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A PLAN FOR RESEARCH ON
FLOODS AND THEIR MITIGATION IN THE UNITED STATES

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Overview

This report presents a carefully developed research agenda for floods and their mitigation. It was funded by the National Science Foundation and developed over an 18-month period through the use of national expertise in various disciplines.

Any study calling for a broad national research agenda about a major issue must firmly rest its case on a realistic assessment of the problem. It must also present its research recommendations in light of the world of today, the current and likely future governmental policies and trends in society relating to the issue under consideration, in this case flooding.

Excellent in-depth assessments of the nation's flood problems are available (White, 1975; National Science Foundation, 1980; National Research Council, 1981). They describe the problems more comprehensively than is needed here. Consideration of the flooding problem in the United States brings forth three salient points:

- Flooding is the major natural hazard of the nation, bringing greater property damage than any other hazard and loss of life in the hundreds.
- Flood losses continue to grow.
- Our approaches for controlling and mitigating flooding have not fully succeeded.

This chapter briefly reviews the flood problem in the United States and the policy issues affecting the problem. It then describes flood-producing conditions and the several measures used to mitigate floods. It concludes with the background and design of the flood research study and the dimensions of this final report.

The Flood Problem

How serious is the flooding problem in the United States? From a national economic viewpoint, floods, both riverine and coastal, are the most destructive category of natural hazards in the United States. The economic losses to homes

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and personal property, to crops, business facilities and stock, utilities, and transportation are major manifestations of flood losses. Of possibly greater magnitude are the losses incurred by entities that never get wet but are forced to close because their suppliers or supply routes are damaged.

Regarding loss of life, flood hazards are roughly comparable to those of tornadoes, each averaging more than 100 lives per year during 1925-1972. It is philosophically impossible to set a monetary value on human life. However, if lives are assessed by the one-time federal standard of. anticipated future earning power of individuals, at average rates of income, then the losses of property during floods, and the related indirect and intangible associated damages, far outweigh the monetary value of the lives lost. Less readily quantified, but clearly important, are the public health effects of floods when they inundate water facilities, chemical waste storage sites, and sewage treatment plants.

Although floods on large rivers attract most attention, the oft-ignored floods in upstream areas are also important. Flood damages in upstream areas were estimated at $1.7 billion in 1975, nearly 40% of the estimated total flood cost of $3.8 billion in 1975 (White, 1975). Over the next few decades, subject to several assumptions as to flood plain use, increases are anticipated in urban and miscellaneous property damages, with crop damage levels remaining about the same (NSF, 1980).

Average annual national flood damages have been increasing during this century at 4% annually in real dollars. There is some indication that this rate has even accelerated during the last decade to 6 to 7%. A 1980 survey by the Water Resources Council (WRC, 1980) estimated that, if certain conditions prevail, expected damages in the year 2000 might exceed $4.3 billion (in 1975 dollars). Damage losses in urban and urbanizing areas will increase the most.

The $4.3 billion figure would be reached presumably in spite of some improved management of our flood plains. Without such improvements, the damages could approach $6.0 million (NSF, 1980).

Although the annual loss of life is likely to continue to average in the low hundreds, it must be remembered that 238 lives were lost in just 2 hours at Rapid City, South Dakota, in June 1972, and that 6,000 lives were lost in the tidal surges caused by the 1900 Galveston hurricane. There is great concern that thousands more will be lost if a great future storm brings tidal surges to the heavily populated coastal and barrier island areas that have grown rapidly in recent years. For example, it is projected that a high tide hurricane surge- in the New York City harbor could isolate and have serious impact on 1.3 million persons in that city alone.

Flooding may produce some benefits, such as the deposition of nutrients on agricultural lands in the flood plain and the replenishment of groundwater. A flood plain location may have large benefits not only for agriculture but also for manufacturing and transportation activities. A flood plain may also be the most scenic location for residential developments. Nevertheless, the preponderance of potential damage makes flooding the nation's worst natural hazard.

Of greatest importance in assessing the flood problem is the fact that despite the nation's investment in flood hazard mitigation and control, including structural and nonstructural measures, the trend in flood damages continues to increase, particularly in urban and developed coastal areas.

Current Flood Problems. The most striking change occurring in the flood regimen during recent years is the alteration of the flood hydrograph in urban areas, as a result of upstream land use and an increase in heavy rainfalls over urban areas due to urban influences. Less widespread but probably significant is the reduction in channel carrying capacity as a consequence of filling and the diminution in peaks by storage works. The possible relocation of the mouth of the Mississippi River is but one example of this problem. Of less certainty but a factor of growing concern to the flooding problem is the evidence of possible long-term climatic change. Ongoing shifts to colder, snowier winters in the eastern half of the United States are producing greater numbers and longer duration winter-spring floods. An increase during the past decade in heavy rainfall events in summer is increasing the frequency of flash floods in the Midwest (Changnon, 1982).

Another key problem relating to floods is the fact that the data on flood losses are incomplete, lacking in desirable specificity, and inconsistent between urban and rural areas. Therefore the aggregated estimates of flood loss for the nation are at best guesses. There are virtually no systematic data as to flood plain use and production, another key data requisite.

Average annual loss of life from floods is accounted largely by a few flash floods. Yet very few data are available on the frequency and dimensions of flash floods (Landsberg, Chapter 2 of this report; Vogel and Changnon, 1981).

Many of today's flood problems are reflected in trends and activities of federal, state, and local flood-related programs. Federal programs for construction of reservoirs having flood control features at federal expense are growing only slightly. The amount of federal expenditures for operation and maintenance of flood control works is rising steadily, but federal programs for construction of local protection works, with required financial participation by local agencies, are advancing very slowly. Federal programs for watershed protection and soil conservation are shifting emphasis away from construction of engineering works. Disaster grants and loans amounted to nearly $8 billion for the period 1972-1981, provided in the form of public assistance, individual assistance, and Small Business Administration and Farmers Home Administration loans, plus additional costs for indirect assistance.

The The National Flood Insurance Program was enacted in 1968 and revised in 1973 to require more stringent conditions for participating communities. As of September 1982, approximately 8300 communities were in the Regular (full participation and compliance) flood insurance program, and 8800 were still in Emergency status (compliance in progress). All within the Regular program had some form of land planning and zoning, but its effectiveness is not known for numerous areas. One important base for local planning, the national flood plain mapping effort, is slowing down drastically. Vigorous efforts are being made to place the National Flood Insurance Program on a self-sustaining basis by readjustment in the premium schedule. Currently 1.8 million policies are in force with a coverage of $103 billion. Annual premium income in 1982 was $277,142,216, and claims (28,849 paid losses) amounted to $155,405,839. Based on data for January 1978 through 1982, flood insurance claims were concentrated in 4 states. Texas had 29% of the total, Louisiana 18%, New York 6%, and Alabama 6%, together amounting to 59% of the nation's total.

