done and what needed to be done about the problem; what were the chances of disaster and what were the likely consequences; and how the community and individual should act if a disaster occurred.

The documentary made use of visual aids, such as maps and diagrams, to convey information on flood spreads and depths, as well as excursions into the field to show good and bad land use practices. Some comparisons with other communities--especially Rapid City--were made. Because of rapid population turnover, updated versions of the documentary were shown annually.

In addition markers were set up on the flood plain to show the lateral spread of the 1% flood and depths at various points within it, and informational brochures were sent out periodically with the Water and Flood Control Utility account to property owners. A map of flood-spread and information on evacuation actions to take in time of disaster were included in each edition of the Telephone Directory.

As the years passed and the program took hold, an aware public began to develop a demand for information on short-term property-saving measures. This demand coincided with the near completion of removing all residential property off the 1% flood plain of Middle Boulder Creek.

Having substantially reduced this important sector of casualty potential, the Flood Control Utility saw fit to revise its 1974 decision and began developing an education and information program on property-saving warning-contingent flood-proofing and emergency actions relevant to commercial, industrial, and public property.

When asked to pinpoint the success of the city's evacuation in the May flood of the year 2000, the Mayor cited four main factors. First, information on critical flood-levels had been quickly relayed from the automatic stream gages to the Boulder receiving station so that the Director of the Flood Control Utility was able to take prompt and decisive action. Second, information about the flood threat and evacuation procedures was disseminated simultaneously through local radio and television to a public already made well aware of the flood danger by the city's ongoing flood education program. Third, in order to reduce the confusion that so often accompanies news flashes by station staff, all radio and television reports on the flood were controlled and delivered by staff of the Flood Control Utility. In the case of television, messages were accompanied by pre-prepared visual aids of the areas to be affected and evacuated. And, fourth, police power was immediately invoked to help evacuate expeditiously the affected population. Again, a decision taken on behalf of an already well prepared and aware public.

In short, the long-term community preparedness plan had alleviated the common problem of leadership credibility and public belief when an extraordinarily severe flood occurs. In the short-term, strict control over the content and delivery of warning messages and evacuation measures by the Director of the Flood Control Utility had reduced the ambiguity and conflict of information often experienced in disaster situations.

In spite of the fact that the flood was closer to the 200-year Standard Project Flood than the 100-year planning flood, human casualties were extremely low with only one death, although property losses were disappointingly high.

## Scenario Five: Levees Revived

> The historical review outlined several engineering protection works possible for Middle Boulder Creek, including dams, diversion channels, a diversion tunnel, and hard and soft-channel treatment (Figure IV-10). In this scenario the focus is again on soft-channel treatment, or levees, since it is that engineering measure that currently has the most likely chance of being adopted.
>
> Although not a particularly attractive solution to the people of Boulder because of its disruption of the ecological environment, levees did emerge with the most favorable benefit-cost ratio as devised by the Corps of Engineers and command that agency's unqualified support. To provide for the adoption of levees along Middle Boulder Creek it is necessary to speculate on the circumstances that might induce Boulder to change from its existing flood plain regulations to subsidized levees, and possible consequences therefrom.
>
> Underscoring the consequences of levee adoption (and related engineering works) on flood damage potential are factors implicit to the levee scenario of an alternative past. First, levees stifle the search for alternative measures because damage from less than the design flood is seldom experienced. Second, for the same reason, levees suppress the implementation of measures already adopted. Third, because damage is seldom experienced, the community confidently invades the flood plain with high-risk development both in protected and unprotected areas. Fourth, because flood plains are more highly developed, there is public pressure for extension of the levees whenever they are threatened or when adjacent unprotected areas are damaged. And fifth, combined, these factors increase catastrophe potential and the magnitude of disaster should the levees fail.

By 1978, inexorable pressures from vested interest groups were seriously and adversely compromising application of Boulder's flood plain regulations. Their rigorous implementation was made more difficult by the fact that damaging floods had not occurred on Middle Boulder Creek since 1969. Those on tributary streams promised containment by the developing sequence of engineering works. Consequently, a strong lobby developed which argued for more capital intensive use of the flood plains along with protection by levees and perhaps even a dam up-canyon. It pointed to official Corps of Engineers' recommendations as support for their demands.

This argument gained impetus after the 30-year flood of 1980 (3%), for it had caused considerable damage ($6 million) to property lining Middle Boulder Creek, including much which was supposedly adjusted to more serious flooding under the city's flood plain regulations. The advocates for levee protection pointed also to the disastrous consequences possible had the 100-year flood occurred, and $40 million was an oft quoted damage estimate in their arguments. Rightly, they noted that only 8% of damaged property was covered by flood insurance. They reasoned that not only had the community been subjected to high costs in flood-losses in 1980, but that the potential cost would be much higher for many years to come. To this cost they added the lost opportunities for investment in the flood plain: a cost caused by an overly restrictive flood plain regulatory program.

The proponents of non-structural management of Boulder's flood plains lost much public support as a result of the 1980 flood, and the apparent failure of their approach, helped, no doubt, by the backlash of opinion against environmental concern that had evolved during the 1960's. Consequently, the lobby for levees gained much public support for extending the successful engineering schemes of the tributaries to Middle Boulder Creek.

The changed composition of the City Council following the elections of 1980, led directly to the necessary legal and administrative requirements for implementing a slightly modified version of the Corps of Engineers' 1972 levee scheme. Public attitudes were unequivocal. If $7 million (1973 dollars) was to be spent on levee protection, then why pay twice in lost opportunities from restrictive land use regulations? The political reality seemed clear. Under pressure from the general public and private developers, the regulatory measures were, in effect, dropped as a flood plain management alternative.

By the time the levees were completed in 1984, development on the flood plain had already regained pre-regulatory rates of growth: growth which opponents of levees predicted could reach a damage potential of $90 million from the type of event hypothesized as the 1973 1% planning flood.

## Scenario Six: Flood Control Dam

The most compelling reason in Boulder's decision to adopt a multi-purpose flood control dam was the catastrophe potential inherent in both major alternatives--land use regulations and levees.

The 320 feet high dam would be located 1,000 yards downstream from Orodell, where Fourmile Creek runs into the Middle Boulder some two miles upstream from the city, and would create a lake two miles long with a head of water averaging 280 feet.

The Corps of Engineers had estimated that by controlling extreme fluctuations in the stream-flow regime, the dam would reduce the $465,000 annual average property damages in Boulder by 90%. Additional benefits would accrue by way of water for irrigation and electricity and increased productivity from both rural land and the urban flood plain.

Against the benefits, costs were counted mainly as: dam construction; removal of 25 houses; annual maintenance; 4-5 miles of new highway diversions; assorted property purchases; and tree-clearance up to lake-line limits. The total cost of $23 million was to be partially subsidized by the Federal government.

Residents and pooperty owners above the proposed dam vigorously protested the project because it would require acquisition of their property which lay within that part of the canyon to be inundated by the lake. However, experts agreed that residential development on the very narrow flood plains and benches along the canyons of Fourmile and Middle Boulder Creeks was exposed to extreme danger from even moderate floods. Some property butted into the stream-bed (Chapter V). Although an alternative scheme of three small flood control dams on each main-stem stream would have protected this property (and was much favored by canyon residents), analyses by the Corps of Engineers demonstrated that it would be less effective and beneficial to the principal population at risk--Boulder--than the multipurpose dam.

County authorities, which had grown very alarmed at the risk to property from flooding in the canyons, had already implemented flood-plain regulations and were, therefore, ready to adopt the proposed new dam.

Because of the lengthy period required for Congressional authorization and works construction the dam was not in operation until 1981. (In 1972 the average time for projects from initiation to completion was 17 years.) The dams progress had been hastened by a very severely damaging flood in 1977.

To those in Boulder who had most vigorously opposed the dam, it now appeared as a scar on the landscape, the ruination of a pleasant canyon ecology almost within walking distance of the city. And, for them, there was always the chance that excess releases from the dam in times of extreme runoff would cause drastic flood-losses to the rapidly filling flood-plain below.

But to some earlier detractors, the uncommitted, and especially its supporters, the dam provided a new amenity. For them the aesthetic and ecologic loss of the canyon had been more than offset by controlled waters which had very markedly improved fishing both above and below the dam, and fresh-water ecology downstream from it. As well, the lake now served as a pleasure park for recreationists avidly seeking to fill-in their ever increasing leisure-time with boating, skiing, fishing, and camping activities.

## Scenario Seven: Voluntary Insurance and Flood-Proofing: A Quantitative Scenario

> The progression of Boulder's comprehensive flood plain management program in Scenario One did not auger well for the federally subsidized voluntary insurance program. This was so for two main reasons: first, because of certain provisions within the National Flood Insurance Act of 1968 itself, and second, because of the likely behavior of individuals required to flood-proof their buildings.
>
> In this scenario, an attempt is made to quantitatively project the future outcome for voluntary insurance hypothesized in Scenario One. Assumptions used in this projection, depicted in Figure VII-3, are derived from current and proposed policy on flood insurance (Scenario One), past adoptions of insurance in Boulder (Table IV-4), and trends in future development outlined for planned unit development in Scenario Two.