At the state level, the most lively and widespread nationwide activity with respect to floods is the provision of technical assistance. At least 47 state flood plain management agencies are assisting local municipalities and counties. Certain federal agencies such as the Federal Emergency Management Agency (FEMA) are providing technical assistance directly or through support of state agencies. Other support is available through reprogramming of community development and housing support funds where disasters occur.

Local action programs are a third part of the governmental functions attempting to address the flood problem. Several hundred communities have undertaken innovative schemes for managing their flood plains, including land management, land acquisition, floodproofing, and warnings. This has been done without primary dependence on federal funding (Kusler, 1982).

It has been estimated that the approximately 17,000 urban communities reported to have flood problems can be classed into six levels of problems (White, 1979).

Urban Problems	Approximate Number of Urban Communities with Stated Problem
Chronic sufferers	100 - 200
Undergoing post-disaster readjustment	30 - 100
Anticipating disaster	100 - 200
Flood problems corollary to other problems	1000 - 2000
Flood problems chiefly in fringe areas	8000 - 12,000
Protected by engineering works	900 - 1000

Recent population trends indicate that development is increasing in those areas of the country that have the most severe flood problems. Almost half of the nation's flood insurance exposure is in 4 metropolitan coastal areas, including the Miami, Tampa, New Orleans, and Houston areas. These are also areas where significant population growth is occurring. These population shifts alone present major local problems to these areas and represent significant increases in the population at risk from floods.

In the most sizable urban communities, the management of storm water drainage is seen increasingly as requiring an integrated application of both structures and nonstructural measures. This trend is encouraged by a recognition of the problem related to the exceptionally high cost of conventional storm drainage. More attention is being given to the use of urban flood plains for groundwater recharge and to the protection of groundwater quality. Communities are beginning to address the problems by employing flood plains as a part of unified efforts to store groundwater, as well as to maintain critical flows for aquatic ecosystems.

Many of the more critical problems and related decisions with respect to the use of flood plains are being made in rural areas, in communities under the emergency insurance program, or on urban peripheries where rapid conversions to urbanization are projected or under way.

This description of some of today's problems, as reflected in the physical aspects of flooding, in the flood data base, and the activities of governmental entities, has been provided to illustrate the complexities and the magnitude of flood problems in the United States.

<u>Translation of Problems to a Research Agenda</u>. Any thoughtful review of the magnitude and complexity of flood problems leads to the conclusion that future research, to be useful, must often be interdisciplinary in nature. Many of the problems crosscut several disciplines and can only be successfully addressed by a mix of scientists and engineers from various fields of study. Hence this research assessment has focused on interdisciplinary research, as well as on traditional disciplinary research.

It must be remembered that floods are natural phenomena but their impact is often aggravated, if not actually caused, by man's activities and occupation of flood plains. Such problems have been enhanced by urbanization.

The age-old hope for relief from flood problems by <u>flood control</u> has given way to a realization that a more realistic national goal is <u>flood hazard mitigation</u>. Thus, this research assessment chose to address the question of how to view and define flood hazard mitigation.

<u>What is Flood Hazard Mitigation?</u>

In addressing the research needs relating to floods and flood hazard mitigation, it was essential to establish a clear definition of flood hazard mitigation. Is flood hazard mitigation the

- reduction of flood losses, or the
- enhancement of the total productivity of the flood plain wherein losses are only part of the equation?

In answering these questions, we deemed it important to recognize that flood plains are used for a variety of purposes, and that every flood plain use involves a probable gain and a probable loss. Without this orientation, discussions and views of damage reduction are incomplete.

Let us examine the issue more fully. Disciplinary views of flood hazards and related research have typically referred, in some fashion or other, to the problem of mitigating flood losses. Some have touched on the aims of enhancing the economic productivity of flood plains, or of preserving the productivity of the flood plain ecosystems. In most instances, past views have implied but not directly asserted that the principal goal is to minimize the average annual national damages.

Such a formulation of the basic problem ignores much that has been learned about the process by which people come to grips with the hazard of flood peaks in rivers, and it obscures the aim that "benefits. . .shall exceed the costs" explicitly stated in the first federal flood control legislation (the lower Mississippi and Sacramento Valleys in 1917), in the Flood Control Act of 1936, in Executive Order No. 11296 in 1966, and in various other efforts to express national policy.

The uses that people make of flood plains and flood—prone areas always involve a resource use coupled with the hazards of an unpredictable time and magnitude of overflow. People rarely decide to curb or avert flood losses in terms primarily of the social costs. They make the choice in the context of what the resource of land, water, vegetation, and site will yield, taking in account not only floods, but all other factors affecting their likely expenses and income. In some instances, it may be a carefully calculated choice, as in an industrial location where flood losses are expected, whereas in other instances it may be a rough judgment, as for example that a system of reservoirs, with all the benefits to the construction industry, is warranted to prevent the loss of 300 lives in 1% of the years. The reality of the net gain approach to flood plains often is reflected in the decision made by a municipality with regard to land use.

The broader definition of flood plain enhancement has been forgotten or neglected in more instances than not. Economists have worked out benefit-cost analyses in terms of losses averted rather than in productivity gained. Engineers looked at the effects of structures to reduce flood flows and therefore flood losses rather than at alternative measures to enhance the economic output and the environmental quality of the lands flooded. Hydrologists calculated the damages prevented in a factory by an accurate flood forecast, rather than the possible ways forecasting could increase the output at that site.

Partial explanations for the development of the bias, or narrow view, are not hard to come by, but a fully satisfactory one is still lacking. There may be small comfort in noting that several other industrial countries have experienced similar although not identical trends. It is easier to compute losses than production gains. The broader definition usually requires interdisciplinary analysis which scientists find troublesome to organize. Professionals tend to emphasize the one or two techniques they feel most confident in applying. Administrators often avoid choices among complex options. Politicians are attracted by war against disaster and prefer an unambiguous solution whose execution minimizes sequences of social interactions: a concrete dam can be constructed under one contract and is operated by one technical office, whereas a plan for flood plain use for commerce and/or wildlife propagation is a never-ending exercise in group and agency accommodation.

The point here is that as long as the national flood problem is defined as primarily flood loss reduction, and not as maximization of the net gain from the flood plain, the policy will favor one set of remedial actions and indeed will encourage -- and use -- research along those lines in preference to the others. Research in the broader context fights that preference, but unless it does so, it will help perpetuate the prevailing policies and their outcomes.