Generally, the remaining 2,000 acres of potentially developable flood-prone land in Boulder is assumed to support one building per acre by 1990. Thus, potential insurance adopters per building by 1990 could number 6,000 made up of current potential adopters (3,450), minus 2% per year for building decay (600), plus 25% filling in of the existing built-up area (860), and the 2,000 new buildings outside of the existing built-up area, 1973-1990.

The graph of potential adopters in Boulder under the National Flood Insurance Act of 1968 shows the expected increase in adoptions through to 1975 based on trends, 1971-1973 (top half of Figure VII-3). It also shows the approximate number of buildings that will not be insured by 1975. According to the Act, buildings uninsured by 1975 will be ineligible for any form of post-disaster Federal relief. In 1975, this could involve over 3,000 buildings, or about 85% of the total flood-prone building. The decay of these buildings at 2% per year is shown through to 1990 along with the increase in post-1971 building which, because located upon the 1% flood plain after the adoption of flood plain regulations by Boulder, should in theory all be flood-proofed.

Two major factors suggest that, flood-proofed or not, very little post-1971 building will be insured by 1990.

First, according to the Act, new building not flood-proofed will be ineligible for insurance after 1974. Although short, the history of implementing flood plain regulations in Boulder provides many examples of variances, including inadequate and non-existent flood-proofing. Theoretically, at least, such building will be ineligible for flood insurance.

Second, if individuals are forced through city regulations to flood-proof (or partially flood-proof) their buildings, it seems very unlikely that they will also take out flood insurance. First, because they will already feel protected against flood-losses by virtue of the fact that they have flood-proofed, at considerable cost, their buildings. Second, because the annual cost of insurance is too high. And third, because, legislation notwithstanding, they will feel that, should losses occur, the government will step in and bail them out.

Obviously, future trends in insurance adoption will not be nearly so steady and straightforward. Factors that could create sudden change in the progression towards increased adoption include: 1) an information-education program of the sort outlined in Scenario Four; 2) a damaging flood or series of floods; 3) a change in the Act to allow premiums to be decreased in relation to the adequacy of flood-proofing measures adopted by insurees; 4) more rigorous city requirements for flood-proofing being offset by a partial or total city subsidy for flood-insurance; and 5) change from a voluntary to mandatory insurance program.

# BOULDER
# COMPARISON OF FEDERALLY ASSISTED FLOOD INSURANCE PROGRAMS
# 1971 - 1990

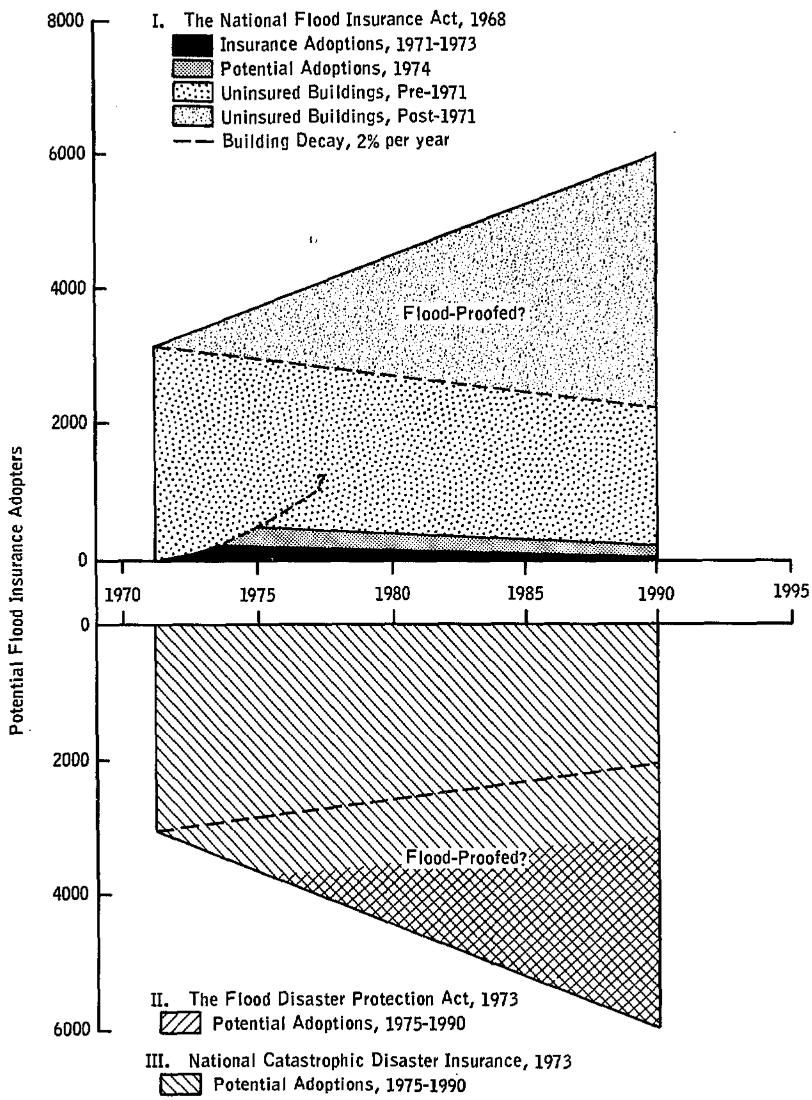


FIGURE VII-3

Scenario Eight: Mandatory Insurance

The Federal Insurance Administration recognizes the difficulty of getting individuals to adopt insurance voluntarily. It can point to automobile and fire insurance as historical precedents for change to a mandatory program. Consequently, two Federal bills requiring flood insurance to be mandatory for property owners within the 1% flood plain are under debate. The implications that each bill could have on flood plain management in Boulder are speculated upon below.

1. The National Catastrophic Disaster Insurance Act of 1973

This Act would at once replace and expand the existing flood insurance program to include most natural hazards and some man-made ones as well. Insurance would be mandatory to the extent that it would be funded by a compulsory add-on charge to all existing real estate and personal property insurance policies. Thus, all fire, homeowner, burglary and theft, commercial multi-peril, and any other liability or casualty insurance would be levied by up to 5% for the Federal disaster fund. However, communities would still be required to adopt measures to reduce flood-prone development, and individuals to comply with jurisdictional regulations in order to be eligible for coverage. Given the coverage, an individual would not, in event of disaster, be able to apply for other forms of Federal disaster relief.

Once adopted, this Federal program caused all existing and new property in Boulder to become immediately insured against specified disasters, that is, as long as the property owner held an insurance policy of an appropriate type. In Boulder, this meant just under 95% of all property owners, including renters, were insured against disasters, like flood.

In the severe wind-storm of January, 1980, over 3,000 claims were made by Boulderites on the Federal Disaster Insurance Administration for damages ranging from $100 to $10,000 and totalling $5.3 million.* An

*Severely damaging winds have occurred about once every two to three years in Boulder. Property damage estimated at $0.50-$0.75 million occurred during two weeks of December, 1964; $.75 million on January 15 and 16, 1967; $1.5 million on January 7, 1969, when wind speeds exceeded 125 mph; and $2.5 million on January 11, 1972. These four storms injured over fifty people and killed three. Analyses of the physical phenomenon and human adjustment to it can be found respectively, in Waltraud A. R. Brinkmann, A Climatological Study of Strong Downslop Winds in the Boulder Area, NCAR Cooperative Thesis, INSTAAR Occasional Paper (Boulder: National Center for Atmospheric Research, 1973), and Donald J. Miller, Human Perception of and Adjustment to the High Wind Hazard in Boulder, Colorado. Unpublished M.A. Thesis, Department of Geography (Boulder: University of Colorado, 1972).

interesting response of those requiring assistance was the widespread ignorance of their eligibility for reimbursement through the National Catastrophic Disaster Insurance Act. Knowledge of the availability of assistance had come principally from outside by way of Federally appointed insurance assessors quick to the scene of disaster.

This reaction compared with that found in several other community disaster situations. Social research attributed the main cause of this response to the fact that disaster victims did not realize that they had been paying into a disaster fund. This was because payment was not by annual premium paid specifically for disaster insurance, but by an obscure add-on-charge to premiums for insurance purchased for entirely different reasons.

It was apparent, therefore, that the disaster insurance scheme would be having very little informational and educational value for occupants and developers of Boulder's flood plains. Certainly, it would be doing little to help inhibit unwise flood plain encroachments, damages to which the insurees of the whole nation would be required to subsidize (Ericksen, 1971).

2. The Flood Disaster Protection Act of 1973

This would amend the existing Flood Insurance Act of 1968 to require all property owners within special hazard areas to purchase insurance if property is to be acquired or developed in connection with federally related financing. Thus, to obtain direct or indirect financial assistance in any form of loan, grant, guaranty, insurance, payment, rebate, subsidy or disaster assistance, the flood plain recipient would have to take out subsidized flood insurance for full development costs (less land cost) or the limit of coverage for the property type, whichever is less. In addition, federally regulated lending institutions, such as banks, would be directed by relevant Federal agencies to require flood insurance on all real estate and personal property loans up to the same maximum limit or the balance of the loan, whichever is less.