In this research assessment, we have adopted the broader view and where possible we have addressed research needs as they relate to the enhancement of the total productivity of the flood-prone lands. This orientation helped set priorities for the research recommended, as well as in indentifying the research needs.

The Real World - Policy Issues

In addition to placing the research assessment within the context of a broader definition of flood hazard mitigation, it was a goal of this effort to assess the research needs within the context of the real world, of today and tomorrow. Two of the major complaints about research, not only that about flooding but in many other areas, have been that the findings often do not relate to the issues and the users, and that the transfers of information and technology are far from optimum. The recent study of flood hazard mitigation (NSF, 1980) revealed two major findings: 1) the primary responsibility for flood hazard mitigation efforts should be at the local government level, and 2) the social aspects of floods deserve a great deal more attention.

Thus, we sought to make this research assessment and ensuing recommendations relevant. We attempted where possible to identify research and to set priorities with a view to interrelating likely research products with state and national policies, and with a view to recognizing the major need to transfer findings at the local level.

To this end, we considered in our selection of research needs, six relationships between flood research and other programs or policies. These were:

- The trends in fiscal federalism of the last five years with a shift of emphasis to state and local responsibilities.
- The evolution of the National Flood Insurance Program as the dominant element of current and future national flood plain activities.
- The totality of water resource management policy, recognizing flooding fits often within multipurpose water projects and must be considered within the context of water quality regulations.
- The trend toward multi-hazard mitigation activity of federal and state emergency management and services agencies.
- The holistic concept of flood plain management developed by the federal government since 1966 and accelerated since 1979, which views flood

plain management as a decision process with the goal of wise use of flood plains for any purpose(s), with the constraint on usage being the satisfactory accommodation of the existing flood hazard.

Issues of an administrative and fiscal nature that constantly arise: allocating responsibility for action; setting what criteria to determine the exercise of responsibility; and deciding who pays the costs for actions.

Review of these relationships and rapidly evolving technologies reveals that this research assessment of flooding has been done at a time of major changes. In essence, we faced a "moving target" in three key areas:

1) Federal, state, and local policies are undergoing a major shift to local-state responsibilities and funding.
2) Means to address flood mitigation are shifting from an exclusively structural approach to mixed nonstructural approaches.
3) Efforts to transfer research results and information to the users are multiplying.

Reacting to the Problem and Issues: Developing a Research Agenda

The recent assessment of flood hazard mitigation (NSF, 1980), in response to a Congressional directive, was a reflection of a growing concern about the effectiveness of existing approaches to flood hazard mitigation. Although distinctive, that report was not the only recent or ongoing contribution to the subject, nor did it elaborate on the research needs. Among many efforts is the recent report "Issues and Options in Flood Hazards Management" by the Office of Technology Assessment of the Congress of the United States. The Water Resources Council published the report "A Unified National Program for Floodplain Management" in 1979 (WRC, 1979) and within the past two years has issued other reports dealing with various aspects of the flooding problem. However, none of these recent assessments delved in any depth into the research needs relating to flood hazard mitigation. The current assessment of research needs is an outgrowth of this great national concern over floods.

This assessment focuses on research dealing with flood hazard mitigation across all disciplines. It has been written by a group of national research specialists, none of whom is affiliated officially with any agency directly responsible for administering federal or state policies. It presents the physical, societal and interdisciplinary research needs relating to flooding and flood hazard mitigation. Much attention is devoted to the research in the various behavioral and social areas. It concludes with recommendations for key research, both of an interdisciplinary nature and that specific to the physical sciences, the legal area, the economic area, for public health, in sociology and in political science.

The message is clear: innovative approaches emanating from increased research attention to flood problems nationwide are required if the United States is to arrest, much less reverse, flood losses and the social and economic burdens they place on people and the nation's tax-supported flood-relief institutions. Without a coherent national research program supported and conducted at the federal, state, and university levels, such losses will increase steadily.

Flood-Producing Conditions

Floods are characterized by great variability, both in time and space. Within a given climatic region, tremendous variations of flooding occur due to different effects of cyclonic storms, severe thunderstorms, hurricanes, snow-melt, and other weather-related conditions. It should be recognized there are sizable differences across the United States in the types of floods. For example, the Gulf Coast and East Coast are concerned about hurricane-related floods of summer and fall; the Pacific Northwest has floods related to winter rains and snowmelt; the semiarid portions of the United States are subject to violent flash floods typical in summer; and in other parts of the humid eastern United States, floods are related to snowmelt or severe rainstorms. This research assessment of flood mitigation was done by considering two broad categories of floods.

One major type of flooding is identified as riverine, or flooding along streams. This major category of flooding occurs in all parts of the United States and has two versions. The first is that which occurs over sizable areas and along major rivers. These floods are caused by a variety of factors including major cyclonic storms, excessive and rapid snowmelt in spring, ice jams, or breakage of man-made dams or levees. The other type of riverine flooding occurs in upstream areas and poorly drained flat lands. These are due to intense rainstorms. Their effects are intensified when they occur over an urban area where impervious surfaces produce rapid runoff or channel capacity is reduced. Urban areas also enhance precipitation, particularly in heavier rainfall rates, bringing additional flooding to urban and suburban areas, as well as rural areas beyond the city.

The other major type of flooding under consideration in this research assessment is that which occurs in coastal areas. Coastal flooding, which includes that along our major Great Lakes, can result from several factors. One important factor in coastal flooding is storm surge. A storm surge is the result of a hurricane or other major extratropical storms that occur at sea. Other causes of coastal flooding are tsunamis or so-called tidal waves. These are long waves, lasting 10 to 20 minutes, which are set in motion either by undersea earthquakes or landslides. Another factor causing coastal flooding is the coincidence of the normal high tide with storm surges. The degree of flooding in coastal areas is also influenced by other factors. Included are land subsidence in coastal areas, erosion of barriers, and the simultaneous occurrence of river floods at a time of a storm surge or tsunami. Seiches, which are waves trapped in a basin, occur in large lakes. These also can produce coastal flooding. Damages from coastal flooding, as with riverine flooding, can be aggravated by the presence of major urban areas.

The subject of land use is one of the most difficult with which to deal in flood mitigation. With respect to the atmosphere, it has been demonstrated by studies at St. Louis and Chicago, that our larger cities increase the severity and frequency of heavy convective rainstorms. With respect to hydrology, changes in rural land use from forest and grass to row crops may have a marked effect in increasing the rates and amounts of flood runoff. Urbanization, which decreases infiltration and hastens runoff, changes flooding patterns so that both the height of and the area covered by floods of a given frequency increase locally and downstream. Encroachment on valley storage by levees, fillings for buildings, construction of navigation facilities, and other structures can alter the height and duration of floods. Such alterations in a basin's hydrologic regimen can increase the risk of damage to structures that originally were designed and located to minimize flood damage. As noted above, the land subsidence resulting from a number of man-made causes is a special case along our coasts where the effects of floods can worsen when land settles.