3. Scenario

Once in effect, this Act began to achieve what other programs, both Federal and local, had failed to do--to inform and educate institutions responsible for building development (banks, realties, and the like) of the threat to property and lives posed by local flood hazards. To comply with Federal regulations, important financial institutions were forced to take note of already established local flood plain regulations whereas before, the city had fought a losing battle in trying to make known to them relevant flood hazard information to which their investment should adjust. (Note that the effectiveness of this insurance program would be very dependent upon the definition of the flood hazard problem by local authority and the rigor with which its flood plain regulations were implemented. Contrast, for example, Scenarios One and Two.)

Because it was politically impossible to make the Flood Disaster Protection Act retroactive, pre-1975 property on Boulder's flood plains remained without cover. (The amount of building assumed not to fall under this Act by 1990 is shown in the bottom-half of Figure VII-3.) Although still eligible for insurance under the Act of 1968, relatively few pre-1975 property holders availed themselves of it. (Compare Scenario Six.)

In the 1% flood of 1990, close to half of the affected population held flood insurance on their property. Post-disaster research revealed that these people showed a marked behavioral distinction from uninsured people both before and during the flood. People with insurance seemed less inclined to delay evacuating the flood plain in order to save and protect goods and property from being damaged. Thus, for this sector of the population, there was a marked aversion from implementing warning-contingent flood-proofing and other property saving emergency actions.

While it was felt that this behavior actually increased the flood-loss bill, it was nevertheless acknowledged that it had also been an important factor in holding down casualties since the focus of warning response had been upon human welfare. (Compare Scenario Four.)

4. Discussion

In terms of individual adoptions and community adjustment to flood hazard, both proposed mandatory insurance schemes would provide improvement over the existing voluntary scheme for Boulder. In the event of a severe flood, damages residual to land use regulation or levee protection, for example, would be covered to a far greater extent under mandatory rather than voluntary schemes. How much so by 1990 is indicated in Figure VII-3.

The effectiveness of the three schemes for covering pecuniary losses is illustrated in Figure VII-4 in the following section. There it is assumed that each insurance program is combined with the existing flood plain management program in Boulder. It is also assumed that about 20% of pecuniary losses will be to uninsurable property.

Under the existing voluntary insurance program, it is assumed that 15% of insurable property will be covered by 1990. Thus, well over

A COMPARISON OF POST-DISASTER RELIEF AID
NEEDED FOR ALTERNATIVE ADJUSTMENTS TO FLOODS
ON MIDDLE BOULDER CREEK

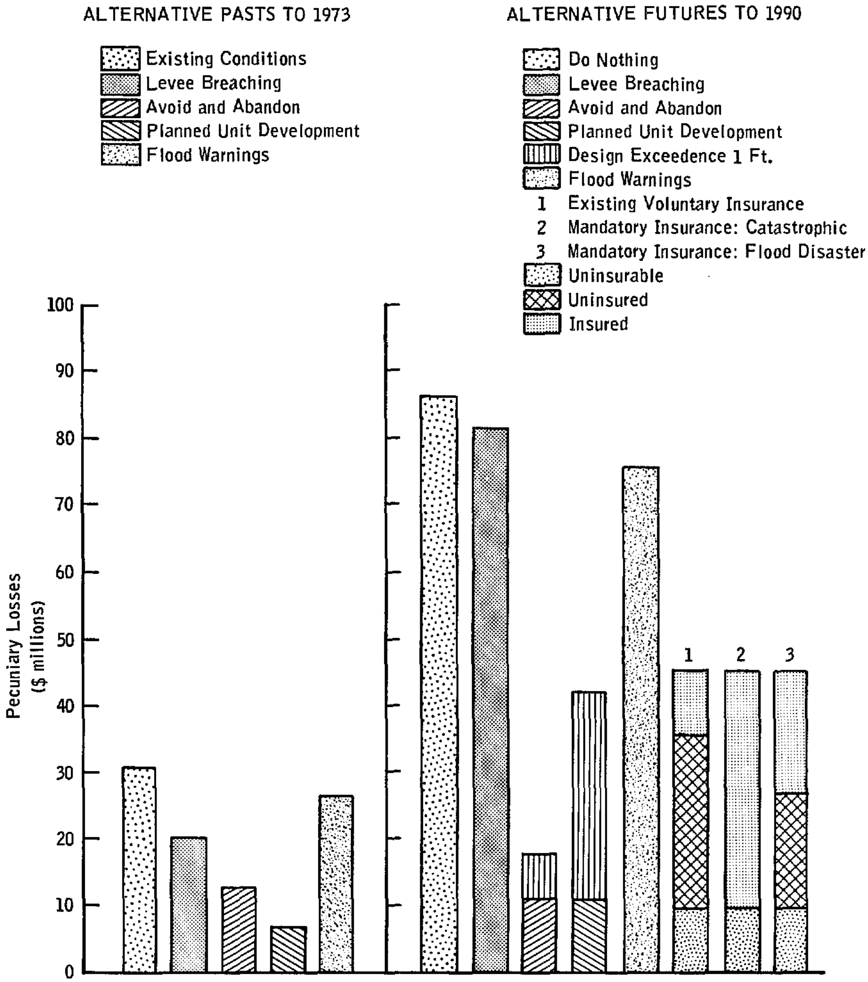


FIGURE VII-4

$30 million of damaged property would be dependent upon post-disaster relief funds. Under the proposed mandatory National Catastrophic Disaster Insurance Program, all insurable property would be covered by insurance. Thus, the replacement of damaged property would come largely from a national disaster fund. This would still mean that the insurers of the nation, whether in floodable locations or not, would be helping to pay for a local community cost. However, resources would come from a fund earmarked for that purpose, rather than by diversion from other programs, as is the case under existing relief policies. There would, nevertheless, be a substantial amount of uninsurable property damage, $10 million, that would require post-disaster relief funds. Finally, under the proposed mandatory Flood Disaster Protection Act, it is assumed that all new building after 1975 would be insured, as well as 15% of all pre-1975 building. The uninsured loss by 1990 would amount to well over $25 million. Although the proposed Act provides that insurable property not covered after 1975 would be ineligible for Federal relief, past experience indicates that such a provision is difficult to uphold whenever a disaster strikes.

## Relief and Rehabilitation: Future Options Reviewed

Relief and rehabilitation programs are usually seen as short- to long-term post-disaster operations handled primarily by Federal and state agencies, and private voluntary organizations such as the American Red Cross.

In some ways, relief and rehabilitation can be used as a convenient yardstick against which the efficiency of future options may be measured--especially the extent to which each scenario would reduce the current level of pecuniary losses.

The extent to which outside assistance would be necessary to help Boulder recover from a 1% flood was indicated in the scenario, "Experiencing the Unexpectable....". A large proportion of the pecuniary loss of almost $40 million in that hypothetical flood, would be paid for by the American taxpayer through disaster relief and rehabilitation programs.

The extent to which relief funds would be necessary under alternative adjustments to Boulder's flood problem has been given in the preceding scenarios. These are summarized for Middle Boulder Creek in the graph in Figure VII-4.

It is obvious from Figure VII-4 that post-disaster relief would be necessary under all of the listed adjustments. It would be most required under the continuation of existing flood plain management policy and least under the proposed mandatory program for National Catastrophic Disaster Insurance, followed closely by programs of avoidance and abandonment and planned unit development. Under the latter program, however, the potential for high levels of relief would be realized if flood-proofing designs were to be exceeded. The same is true for levees.

It has been suggested with increasing frequency that the large scale participation of Federal agencies in post-disaster relief during the 1960's and early 1970's has actually encouraged development on the nation's flood plains (Kunreuther, 1973). This is thought to be so because it is believed that individuals and communities are more prepared to take chances with flood plain locations knowing that the Federal government will bail them out when a large flood occurs.

Given the negative influences associated with post-disaster relief, it seems reasonable to expect that, in future, programs will be developed to allow Federal, state and local funds to be used for *pre-disaster* relief purposes. Already this type of relief is emerging. The Federal Defense Civil Preparedness Agency has trained personnel that, upon request, help communities organize against potential disasters. Boulder has not yet applied for aid under the DCPA program. Similarly, the National Weather Service provides equipment and technical assistance for the installation of flash flood warning devices. Again, Boulder has not availed itself of this opportunity.

Wright and McLaughlin (1969) have outlined twenty-four financial strategies that have potential for providing financial assistance for flood control and storm drainage in Boulder: six Federal; two state; ten county; and six city.

For land use management through avoidance and abandonment and/or planned unit development, the most notable Federal relief programs would be those relating to acquisition of open space and urban renewal, and, more recently, through flood plain management programs of the Corps of Engineers.

Yet, for all the good sense it seems to make to provide relief for *pre-disaster* adjustment to flood hazard, there rises the spectre of publicly subsidizing planned unit development in a way which could lead to future increases in damage potential. In changing the flood-loss reducing philosophy from primarily technological solutions to primarily legal and social solutions, the nation may be changing the means, but not the outcome--a continuing increase in flood losses in spite of increasing public expenditures on supporting planned unit development. A new flood control flood-loss paradox!

The implications that this might have on evolving national strategies for flood plain management at the local level is treated at length in the final chapter on research opportunities. In the meantime, principal findings from this and earlier chapters on the application of the scenario method to Boulder's flood problem are summarized in the following synthesis.

# CHAPTER VIII

## A SYNTHESIS OF SCENARIO FINDINGS

In a systematic way the foregoing analyses have tried to delimit the dimensions of the flood hazard problem in Boulder and to anticipate, through scenarios of alternative pasts and futures, possible outcomes in the system's evolution.

In this chapter, an attempt is made to synthesize what has been learned about the dynamics of adjustments in the previous four chapters--the historical evaluation of flood plain management, current cross-sectional images, alternative pasts, and alternative futures for Boulder. To facilitate the synthesis, the two matrices described in Chapter III are employed: the first showing relationships between adjustments and principal components of the social system that predicate losses from flooding (Figure VIII-1); and the second, interactions of adjustments with one another (Figure VIII-2). From this evaluation emerges a summary of several public policy options for Boulder and their social consequences (Figure VIII-3).

### Adjustments and Flood Losses

Figure VIII-1 indicates the way in which each adjustment, by itself, either increases (arrow up) or decreases (arrow down) flood loss potential in Boulder between the 20-year planning period 1973-1993. Flood losses are assumed to be primarily composed of: (1) direct property losses, including public service systems; (2) human casualties, injuries and lives lost; and (3) social disruption, which reflects both tangible and intangible flood losses, such as disruption that accompanies damaged public service systems, homes, or the loss of life. In aggregate, they represent the potential for catastrophe in Boulder.

For five of the adjustments listed in Figure VIII-1, catastrophe potential is clearly influenced in either a positive (detrimental) or negative (beneficial) way across all factors. Positive effects are noted for do-nothing, post-disaster relief and rehabilitation, and subsidized

THE INFLUENCE OF ADJUSTMENTS ON SELECTED
FLOOD - LOSS ELEMENTS OF CATASTROPHE POTENTIAL

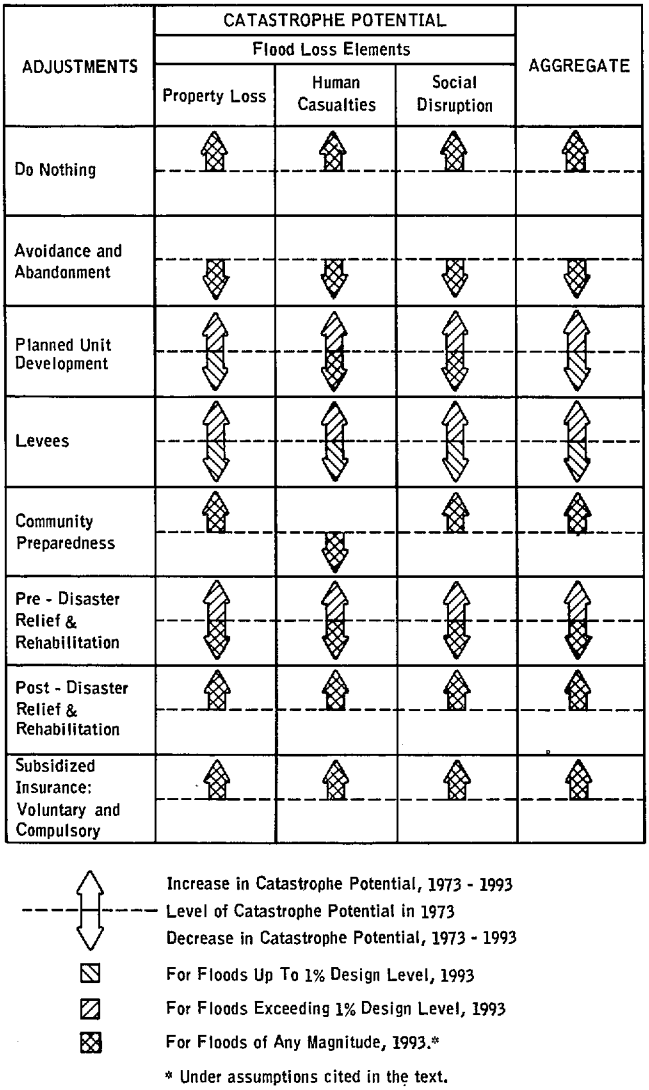


FIGURE VIII-1

insurance, which by themselves (or in certain combinations) will lead to an *increase* in catastrophe potential in Boulder by 1993. Although relief and rehabilitation and insurance would alleviate the burden of financial loss for individuals, losses of life and property and social disruption at community level would still be catastrophic.

Negative effects may be seen in a land use management program that pursues a policy of avoiding and abandoning the percent flood plain and which would therefore *decrease,* by 1993, the 1973 potential for losses.

In addition social response to community preparedness (forecasting, warning, and emergency action) would, if effectively executed, *decrease* human casualties in 1% flooding in 1993, but by itself would not beneficially affect either property losses or social disruption in a significant way. The latter outcome assumes that flash-flooding in Boulder would not allow enough lead time for adopting warning-contingent flood-proofing measures. Thus, the catastrophe potential by 1993 would *increase* over that described for 1973. It may transpire that, in reality, this assumption about behavioral action is too severe.

The most significant presentation in Figure VIII-1, is the degree of uncertainty that surrounds the policies of levee construction, planned unit development, and pre-disaster relief and rehabilitation.

1. Levees

If the design level of 1% flooding is not exceeded, then levees will prevent losses, but only within the protected area. If the design level is exceeded, then heavy losses can be expected. The catastrophe potential in 1993 will, in all likelihood, exceed that of 1973 because development can be expected to occur behind the levees as well as in adjacent unprotected areas.

2. Planned Unit Development

The most uncertain future emerges from application of land use management that employs a policy of planned unit development.

If the design level of flood-proofing in planned unit development is exceeded sufficiently by flooding in 1993, property losses will *increase* over 1973 levels due to expected increases in development of the flood plain. Otherwise, property losses should *decrease*. If it is assumed that under planned unit development residences will be kept off the 1% flood plain, then human casualties should *decrease* whether or not the design flood is exceeded, otherwise they could increase. The same should also apply to social disruption if public service systems are appropriately modified during the next 20 years. Thus, certain elements of catastrophe potential could *decrease* by 1993 whether or not the design flood is exceeded. But property damages will increase very significantly should the design levels be exceeded for reasons similar to those given for flood protection works.

However, wehther or not the design flood is exceeded, the potential for catastrophe will remain high during the first half of the 20-year planning period, and perhaps longer, because of the time-lag involved in fully implementing planned unit development policies.

3. Pre-Disaster Relief and Rehabilitation

Uncertainty of outcome surrounds pre-disaster relief and rehabilitation simply because it is a program of flood-loss reduction that would be tied to other adjustment policies, including those described immediately above. If tied to avoidance and abandonment, pre-disaster relief and rehabilitation would decrease losses across all factors, including catastrophe potential. If, on the other hand, it is tied to planned unit development, it will reflect the uncertainty of that program as illustrated in Figure VIII-1.

For the most part, the adjustments in Figure VIII-1 have been discussed independent of each other. To assess public policy strategies for coping with the flood problem in Boulder adequately, it is essential to consider interactions between adjustments.

## Interactions Between Adjustments

The matrix in Figure VIII-2 illustrates the positive (arrow up) and negative (arrow down) relationships between each adjustment (vertical) with every other adjustment (horizontal). Where positive and negative feedback between any two adjustments differ according to implementation at individual or community levels, that difference is shown by two arrows in one cell. Where positive and negative relationships between adjustments are difficult to identify no arrow appears in the respective cell. *Once more it should be carefully noted, that a relationship that is shown to be positive in the matrix should not be automatically equated with one that is desirable in terms of reducing flood losses, although that might well be the case.* The converse holds true for negative relationships. This is made more complex by the fact that a positive (or negative) relationship may be seen as beneficial or detrimental depending on one's point of view or accounting stance. For example, the levee-by-levee

BOULDER

INTERRELATIONSHIPS BETWEEN ADJUSTMENTS

| ADJUSTMENTS (Independent Variables) | ADJUSTMENTS (Dependent Variables) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Avoidance and Abandonment | Planned Unit Development | Levees | Voluntary Insurance | Compulsory Insurance | Community Preparedness | Pre-Disaster Relief and Rehabilitation | Post-Disaster Relief and Rehabilitation |
| Avoidance and Abandonment | ↑ | ↓ | ↓ | ↓ | ↓ | ↑ | ↑ | ↑ |
| Planned Unit Development | ↑ | ↑ | ↓ | ↓ (I) ↑ (C) | ↑ | ↑ | ↑ | ↓ |
| Levees | ↓ | ↓ (C) | ↑ | | | ↑ (C) | ↓ (C) | ↓ |
| Voluntary Insurance | ↓ | ↓ (I) ↑ (C) | ↓ (I) ↑ (C) | | | ↑ | ↓ | ↓ |
| Compulsory Insurance | ↓ | ↑ | ↑ | | ↑ | ↑ | ↓ | ↓ |
| Community Preparedness | ↓ | ↓ | ↑ ↓ | ↑ | ↑ | ↑ | ↓ | ↓ |
| Pre-Disaster Relief and Rehabilitation | ↑ | ↑ | ↑ | | | ↑ (C) | ↑ | ↓ |
| Post-Disaster Relief and Rehabilitation | ↓ | ↑ ↓ | ↑ ↓ | ↓ (I) ↑ (C) | ↓ (I) ↑ (C) | ↓ (I) | ↓ | ↑ |

C Community; I Individual

↑ Positive Relationship

↓ Negative Relationship

FIGURE VIII-2

relationship is shown as positive, that is, levees are self-perpetuating. While on an expected value basis levee protection may appear to reduce annual average damages, it may in the long-run increase the potential for a catastrophic event: an event based on dynamic changes to the flood hazard system which do not usually figure into traditional estimates of annual average damages. Thus, from one accounting stance, (The Corps of Engineers), the positive relationship of a self-perpetuating levee system may be seen as beneficial and, therefore, desirable; yet, from the viewpoint expressed in this study, it is seen as detrimental in that it increases the flood-loss potential.