Another aspect of land use relates to the use of flood-prone lands to avoid unwise development, or for the protection of natural and environmental value. As a nation, we have been slow to adopt land use restrictions in view of property rights. Although basin-wide restrictions are seldom invoked, there is increasing acceptance of land use controls as a part of land management in flood plains. Zoning is one of the primary tools for management of land use and flood plains, based upon reasonable police powers of the states. Alternatives include public acquisition of lands, easements, development rights, or purchase and leasing back.

Measures Used to Mitigate Floods

A variety of well-established measures are used to mitigate floods. These are the means by which action is taken, and they may be employed singly or in any number of combinations.

The usual practice of classifying these measures into either structural or nonstructural is adopted here, and the various individual measures are briefly described.

Although important as operational approaches to flood mitigation, they are not ideal as a framework for developing a comprehensive plan of research. Thus, the body of this report on research has been organized according to the physical, social, and interdisciplinary fields which cut across the operational measures and represent the scientific disciplines producing findings that ultimately improve the operational measures.

Structural Approaches

Storage Reservoirs - Reservoirs to store excess runoff during flood periods are typically created by the construction of a dam with controllable outlets. Such facilities may be multi-purpose and also provide for water supply, hydropower, recreation, navigation, and other activities.

Detention Basins - These are impoundments with uncontrolled outlets which retard flood water to achieve a reduction in flood peaks immediately downstream. They may have other benefits in improving infiltration, trapping sediment, and improving water quality, and they may include conservation pools for recreation.

Levees and Flood Walls - These are structures constructed in the flood plain and parallel to the river or along coastal beaches to prevent the flood or storm surge from extending farther in a landward direction.

Channel Modifications - Stream channels may be modified by deepening, widening, straightening, or by the removal of obstructions to increase the channel capacity to carry higher flows.

Land Treatment - This includes such measures as improving vegetative cover, contouring, and terracing which increase infiltration and delay or reduce surface runoff.

Emergency Flood Fighting - Emergency measures include use of flashboards or sandbags as a means of increasing the height of existing levees or for the temporary protection of low places along streams and coastal areas.

Floodproofing - This refers to a series of structural steps which can be taken or may be required in building codes for new or existing structures. It is accomplished by elevating, constructing temporary barriers, choosing water proof construction materials, and rearranging or protecting damageable property within a building. It may be combined with evacuation measures and land-use regulation.

Stormwater Management - Through the proper use of meteorologic, hydrologic, and hydraulic data, systems for collection and conveyance of stormwater are provided including drains, storm sewers, and channels.

Nonstructural Approaches

Flood Forecasting - Through application of meteorologic and hydrologic data in models it is possible to predict some stream flows and coastal storm surges. When linked to an effective communication and response system, advance actions can be taken to reduce loss of life and property damage.

Flood Plain Regulation - The location of damageable property in flood plains can be discouraged or prevented by controlling the location of facilities such as public buildings, roads, water supply, and sewers. Zoning and subdivision ordinances can be employed to regulate new or existing facilities by, for example, preventing construction within the floodway and controlling the nature of any building or activity in the flood fringe, or by enhancing recreational and wildlife uses.

The success of flood plain regulation depends upon availability of flooding maps and the action of local government. The courts have generally upheld reasonable regulatory action taken to protect health, safety, and property, and to curb unwarranted demands for public subsidy.

Coastal Zone Management - Thousands of miles of coastline are subject to damage from storm surges and heavy winds. Similar to the steps employed in riverine locations, development can be discouraged or prevented by zoning or other regulation. In the coastal circumstance not only loss of life, property and structural damage are at risk, but frequently wetland values to wildlife are involved.

Evacuation - The evacuation of potential flood victims and vulnerable property when accompanied by advance planning, warning and response, and subsequent sheltering is an important means of reducing loss of life. Evacuation -- horizontal or vertical — is particularly important with respect to coastal flooding, and at times of expected hurricanes may involve hundreds of thousands of persons.

Relocation - When a flood subsides there may be a strong desire on the part of individuals and agencies to return to the places of normal activities; a number of governmental and private relief programs tend to encourage this. Others may wish to move out of the vulnerable zone but may lack the funds to do so. However, this is the most opportune time to consider relocation to higher ground, and thus avoid a repetition of flood losses. There are a few examples of support given to individuals, neighborhoods, and even entire communities to relocate away from flood-prone sites.

Flood Insurance - Since passage of the National Flood Insurance Act of 1968, this program is the most dynamic phase of current flood mitigation efforts. The program spreads losses over a wide base of policyholders and the general public, and is intended to reduce total future losses through combination with required local flood plain regulations. The Act was strengthened in 1973 by requiring flood insurance participation and regulations before a community can receive federal assistance for acquisition, construction, loans, or flood relief.

Land Acquisition - Development rights or outright land purchase are selective means for public agencies to guide land use in areas subject to flood. At the same time such lands can be dedicated to nondamaging uses such as parks and wildlife protection.

Current Status of Flood Research

Recognizing that the bulk of U.S. research on floods and their mitigation is performed or sponsored by the federal government, an attempt was made to ascertain the type and amount of ongoing federal research related to floods, primarily by direct inquiry to the federal agencies known to conduct or fund research in related areas. It was beyond our resources to attempt to search out the more localized flood research plus modeling and other statistical innovation that undoubtedly exists in certain universities and various state agencies.

Responses were received from U.S. Department of Agriculture/Soil Conservation Service; U.S. Army Corps of Engineers' Research Laboratories (Fort Belvoir VA, Davis CA, and Vicksburg MS); FEMA/Natural Hazards Division; U.S. Department of Health and Human Services/PHS, Centers for Disease Control; U.S. Department of Interior/Bureau of Reclamation; U.S. Geological Survey; NOAA/National Weather Service; U.S. Department of Transportation/Hydraulics Branch; and Tennessee Valley Authority. These responses indicated that the largest amount of flood-related research at this time exists in the research laboratories of the Corps of Engineers, which had 17 research efforts directly related to floods. In many cases it was difficult to discern whether some water resources research projects may have related indirectly to floods. NSF provides substantial support for research related to floods.

The responses also showed that the preponderence of current research was in one disciplinary area — hydrology and hydraulics (44 of 58 projects). The breakdown by topical areas was: Meteorology, 5; Hydrology and Hydraulics, 44; Public Health, 3; Economics, 1; Sociology, 1; Political Science, 2; Law, 1; and Interdisciplinary, 1.