1. Land Use Management

Although the matrix shows land use management to be a self-perpetuating system (it has a positive effect on itself), it would seem that that state can only be achieved in Boulder if regulations are strengthened and property sanctioned. These sanctions could be simulated by Federal subsidies for land use management similar to those which have long existed for engineering flood control works. If this were done and severe flooding did not occur during the sub-maximal period of its application, then land use management would likely preclude adoption of a levee system.

The effect of land use management on adopting voluntary insurance is likely to be a negative one. Forced into modifications of structure or lot through land use regulations, the individual is unlikely to voluntarily adopt insurance as well, even when subsidized at present rates of up to 90%. There may, however, be individuals who voluntarily choose to adopt flood-proofing and who may wish to protect their investment by taking out insurance. Past experience would suggest, however, that individuals who voluntarily adopt either type of adjustment, let alone both, are in a distinct minority.

Land use management could have much the same effect on a community preparedness plan as it has on voluntary insurance. For example, having instituted flood-proofing measures, individuals may be less responsive to warning messages during an emergency. This speculation has some support in the fact that such a relationship has been observed in New Zealand which has a long history of disaster insurance and to some extent, voluntary flood-proofing (Ericksen, 1971).

Land use management will not obviate the need for relief and rehabilitation. In the short run, relief may be used in the pre-disaster phase to assist with land use changes either through avoidance and abandonment or planned unit development at both community and individual levels. Until enough time has passed for land use changes to reach their optimum, flood occurrences could require large relief and rehabilitation efforts. Even after the optimum is reached, floods that exceed the design level of land use regulations will result in the need for post-disaster relief, especially if planned unit development was the land use management program opted for.

2. Engineering Protection Works--Levees

Although not necessarily exclusive of each other, given a full levee program, land use management is an unlikely prospect. Flood threat to expanding development would probably result in perpetuation of the levee system. The self-generating feedback of levees would indisputably lead to higher loss potentials than that under a land use management policy.

The effect of levees on insurance is similar to that described for land use management. Under a voluntary program, individuals are unlikely to adopt insurance while levees successfully contain sub-design flood-flows. However, insurance might become a more attractive proposition if rates were to be based upon the risks that are residual to levee and other types of technical "protection", such as flood-proofing. But the computation of these rates could turn out to be a highly complex matter.

The effect that levees would have on community preparedness is not at all clear. If the levees are periodically threatened or overtopped, then it seems reasonable to expect that a community preparedness plan would emerge. Otherwise, it is easy to speculate that the construction of levees in Boulder would result in less vigilance for the extreme event.

The relationship between levees and relief is similar to that between land use management and relief. If the design level is exceeded, relief will be necessary. But unless that occurs, levees, unlike most forms of land use management (flood-proofing is an exception), obviate the need for relief in protected areas in sub-design floods. This would not be so, however, for unprotected development.

3. Federally Subsidized Insurance

It has already been noted that in its relationships with levees and land use management, a more successful insurance program would result from a compulsory rather than voluntary scheme--for reasons given in the preceding sections. If, however, owners of pre-regulation development do adopt insurance, voluntary or compulsory, it is unlikely that they will also voluntarily adopt flood-proofing and related measures unless a financial incentive, such as a subsidy, is made available or a requirement imposed. For owners of post-regulation development--whose structures are made "flood-proof" by law--compulsory insurance would cause the flood plain locatee to bear the burden of residual losses and not the public at large through relief and rehabilitation programs. Relief would still be necessary, however, for the recovery of community systems that could not be insured.

Insurance may evoke a mixed response to warnings. It could have a positive impact on personal evacuation in that people may be less inclined to delay evacuating in order to save and protect goods and property. If this is so, then it could also have a negative influence on implementing warning-contingent flood-proofing and other property saving emergency actions. Although this would increase the flood loss bill, it could decrease the length of the casualty list since the focus of warning-response would be upon human welfare.

4. Community Preparedness

It seems reasonable to speculate that if a sound community preparedness plan is adopted--one that provides for long-term and on-going information about flood threat, etc.--it will have a positive and beneficial influence upon all other adjustments, except relief and rehabilitation which would be negative, but also beneficial since it would reduce its need. With heightened awareness of catastrophe potential (through educational programs developed within the community preparedness plan) implementation of land use measures and insurance should be more easily affected.

5. Relief and Rehabilitation

Relief and rehabilitation displays the obverse of relationships shown for community preparedness (Figure VIII-2). The pattern assumes that relief and rehabilitation is a *post-disaster* activity and one that is well known to community leaders and individuals who occupy Boulder's flood plains. On this basis, relief and rehabilitation could encourage negative relations with other adjustments and would, therefore, be tantamount to adopting a do-nothing policy.

The relationships can be changed, however, by using relief and rehabilitation as a *pre-disaster* alternative that would encourage implementation of sound land use management and community preparedness programs.

## Selecting Strategies for Managing Boulder's Flood Plains

It is obvious from the two matrices in Figure VIII-1 and VIII-2 that once development has occurred on the flood plain, there is no simple solution for preventing and reducing flood losses. No one adjustment or even combination of adjustments can negate the flood-loss potential in Boulder by the end of this century. In the very long term, perhaps fifty or more years, a program of avoidance and abandonment could achieve negligible damage potential. That, however, is neither a realistic nor desirable objective.

It would seem, therefore, that decision-makers may need to select adjustments according to specific elements of the social system that have highest priority for flood-loss protection. Priority values would need to be allocated on some notion of acceptable risk. Thus, in Boulder, a recent social survey showed that avoiding human casualties was the most serious concern among the public. They would accept less risk when human life, rather than physical property, was the criterion (Hill, 1972). Given specification of desired objectives and a selection of means for working towards them, resources would then be channelled into the most efficient strategy for achieving them.

This approach would contrast current practice in Boulder where broad policies have been established for achieving equally broad and ill-defined objectives of flood-loss reduction which have no specified time horizon for achievement. For example, what objectives for flood-loss reduction does Boulder hope to reach with its land use regulation program, and by when? What would be the future effect, both short- and long-term of implementing land use regulations on flood-loss reduction; on other aspects of the urban system? How does this approach and objective interrelate with other flood-loss reducing measures? Can such objectives and measures be made compatible with other objectives in planning the urban system (Sheaffer, *et al.*, 1970)?

A principal determinant of an efficient program would come not so much from deriving the benefits and costs of a specific adjustment based upon the concept of annual average damages, but from a search for sets of adjustments that relate in synergistically beneficial ways to reducing specified elements of the flood-loss potential, including catastrophe potential.

Several flood plain strategies are specified and their synergistic qualities and flood-reducing capacities conceptually illustrated in Figure VIII-3. This figure is a combination of the matrices shown in Figures VIII-1 and VIII-2. The flood-loss potential of each strategy is considered from two points of view: the first, for a flood equivalent to the 1% design flood occurring around 1990; and the second, for a flood that exceeds the design flood in 1990, perhaps by the Standard Project Flood. Both viewpoints assume no flooding to occur over the planning period 1973 to 1990. The values shown in Figure VIII-3, are derived from the scenarios and are not intended to appear as precise quantitative statements, but rather as general indicators of the efficiency of each named strategy for reducing flood losses. The comparison between each strategy is based on a percentage value of the effects of the flood-loss outcomes described in the scenario, "Experiencing the Unexpectable: The One Percent Flood in Boulder in 1973."

Although they appear as the best reducers of flood-loss potential in Boulder, avoid and abandon the flood plain and flood control dam(s) have little or no prospect of being adopted due to socio-economic and environment-aesthetic constraints, respectively. At the other extreme, while it might appear best to many with vested interests on the flood plain, and in the absence of experience with severe flooding, to rely upon either subsidized insurance or post-disaster relief, such courses of action would result in extremely high flood-loss potentials and invite upon the community a catastrophe of appalling consequences.