In addition, we looked at recent research supported by the Office of Water Research and Technology at the state Water Resources Centers. Of the 590 water resources research projects listed in the 1979-1980 summary (OWRT, 1980), 11 related directly to flooding. Seven of these were in Hydrology and Hydraulics, one in Economics, and three in Sociology. Reduced funding has since curtailed the support of such research which is now managed by the Bureau of Reclamation.

Background of Research Assessment Study

The National Academy of Sciences released in 1981 a report "Federal Water Resources Research: A Review of the Proposed Five-Year Program Plan." This serves as a useful background for the current study because of its recency and the stature of the Academy and its authoring committee.

The Academy report had its genesis in the Water Research and Development Act of 1978 which directs the Secretary of the Interior to develop a five-year water resources research program in cooperation with federal agencies and other bodies. The federal draft report "U.S. National Water Resources Research, Development, Demonstration, and Technology Transfer Program 1982-1987" was the subject of the Academy review study.

As a basis for its judgment of the federal report, the Academy Committee developed criteria by which to determine the research areas of highest priority. The criteria were based upon 1) the importance or severity of a water problem, 2) the probability that research will lead to its solution, and 3) the cost of the proposed research in relation to possible benefits.

The Academy report identified 31 critical research areas where, in its judgment, emphasis should be placed in programming water resources research over the next five years. These research areas cover atmospheric, hydrologic, hydraulic, ecological, environmental, water quality, management, and institutional areas. From the 31 topics, a list of seven priority areas can be considered relevant to flood hazard mitigation, and these appear in the Appendix.

The most direct antecedent to the present project is a study entitled "A Report on Flood Hazard Mitigation" noted above (NSF, 1980). The Congress requested that the study "undertake an evaluation of the problems and needs . . . deficiencies in flood recovery policy, the practical application of science and technology . . . and such other flood related matters as the Foundation deems appropriate."

The resulting report was quite broad, with major topics on Nature and Causes of Flooding, Flood Damages, Approaches to Flood Mitigation, Institutions, Behavioral Responses, Public Policies, and a list of 34 Conclusions with related Recommendations. The recommendations covered all aspects of flood mitigation, and a list of 27 research topics has been abstracted and appears in the Appendix. This led to the decision to prepare a comprehensive plan of research on floods and their mitigation, which is the subject of the current study and report.

The Design and Execution of the Flood Research Assessment Study

The foregoing text has established that:

1) Floods are the most serious of the national hazards and affect all parts of the United States;
2) After major expenditures involving numerous approaches, the flood problem remains and flood losses continue to grow;
3) Currently, flood-related research is heavily concentrated on physical approaches to management of water, and
4) Recent broad assessments of water research and flood mitigation have set the basis for an in-depth research assessment of floods and means to mitigate them.

A plan for such an assessment was developed by the Illinois State Water Survey and proposed to the National Science Foundation in 1981. It was funded and launched in the fall of 1981.

The Illinois State Water Survey conceived this effort, in concert with Chief Emeritus William C. Ackermann, because the Survey has a long history of flood-related research including the meteorological, hydrologic, economic, and policy aspects of floods (Changnon, 1980; Changnon et al., 1977; Huff and Vogel, 1976; Knapp and Terstriep, 1981; Lardner et al., 1971; and Singh and Adams, 1980). The Illinois State Water Survey is a unique state agency with an 86-year history and a broad charge to make "studies of the atmospheric and water resources of Illinois." As such, we have a diverse staff including chemists, hydrologists, meteorologists, economists, lawyers, and engineers. We work closely with many other university scientists and have a long history of involvement in interdisciplinary research.

The objectives of the assessment were twofold. One was to provide guidance to scientists and engineers as to more meaningful flood research topics, and the second was to inform federal and state agencies of the research needed to most wisely address and help solve the flood problems. The project set out to first assess the research needs for floods and their mitigation, and then use this evaluation to prepare a comprehensive plan that is basically national in scope.

The work was designed to bring the maximum amount of scientific and engineering expertise to the issue. A disciplinary-oriented approach was deemed necessary to address the research of scientists and engineers along traditional research routes. Simultaneously, we sought to present interdisciplinary research, as identified through the disciplines and through a broad interdisciplinary overview.

To serve these needs, and from among many possible disciplines, nine topical areas involving both physical and social sciences were selected. The scope of these is sufficiently broad to encompass relevant issues in several other disciplines including pyschology and geography. The nine topics have become chapters in this report. The topics and their authors are as follows:

1) Hydrology and Hydraulics - Ray K. Linsley
2) Meteorology and Climatology - Helmut E. Landsberg
3) Environmental Sciences - G. Richard Marzolf
4) Health and Sanitation - Flora Mae Wellings
5) Economics - Jerome W. Milliman
6) Sociology - Thomas J. Drabek
7) Political Science - Henry P. Caulfield, Jr.
8) Law - William A. Thomas
9) Interdisciplinary - Gilbert F. White

Each of the authors of these chapters was requested to identify research needs under the following considerations: 1) theoretical studies, 2) case studies, 3) field data and related research, 4) modeling, 5) interdisciplinary research, and 6) for the societal chapters, research about incentives and decision making.

Given this format, national expertise was brought to the effort. The approach to the assessment was a highly interactive one, attempting to bring to it the views of the widest possible number of flood specialists. Each author prepared a draft of the research needs in his or her specific area of expertise. This was done within a framework of definitions and boundaries established at the beginning of the project and described in the following section under the "Dimensions of the Report." A consensus approach was inherent to the entire assessment.

The project schedule, shown in Figure 1, reveals the process utilized to obtain a maximum amount of expertise and to achieve reasonable consensus on the national research agenda. As noted in step 1, we worked initially with a NSF coordination group and with representatives of other federal agencies. From this initial interaction, we produced a list of nine authors to develop the chapters. Step 1 was completed in December 1981. Step 2 began with a meeting

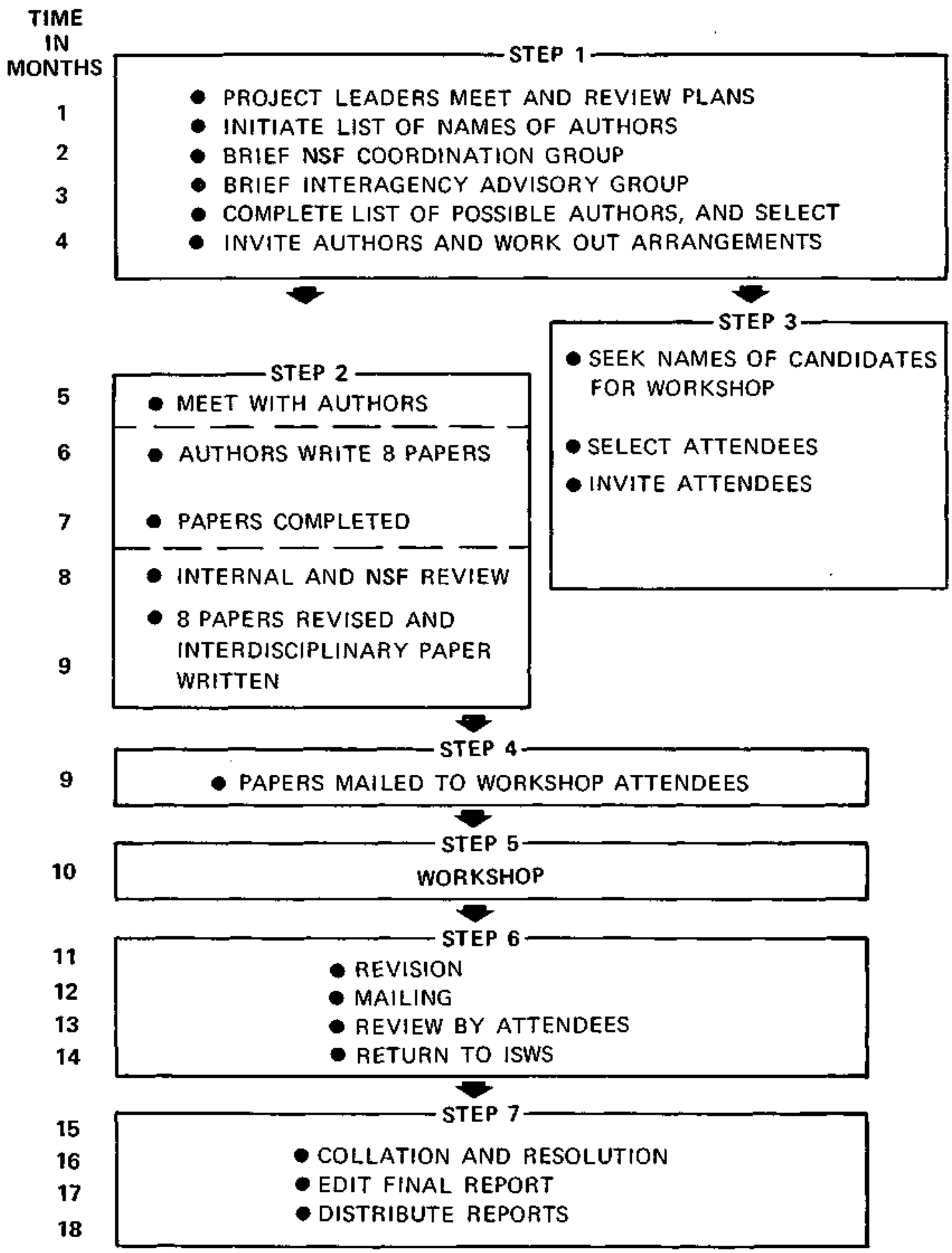
TIME IN MONTHS
1
2
3
4
STEP 1
● PROJECT LEADERS MEET AND REVIEW PLANS
● INITIATE LIST OF NAMES OF AUTHORS
● BRIEF NSF COORDINATION GROUP
● BRIEF INTERAGENCY ADVISORY GROUP
● COMPLETE LIST OF POSSIBLE AUTHORS, AND SELECT
● INVITE AUTHORS AND WORK OUT ARRANGEMENTS
5
6
7
8
9
STEP 2
● MEET WITH AUTHORS
● AUTHORS WRITE 8 PAPERS
● PAPERS COMPLETED
● INTERNAL AND NSF REVIEW
● 8 PAPERS REVISED AND INTERDISCIPLINARY PAPER WRITTEN
STEP 3
● SEEK NAMES OF CANDIDATES FOR WORKSHOP
● SELECT ATTENDEES
● INVITE ATTENDEES
9
STEP 4
● PAPERS MAILED TO WORKSHOP ATTENDEES
10
STEP 5
WORKSHOP
11
12
13
14
STEP 6
● REVISION
● MAILING
● REVIEW BY ATTENDEES
● RETURN TO ISWS
15
16
17
18
STEP 7
● COLLATION AND RESOLUTION
● EDIT FINAL REPORT
● DISTRIBUTE REPORTS

Figure 1.

of the authors and the Survey investigators in March 1982. Then the authors wrote their first draft papers. These were reviewed by the Survey staff, by the NSF coordination group, and by a variety of reviewers. The interdisciplinary paper, which was designed to be based partially on the assessments by the eight discipline oriented papers, was written in month 9 (Figure 1) after the discipline chapters were completed.

Step 3 (Figure 1) was ongoing at the same time. A second major review of the papers was accomplished at a workshop held in August. Candidates to serve as reviewers at this workshop were carefully screened and selected. They were all provided a copy of the revised "second draft" papers (step 4) prior to the workshop. The 3-day workshop (step 5) involved some 45 reviewers and concentrated on two goals: 1) discipline-oriented discussions attempting to identify any missing research items; and 2) then prioritizing the research tasks. Simultaneously, the interdisciplinary expertise group was working with all the discipline groups to identify major interdisciplinary research topics.

Step 6 involved revision of the nine papers by the authors, and the workshop reviewers were asked to review these "third drafts." Following these reviews and some adjustments, the fourth and final drafts of the papers were completed. These appear as the nine chapters in this report. The findings of these nine chapters have provided the basis for the summary chapter. This report, in draft form, has subsequently undergone review by the NSF coordination group. The following section describes the dimensions of the study and this report.

Dimensions of the Report

We recognized that any topical research assessment, such as this one for research on floods and their mitigation, faces some major "grey area" problems. In our case, these were problems of how to draw definitive boundaries between flood mitigation and 1) other water research (e.g., hydrologic research for floods vs hydrologic research for hydropower), and 2) other hazard research (e.g., economic research on floods vs economic research on other hazards). In addition, we faced the problem of defining boundaries between closely related disciplines such as meteorology and hydrology or certain areas of sociology, psychology, geography, and political science.

Although our decisions, made jointly with the nine authors, are probably different from those others would make, we did proceed to define the boundaries to be used in each discipline and these will be seen in the chapters that follow. Each author made discrete decisions about what to recommend as "flood research" and what to leave to the broader research of the discipline. Disciplinary overlap was handled through arbitrary decisions between the authors to cover certain facets of the research of concern. Not all overlap was eliminated, however, and this was viewed as acceptable because of the need 1) to allow a researcher reading a chapter in his field to gain a full picture of the research needs therein (without necessarily reading all chapters) and 2) to maintain the desired integration of interdisciplinary research.