Somewhere between these extremes may be found combinations of adjustments that go far towards reducing flood losses and catastrophe potential, but with varying degrees of efficiency and public acceptance.

Until recently, levees and related measures (5) have enjoyed prominence as an urban flood-loss reducing strategy, although increasingly communities are rejecting this strategy on environmental and aesthetic grounds, as have Boulder and Littleton in Colorado. Whether these communities also perceive the full implications and consequences of levee design exceedence is a matter of conjecture. Indubitably, most flood communities that have adopted engineering control works since the Flood Control Act of 1936 have done so because: (1) they had had recent experience of a severe flood event; (2) they were offered only engineering alternatives by flood control agencies; and (3) engineering flood control works were heavily subsidized by the Federal Government. That Boulder has long resisted such schemes is principally the result of its experience with small to moderate, rather than severe flood events and long-standing concern for its natural environment.

A COMPARISON OF STRATEGIES FOR
REDUCING FLOOD LOSSES
ON MIDDLE BOULDER CREEK

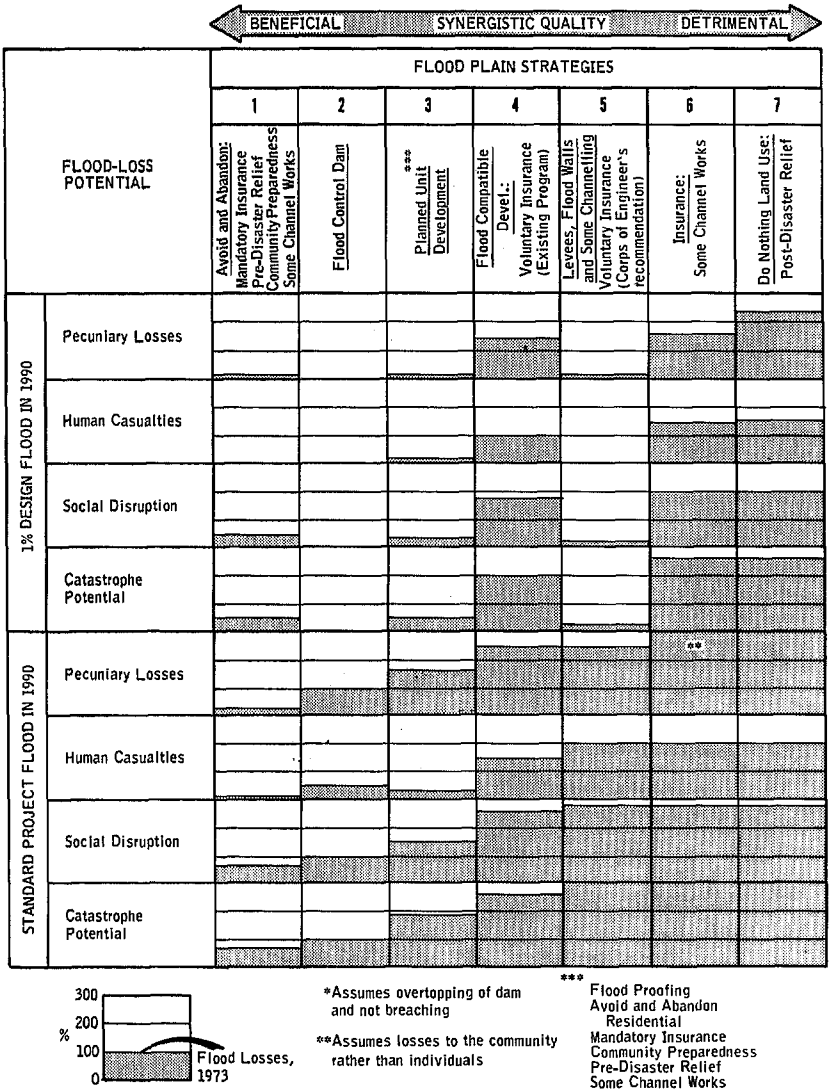


FIGURE VIII-3

From Figure VIII-3 it can be seen that a modified form of planned unit development (3), if carefully sanctioned and monitored, could lead to much greater reductions in flood-loss potentials in either the 1% or standard project flood than would the existing program of flood compatible development (4). This is so because the former selects adjustments according to specific elements of the social system that have highest priority for flood-loss reduction and does so within clearly defined objectives. For Boulder, these priorities might well include:

(1) Although stream channels should be left as near as possible in their natural state, some flood-ameliorating channel repair works would be acceptable.

(2) A certain level of property loss would be tolerated in the industrial and commercial sectors, but not loss of housing and with it loss of life and family suffering.

(3) The disruption of public services, such as public utilities (media communication, sewer, water, gas, electricity, transport) and commercial centers and hospitals, should be reduced to minimal levels.

For this set of flood-loss reducing priorities, an acceptable and synergistically beneficial combination of adjustments would include:

(1) A flood plain regulatory program in which resources are marshalled into excluding and abandoning residential development from the flood plain (as quickly as is feasible to carry out) and for flood-proofing residual development, including new commercial and industrial buildings.

(2) No building to take place within a generously defined flood-way area. Building elsewhere on the flood plain to be carefully regulated as to density, siting, and flood-proofing.

(3) A community preparedness program to reduce the chances of human casualties in severe flooding. An automatic flash flood warning device and ongoing public education programs would be essential elements of the program.

(4) Pre-disaster relief and rehabilitation measures would be sought to facilitate the adoption of measures one to three above.

(5) The adoption of insurance by owners of residual development on the flood plain would be encouraged through a mandatory program which would help internalize flood losses and reduce the community flood-loss burden in a severe flood.

(6) Adopt channel repair works on Middle Boulder Creek such as a small collapsible dam to replace the concrete obstruction at Broadway and small levee type structures or

swales incorporated into the street and park system and located so as to divert overflows back towards the channel.

Specifying a socially agreeable program and having it not only adopted, but fully implemented could be very difficult to achieve for reasons detailed at the end of Chapter IV. What are the likely impediments to the implementation of this modified planned unit development program? What are the factors necessary for effecting satisfactory change in the flood hazard system? In Rapid City, South Dakota in 1972 it was the extreme catastrophic event that precipitated change towards a strategy of planned unit development. This change was manifest not only in the attitude of the community (which had long sought flood protection works), but in the Federal agencies (which had long refused protection on benefit-cost grounds, incomprehensible though those analyses now seem to be). And, in addition to the influence of the catastrophic event on changing attitudes towards flood plain management were the enticements of liberal Federal subsidies for implementing a planned unit development program.

It would seem essential that, short of an extreme flood event, Boulder (and other flood communities) will need liberal infusions of financial assistance from outside sources in order to bring about rapid change in the evolution of its flood hazard system in accord with the principles of planned unit development outlined above. This is quite apart from the technical knowledge that is necessary for the community to recognise its potential for flood-loss and of alternative means for reducing it. Because of the technical skills required, these too will derive mostly from outside of the community. Without this outside stimulus--technical and financial--change will proceed, but in the direction of increased flood-losses at a pace commensurate with development on the flood plain under the guise of flood plain management. But for outside agencies to provide this stimulus they will need to adopt broadened attitudes and skills and to be provided with the appropriate legal instruments for doing so.

# CHAPTER IX

# RESEARCH OPPORTUNITIES AND FUTURE-ORIENTED RESEARCH

This chapter uses the scenario findings from the Boulder case-study to make judgments about the utility of the scenario method. Here, utility is treated in two ways. First, through the role that the scenario method has had in identifying research opportunities, results from which may lead to improved flood-loss management and reduction strategies, and second, through the applicability of scenarios as models for choice in flood plain management.

## Research Opportunities for Flood-Loss Reduction

The scenario findings present a range of judgments about possible future outcomes peculiar to the flood problems of a particular place. Although intentionally idiographic in nature, application of the scenario method to the Boulder flood problem suggests what appear to be some promising lines of research into flood-loss reduction for communities elsewhere. Insofar as one may feel free to assume that the results of the foregoing analyses and syntheses are bound to have implications for communities elsewhere--especially flash-flood communities--the research opportunities specified below may be viewed not only as significant for more efficient evolution of the flood hazard system of Boulder, but for other communities and higher orders of aggregation as well.

The extent to which named research opportunities have applicability beyond Boulder is based only upon general knowledge of conditions in other flood plain communities derived from extensive literature reviews and workshop meetings (White, *et al.*, 1975). Until future oriented research on urban flood plain management has been carried out in quantity elsewhere, the generalizations about research opportunities, outlined below, must be interpreted with caution.

The research opportunities identified through the application of the scenario method in Boulder are of two main kinds. First, research that could lead to the provision of information upon which more judicious decisions and actions in flood plain management would emerge, such as improved flood hazard mapping for implementation of more effective flood plain regulatory strategies. And, second, research into the consequences of existing flood policies or changes in those policies, such as existing voluntary and suggested mandatory insurance programs.

As the topical treatment of research opportunities given below shows, there is considerable overlap not only between topics, but between the two types of research opportunities given above.