We chose to include coastal flooding as well as riverine flooding, and the riverine flooding was to encompass needs for all rivers, not just medium and large rivers, in view of extensive urbanization in some upstream areas that cause flooding. Also to be included were needs for data collection and for technology transfer, though not necessarily as specific research recommendations. (As the assessment evolved, however, the lack of data in so many areas and the need for a uniform, interactively usable data base resulted in a major interdisciplinary recommendation for the design of a basic data system.)

As a framework for the disciplinary chapters, it was decided that each chapter would open with a rationale for the research needs discerned in each area and would continue with discussions of the desired research, ending with recommendations only for high priority research, some of which would be flagged as critical. Since designated experts in each area had been selected, it was decided that summaries of extensive literature searches were not necessary (though some of the authors felt the need to include numerous references, especially for recent research, as a basis for the additional research needs).

However, within this framework, each author has approached the presentation of the disciplinary research needs in a somewhat different manner. The discussions of the needed research range from brief statements of a problem and its recommendation, to fairly lengthy presentations of the philosophy and deficiencies underlying the recommendations plus the many facets of the research involved. Though each author has presented a summary of the research, these vary from "listings" to detailed descriptions; each does indicate the "critical" research and, in some cases, sequences of effort that should be followed. In addition, some of the social chapters have been organized around a temporal approach with a time-sequence of 1) the preparedness/mitigation phase, then 2) the warning, 3) emergency actions, and 4) recovery and restoration activities. However, such a sequence was not appropriate for the strictly physical sciences as their efforts fall primarily into preparedness and warnings. In some disciplines such as ecology, regional thinking was apparent whereas this was not so in others. Further, though each author has assumed a broad audience, there has been no attempt to eliminate entirely the "language" of the disciplines.

These variations have been deemed acceptable by the group on grounds of the variety of users of this report and their differing needs. The summary chapter then attempts to bring the recommendations together in a more holistic format.

As mentioned previously, all research recommendations in this report, whether large or small, were deemed to have "high priority." These choices, as made by the authors interactively with the workshop reviewers, were based on three criteria: 1) the importance or severity of the flood-related problems, 2) the probability that results of the research would directly assist in mitigating the flood problem, and 3) the cost of the research in relation to its possible benefits. In a time/expense relationship, some important research activities were thought to take so long to achieve results and to carry a concomitant high expense that they were given a somewhat lesser priority in the overall research agenda of this report.

Certain priority research tasks were labeled as "critical" because the seriousness of the problem or issue being addressed was so great that immediate action was needed, and research should be launched on these first, particularly if funding was limited. Assignment of criticality was also done on the basis of lack of knowledge. That is, research topics that had as yet little study and were top priority were often seen as critical, or needing attention first. In other instances, criticality was assigned because the research addressed the ongoing shifts in national policies such as the translation of greater responsibilities to the states and local government, shifts from structural to nonstructural approaches, or the National Flood Insurance Program.

The presentation of the disciplinary chapters starts with the physical sciences, the elemental factors of rainfall and resultant streamflow, and progresses through the related environmental and human health areas to the societal chapters embracing the economic, sociologic, political, and legal factors involved in flood mitigation activities. These are followed by the chapter expressing the interdisciplinary research needs emanating from the disciplinary chapters and from the concensus of the authors and reviewers.

The report concludes with a summary of the recommended disciplinary and interdisciplinary research, including a crosscut of these from the aspects of the five major national issues and policy trends identified: 1) National Flood Insurance Program, 2) emergency assistance efforts, 3) the trend from structural to nonstructural approaches for flood mitigation, 4) the new federalism with a shift from federal to state-local responsibilities, and 5) the efficient use of flood-prone lands. These are followed by the general recommendations including an outline of the comprehensive plan for flood mitigation research.

We are immensely grateful to the nine authors for their willingness to participate in this assessment and their great cooperation throughout the study. The thorough reviews of many others are also appreciated. These reviewers are named in the Appendix.

This report is intended for wide distribution to the scientific and engineering communities, and to a large number of federal and state agencies. Hopefully it will be a blueprint to guide, for many years, a well organized national flood research effort.

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CHAPTER 2. METEOROLOGICAL RESEARCH NEEDS ON FLOODS AND THEIR MITIGATION

CONTENTS

CHAPTER 2. METEOROLOGICAL RESEARCH NEEDS ON FLOODS AND THEIR MITIGATION

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INTRODUCTION

The principal contribution meteorological skill can make in mitigating the effects of flood is in the issuance of timely warnings. Excessive rains which can cause rapid runoff into streams can occur anywhere in the United States, though more frequently in some climatic zones than others. Many of these rainfalls will lead to flash floods. In recent years these have been the most damaging natural hazards in the country. In spring, rapidly melting snows are often the cause of widespread inundations, and while rarely endangering lives, their effects on agricultural and riparian properties can be enormous. On the Gulf and Atlantic coastlines precipitation and wind-driven storm surges, while not as frequent as flash floods, have historically caused great loss of life and are potentially a huge threat to persons who have in the past two decades settled near the shores. They could also cause immense property damage.

The prediction of all these catastrophic weather events has always been a major task for meteorologists. Although meteorologically the core of the problem is precipitation observeration and forecasting, this has to go hand-in-hand with predictions of stream stages. Thus, in most governmental services in the world, meteorological and hydrological activities are closely associated.

Rainfall measurements are an ancient art, dating back thousands of years in China. River stages have also been closely monitored for centuries and excessively high river stages have been marked by plaques on buildings near the water front on many European rivers. But the state of the art both in observing conditions leading to floods and making timely forecasts of these events is still not as far advanced as necessary for the protection of the population. Much additional research is called for to improve the situation.

There have been suggestions, from time to time, to use weather modification techniques to dispell flood-producing storms or to weaken hurricanes. Regrettably weather modification has not yet progressed to be a reliable technology even for purposes of precipitation augmentation. Its promise for storm modification is very low in the near future so that flood mitigation research in meteorology must for the time being give higher priority to reachable goals in observing and forecasting.