1. Land Use and Flood Plain Management

The most fundamental research question to emerge from this exploratory scenario study is the dilemma arising out of the option of planned unit development. The relevant scenarios of alternative futures for Boulder strongly suggest that damage potential increases not only under the levee system, but under certain types of planned unit development. This finding, of course, is shorn of specific considerations of the social benefits of locating on the flood plain, and of the costs that would be incurred by various land use types in moving to flood-free or less flood-prone locations, but such factors apply to considerations of both levees and planned unit development.

Given these caveats, what does the above conclusion imply for research on national flood policy?

It is three decades since the strategy of broadening the range of choice to floods was first articulated in White's Human Adjustment to Floods (1942). Since then, public policy on flood problems has evolved to the point where during the late 1960's a unified approach to flood losses has been federally adopted and is finding its way into municipal decision-making. It has meant a move from technological toward social or non-structural solutions to the problem.

The cornerstone of the new non-structural social approach to flood-loss reduction lies in land use management, including flood-proofing, that is, planned unit development. Yet, there has been very little research to date which attempts to assess the municipal consequences of adopting a non-structural sociological fix to flood problems. "Consequence", in this context, refers to more than factors of economic efficiency, as might be expressed in a benefit-cost evaluation of flood-proofing in an urban community (Sheaffer, 1960). It refers to the dynamic interactions manifest in either the impact of the hazard event or in the impact of an adjustment adopted for reducing possible flood losses. (Many of these dynamic factors were discussed in earlier chapters.) While a few published post-audit studies have examined the social consequences of adopting engineering protection works in rural areas (Cook, 1965), no such studies have been carried out for land use management as an adjustment in urban areas. Studies on regulating land use management by Murphy (1958) and the Water Resources Council (1971) examine the rate of adoption and not its ensuing social consequences. A few theoretical studies of land use management based on factors of economic rent and land productivity have been made, but these have not examined the types of dynamic problems posed in this monograph (Day, 1969).

This suggests that a generous sample of the nation's flood communities should be subjected to exploratory analyses that would assess the social consequences of past applications of land use management and the possible future outcomes for alternative land use policies. This research seems essential not only from the viewpoint of expected payoffs in flood-loss reduction, but to assess whether or not a long-held *belief* in flood plain management via planned unit development has perverse consequences that could lead to an increase in community disasters and the nation's flood-loss potential. By this it is meant that one of the principal reasons for broadening the range of choice from technological to social adjustments was that flood losses, especially in terms of catastrophe potential, increase under, say, a levee system due to the dynamic effects described in Chapters VI, VII, and VIII. Yet, the scenarios employed here suggest that this same, or at least similar, effect could be a consequence of some mixes of land use and building regulation--especially planned unit development. If this is indeed the case, then it is best that a program of research be embarked upon to scrutinize carefully this aspect of the nation's unified flood plain management policy now.

2. Insurance and Flood Plain Management

In Boulder, the prospect of subsidized insurance held out by the Federal Insurance Administration appears to have played some part in the city's adoption of land use management in 1969. Adoption by individuals, however, is meagre--especially in the high damage potential commercial and industrial sectors--and is likely to continue to be so without a change in Federal policy from a voluntary to mandatory program. If it is deemed socially desirable to increase the flood insurance adoption rate, then research into reasons for why insurance is not being sold or bought would intuitively seem a useful way of anticipating needed change (Kunreuther, 1973).

Yet, the scenarios show that there are some circumstances under which research into the behavioral aspects of insurance would not be very helpful. For example, given the voluntary nature of the existing program and the individual choice processes likely to occur if owners of property are compelled to flood-proof, research on human behavior (the behavioral-fix) may be quite unproductive, if not wasteful. This is to assume, for example, that if individuals are legally required to flood-proof buildings they will most likely not voluntarily adopt insurance as well, for reasons outlined in Chapters VII and VIII. In addition, if current investigations into the implications of adopting mandatory insurance prove positive and favorable, then research into why people do not voluntarily adopt insurance would be redundant.

The scenarios of mandatory insurance in Boulder indicate a wide difference in long-term outcomes for two schemes (See Figure VII-4). Although the "add-on-charge" scheme was more than twice as effective in terms of total adopters expected by 1990, it would be less a deterrent to flood plain encroachment than a scheme whose rates were based upon risk. Since both types of programs are currently under review in Congress, their implications for flood-loss reduction in other communities and the nation should, therefore, be carefully and thoroughly researched before any policy decision is made.

3. Warnings and Flood Plain Management

The research in Boulder suggests that an effective warning system would greatly reduce human casualties and could reduce pecuniary losses substantially. Although the technology for automatic flash flood warning systems is available, the system has yet to be installed in Boulder. Research seems appropriate on the ways in which warning devices can be disseminated and adopted. Yet, in Boulder's case, it is not lack of knowledge, but funds.

A technically perfect warning system, however, will in no way guarantee that people will respond in the desired manner. First, flood warning information must be disseminated efficiently to respondents. Second, the information must be meaningful enough for people to act. And, third, we should not have to await the actoal flood event in order to test whether or not people will or will not respond to a warning in the desired manner. Rather, it would seem that research is required now that will inform us what measures will best ensure a positive response by Boulderites (and citizens in other communities) to a flood warning message. This research might prove useful if it focused less upon how people behave or respond to warnings, and more upon ways and means for having adopted, at community level, integrated action programs. These action programs would be designed to ensure a high level of response by groups within the community that have responsibility for carrying out aspects of a prearranged emergency plan. In other words, research should focus on factors relative to an integrated action system and to the efficient adoption of that system, rather than upon how individuals respond to warnings *per se*, as is now almost exclusively the case.

4. Relief and Rehabilitation and Flood Plain Management

Currently, public expenditure on this adjustment is massive and relates almost exclusively to post-disaster situations. Consequently, much research also focuses upon the wisdom of this post-disaster beneficence.

Given the recent growth in new social programs for reducing flood losses, it appears essential that there be a coordinated effort at the Federal and state levels for developing financial strategies for assisting local communities in pre-disaster relief programs that will allow more ready adoption of measures other than of the flood protection variety, or its most usual alternative--post-disaster relief. This would include programs and monies for warnings, land use management (including bridge alterations), flood-proofing, and urban storm drainage control.

For instance, legislation on Federal subsidies for flood control projects is well-defined. There appear to be no counterparts to this in the area of flood plain regulations until legislation in 1973 extended the Corps of Engineers program of subsidization to include land use management.

In this respect, two lines of research are suggested. First, research should aim at improving financial strategies at the Federal and state levels for elements of integrated flood plain management. Second, research should aim at providing guidelines to communities on financial strategies for flood-loss reduction programs. Together, this research would likely increase the rates of adoption for various lines of adjustment.

The scenarios of future alternatives for Boulder indicate that there will always be a need for post-disaster relief and rehabilitation efforts. This need is certain to apply to other urban flood plain areas. Flood insurance may lessen the reliance upon post-disaster relief and rehabilitation, but the Boulder scenarios indicate that there is a large variation in effectiveness between the voluntary and mandatory programs, and between two different types of mandatory schemes. It is similar, too, for the three different land use management policies.

Since existing post-disaster relief and rehabilitation programs have been increasingly criticized for their inadequacy, inequity, and negative impact on flood losses, it may be reasonably assumed that in this instance, the need for continued relief measures suggests that there is also a need for research into improving relief and rehabilitation programs (Dacy and Kunreuther, 1969; Kunreuther, 1973; and Mileti, 1975). Specific lines of research have been suggested by White, *et al.* (1975); Mileti (1975); and Cochrane (1975).

5. Comprehensive Flood Plain Management

The evaluation of alternative adjustments for Middle Boulder Creek by the Corps of Engineers demonstrates the perhaps understandable bias in results obtained through methods of analysis originally developed for handling engineering options.

Results of the Corps of Engineers' evaluations of alternative adjustments given in Table IV-5 reveal gaps against social alternatives that at first glance suggest the need for expansion of existing benefit-cost methods and the development of more dynamic methods for handling new options, including various combinations of adjustments. More specifically, results gained from an application of benefit-cost analyses to the named options for Boulder demonstrated the difficulty of treating either social adjustments, such as land use management, or combinations of adjustments; and specific social adjustments, such as land use regulation, were not evaulated at all. Yet, a social survey revealed some of these options to be the ones most environmentally and socially acceptable to the city council and citizens of Boulder!

In recent years, benefit-cost analysis has undergone increased sophistication of method and application. Would further refinements mean that the gaps in application, revealed in the Boulder project evaluation, will be remedied? Even if it were possible to treat social adjustments and mixes of adjustments through improved methods and applications of cost-benefit analyses, it is almost certain that the dynamic aspects of the flood problem raised in this monograph could not be adequately handled because benefit-cost analysis, in spite of its advantage of treating flood losses in an economic-efficiency manner does so in a static fashion, without analyzing either the impact of adjustments on disaster potential or upon one another.

The scenario method recognized a number of problems relevant to the dynamics of the flood hazard system:

(1) The interaction between adjustments and other elements of the flood hazard system, especially those relating to flood-loss and catastrophe potential.

(2) The interaction between various adjustments and the effects these might have on flood-loss outcomes.

(3) Exogenous factors both within and without of the urban system and their influence upon the flood hazard system.

(4) Choice factors that appear significant in creating change in the direction of the flood hazard system's evolution.

(5) The systemic influences generated by catastrophic flood events.

(6) The treatment of basic information about these dynamic factors in the current system in speculations about possible future progressions.

Undoubtedly, one could name a number of methods that could help provide insights and information into some of these problems. For example, dynamic computer simulation for evaluating feedback between adjustments, and between adjustments and the social system, or input-output analyses for assessing the systemic effects relevant to the problems of social disruption. It would still be necessary, however, to develop an operational method for application to problems "in the field." This method would need to draw upon information about the dynamics of the flood hazard system generated by, say, scenarios, dynamic computer simulation, and input-output analyses.

The point to be made from all of this is that knowledge on what is needed to handle the questions about dynamics, that have been increased in complexity by extending the solutions to flood problems from engineering to a comprehensive, integrated approach, is still in early infancy. This in itself is *the* research question: to understand more about the dynamics of adjustments to flood hazard and the means for assessing integrated programs. If a satisfying answer could somehow be arrived at through applications of research effort (the scale of research required is not obvious to the author), then questions such as those that relate to benefit-cost analyses and the development of more dynamic methods for handling new options--including combinations of adjustments--may be more directly addressed. It would seem that at the very least a range of multiple studies using multiple methods, such as scenarios and dynamic computer simulations, should be carried out in a variety of flood plain environments as quickly as is possible to arrange.

6. Information and Flood Plain Management

One of the most peculiar and perplexing conclusions to emerge from this assessment was the fact that in spite of many flood plain studies by expert agencies of the Boulder flood problem, the city has remarkably scant hydrological and hydraulic information of the sort necessary for *detailed* land use planning. It knows nothing of the stage-damage relations for property on the flood plain, little about the flow rates or routes or the effects of bridges and buildings upon the direction and levels of flow, and nothing about levels of obstructed flow, in spite of Corps of Engineers' flood hazard and project evaluation surveys in the 1970's and earlier surveys by them and the U. S. Geological Survey.

While a wide range of estimates for the 1% flood may not be so crucial for the construction of flood protection works, detailed examination of Boulder suggests that it would appear to have important consequences for planning the use of urban flood plain land.

Thus, it would seem that hydrologic and hydraulic data--as well as hydro-economic data--should be made available in detailed form for use by local communities in land use management. At present, such information is retained by the service agency--such as the Corps of Engineers--and is lost when presented in general reports on project evaluations. But worse, unless the local community accepts a project that can be supported by the service agency (i.e., engineering flood control works), no report is produced and the information is lost to even general presentation.

Does this mean, then, that the current practice of producing flood plain information maps showing river profiles and flood spreads should be regarded only as a first step in supplying cities with hydrological information? Is more accurate and extensive information essential for land use planning? Would this require research into improved methods of obtaining relevant hydro-economic data and into ways of making it available to the local community?

If these questions were limited to the Boulder experience, then the answer would be 'yes' to each one of them. In terms of improving policy on flood loss reduction nationally, however, the answers must be far more cautious.

First, there arises the problem of trading off quantity against quality of agency reports. In response to calls during the 1960's for a unified program of flood-loss management, including land use regulations, Federal agencies have been pressed into quickly producing reports for as many flood-prone communities as possible so that planning flood plain use could get under way ahead of unwise encroachment. If more information is called for, the rate of report production would probably be slowed down. Second, there are some areas of the nation where it has not been necessary to provide more detailed information on the flood hazard. For example, in the area of the Tennessee Valley Authority, the question of cities requiring more data rarely arose. When it was required, (in two cases), the data was made available by the TVA. Mostly, TVA officials worked with local communities in using collected data for a range of flood-loss solutions, including the non-structural approach. Third, the experience of communities under the Corps of Engineers across the nation varies from that described for the TVA to that of Boulder. But, generally, the Federal agencies can be and have been criticized for not enlarging on collected data and showing communities how to use it for land use management purposes.

In the context of this discussion, the three questions posed above become themselves the research questions. And, affirmative answers to all three questions would then indicate that research into improved methods of obtaining hydro-economic data, and ways of disseminating it would be helpful in reducing flood losses.

For the past decade, results from geographical research on individual perceptions and attitudes of flood hazard show that in the absence of recent severe and/or frequent damaging floods, people have a poor understanding both of the nature of the event and the risks they are exposed to. This appears to be so in Boulder, for while the potential for catastrophic flood is high, it is eighty years since a very large discharge occurred. Thus, before trying to convince people that they should act on a given warning, go out and buy flood insurance, or flood-proof their buildings, they need to be "properly" informed and educated about their flood hazard problem. The same applies at the community decision-making level. For communities to adopt sound land use plans, protection works, and warning schemes, they need information upon which they can act. In addition, the acceptable levels of risk for the community and individuals under different types of flood-loss reducing programs need to be defined. Yet, the terms used to describe flood-risk: "the 100-year flood"; "Intermediate Regional Flood"; or "Standard Project Flood," scarcely convey the probabilistic notions that they infer. Thus, the 100-year flood is commonly viewed as one that occurs only once in 100 years, instead of one that has a 1% chance of occurring in any one year, irrespective of the recency of the 100-year flood event.

How can these various programs of information transfer best be carried out? This emerges as a fundamental area of research--one which should proceed with, if not precede, the establishment of flood policy on warnings, land use management, and insurance and their various combinations. This may serve to better delimit the nature of risk for decision-makers and to allow them to be more able to establish acceptable levels of risk for various flood plain management policies, and strategies for handling them.

These problems lead directly to consideration of the scenario method as a means for communicating information about flood-loss management to community decision-makers and the public.

## Scenarios as Models for Choice in Flood Plain Management

Having completed the application of the scenario method to one flood hazard area, questions regarding the usefulness of the approach are raised. In the absence of a complete before-after test of the scenario application, little can be said except to review the expected advantages of its use held out at the end of Chapter II. This review can now be made from a background of an application which enabled a detailed review to be made of past and present flood plain management conditions and possible future options.

The applicability of scenarios as models for choice in flood plain management is discussed first in terms of their value as a means for communicating information about flood hazard and management strategies to decision-makers within flood-prone communities, and then in terms of the prospects for having the scenario method adopted by user agencies who have responsibility for evaluating choice of adjustments to floods. Obviously, these aspects are two parts of a circular process.

### 1. Scenarios and Community Decision-Makers

The Boulder experience, both past and current, suggests that decision-makers do not possess appropriate models for making decisions about flood plain management. If the infrequent event is poorly perceived, so too will be the impact, and consequently, the range and mix of adjustments for adoption and their long-term outcomes for flood plain occupance.

One of the principal functions of the scenario method is to create images for planning purposes: images that help portray the consequences of specific actions or the resultant conditions of inaction. That is, the scenario becomes a substitute for experience so that much should be learnt from the application.

The analysis carried out at the end of Chapter IV suggests that the cross-sectional image was favorably received by a range of Boulder's decision-makers. Whether they have similar attitudes towards the scenario progressions has not been tested. Even if favorable, such measures of attitudes may bear little relationship to their subsequent choices for future action.

In review of this first step in the development of the scenario method for assessing flood hazard, perhaps much could be said for refinement that would lead towards more simple and concise packages of information wherein the essence of each scenario progression and cross-section would be presented with a minimum of written material and where maximum use would be made of illustrations and sketches.

It is these refined versions of scenarios that would have most impact in providing the public with insights into the flood hazard management problem, and which might encourage more fruitful participation in the decision-process by them. And, it is in this way that the scenario method may be used to benefit by outside agencies responsible for presenting management options to community decision-makers and their public.

2. Scenarios and the Evaluating Agencies

It is apparent that the scenario is not methodologically rigorous. Further experimentation could, however, lead to its development into a manual-type outline for use by agencies such as the Corps of Engineers.

It is envisaged that the advantages of the scenario's application by user agencies would be at least twofold. First, the agency itself would be forced to consider a broad range and mix of adjustments to flood hazard in terms that would provide a preliminary assessment of the effect of each adjustment, or mix or adjustments, upon flood-loss potentials and the effect of adjustments upon each other. By treating the flood-loss reducing capacities of adjustments in terms of catastrophe potential, the traditional focus upon annual average damages used in benefit-cost analyses would be broadened. The advantage of this broadened perspective is that catastrophe potential appears to provide a more meaningful measure not only for long-term outcomes (a principal purpose for scenario analyses), but for local decision-makers, whether or not their perspective is essentially short-term.

This leads to the second advantage that might be gained from the use of scenarios by user agencies. They may prove useful as a tool for communicating information about flood hazard and choice of adjustment to floods to the decision-makers and populace of local communities. As such, the method does not set out to "sell" any one choice, such as levees, rather, it examines a range of possible outcomes, good and bad, that stem from certain types of decisions.

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