CURRENT STATUS

Status of Observations

In practice the detection of rain occurrence, and especially determination of its intensity, takes place simultaneously with the forecasting process. But for convenience the two essential ingredients for flood warnings will be treated here separately. The ordinary raingage has been used since antiquity to measure rain amounts. There have been few improvements in the circular orifice raingage since. The standard 8-inch (20.3 cm) raingage used in the U.S. is a rather poor sampling device. There are several reasons for this fact. First and foremost, the orifice of the standard raingage has only about 50 in (324 cm) surface. It is usually expected to represent conditions over an area of many square miles. Experiments have shown that, especially in heavy downpours, two gages in close proximity will readily have as much as 10 to 20% difference in catch. In heavy rains water splashes out of the funnel. With strong winds, drops and snow flakes blow over the rim. In urban areas problems of exposure become troublesome. Some of these difficulties can be reduced by use of windshields. For flood forecasting problems the gages have also been equipped with recording and telemetering devices.

For reduction of areal sampling error there has been recourse to dense networks of raingages. Such networks have been operated in the classical study near Uppsala, Sweden, by Bergeron (1967), by the U.S. Department of Agriculture (Hershfield, 1971), and during the METROMEX urban experiment in the St. Louis area (Changnon, 1981). There is one thing the data from these networks show clearly: Rainfall even in a small area is very heterogeneous, especially in summer when convective precipitation prevails. Often raingages only 1 km (0.6 mi) apart show for a series of storms correlations as low as 0.6. "Ground truth" is not easily ascertained and further statistical analyses are needed to interpret the information so collected. These complexities have been ably discussed by Hershfield (1965). These problems have been further discussed in recent work (Flueck, 1981) and gage densities of 4 per 80 km^2 (30 mi^2) are recommended (Silverman et al., 1981). Obviously in mountainous terrain great irregularities in precipitation may require other measurement strategies.

When radar was added to the arsenal of the meteorologist, it became a valuable tool for detecting developing storms and monitoring their areal extent and duration (Battan, 1973). Doppler radar can also yield excellent information on storm motions within the range of the device, which is usually below 300 km (190 mi). There have been numerous attempts to obtain quantitative estimates of precipitation over an area in storm situations. These estimates have the advantage of areal coverage and are particularly valuable where there are few or no raingages. A good review with an excellent bibliography has been provided by Wilson and Brandes (1979). They conclude that with a "reasonable effort" radar measurements of rainfall will be within a factor of 2 for about 75% of the cases. Point rainfall values are more likely to show substantial discrepancies. Automatically digitized and accumulated precipitation values from radar (D/RADEX) have been experimentally used but are not yet quite adequate for routine service operations. But combinations of radar and surface gage observations will yield estimates within 10 to 30% of the true values for gage densities of 1 per 250 to 400 km^2 (96-154 mi^2). A promising technique combines radar reflectivity factors at both horizontal and vertical polarizations. In an as yet very limited number of cases an accuracy of + 15% over an area of 550 km^2 (212 mi^2) with a dense gage network was achieved (Seliga et al. , 1981).

A further step in indirect sensing of precipitation became available when geostationary satellites (GOES) were placed in orbit. A substantial literature has developed in a short period of time. The application of satellite data to the "silent" areas with few or no raingages became very attractive (Woodley et al., 1981; Richards and Arkin, 1981; Jolly, 1981). These estimates over an area were made by use of the fraction of cloud cover combined with the infrared sensed temperatures. The latter indicate the height of the cloud cover. Reasonable correlations with ground observations are claimed for short-lived, isolated thunderstorms (Scofield and Oliver, 1981). These authors have also expanded their techniques to rains in extratropical cyclones (Scofield and Oliver, 1982).

But it must be strongly emphasized that there are also less encouraging reports indicating, for example, that 6-hourly rainfall rates determined by radar and satellite observations show wide discrepancies, with notable underestimates in the satellite-derived data (Griffith et al., 1977). It has also been pointed out that there is a need for different techniques that can apply to fast-moving thunderstorms and slowly moving remnants of hurricanes (Whitney and Herman, 1981). Although the infrared temperatures of cloud tops are an important variable, they show a wide scatter for high rainfall rates. An attempt has been made to use a combination of satellite and conventional synoptic and aerological observations. By using no less than 28 variables and a statistical step-wise regression estimates of rainfall have been obtained. This technique has been applied retrospectively to a fast-moving midwestern squall line and the deteriorating hurricane "Eloise." Although a valiant effort, it left much to be desired (Whitney, 1982).

Status of Predictions

There is a great variety of meteorological events that can lead to flooding, and there are different types of floods. The weather processes can be fast or slow. They can lead' to flash floods which are an explosive development that presents a particularly difficult problem in mountainous terrain. They present a different forecasting problem from more slowly developing floods resulting from the melting of snow covers. The prediction of the rapidity of melting is an entirely different task from the prediction of convective activity usually involved in flash floods. Still different is the prediction of direction, speed, and rain intensity in tropical storms or hurricanes. The latter, depending on wind speed and direction of motion, can also produce coastal storm surges, which may constitute a far greater hazard than the rainfall of the hurricane.

Forecasting of excessive precipitation leading to floods, especially flash floods, has been a principal target for both researchers and practitioners for a considerable period of time. Singling out the flash floods is justified for issuing warnings. They also are major killers, not infrequently causing dam breaks. Nocturnal events present a particular problem.

Of course, precipitation predictions, first in qualitative terms, and more recently, quantitatively, have been the main preoccupation of meteorologists. These predictions even for relatively short time intervals, such as one or two days in advance, have not been nearly so successful as forecasts of other meteorological elements. Forecasts of upper air flow patterns have steadily increased in number and quality over the past two decades. These are the main guidance for the forecasters and are based on computerized dynamical models. Even though the present systems have a so-called fine-mesh output with 130 km (81 mi) resolution, they are not adequate for assessment of small-scale convective storms over small watersheds. Yet while these models and conjoined model output statistics (MOS), based on past observations under similar flow conditions, have made some improvements, they have failed essentially in the prediction of large amounts of precipitation.

The skill has been assessed by Charba and Klein (1980) who state "while there has been a notable improvement in the probability of precipitation forecasts for up to 48 hours the quantitative precipitation forecast skill has only slightly increased. It is better in the cold than in the warm season. Particularly low are skills for values > 1 inch" (25 mm). For the flood threat, these high values are the information needed. Especially the small-scale events are not resolved by the synoptic data networks and by the model grids. The modeling of convection is too crude for prediction of heavy downpours. Ramage (1982), in analysis of forecast improvements since 1966, concluded that the accuracy of precipitation occurrence was inversely related to relative frequency of precipitation and that winter forecasts were much better than those for summer. In fact, there has been very little progress at all in forecasting the small-scale convection rainfall events of summer. But these latter are the progenitors of flash floods.

On this small scale there has recently been more research on the trigger mechanisms of thunderstorms. These include the interesting observation of cloud merger as an initiating process (Purdom and Marcus, 1982). The important small, subsynoptic scale processes responsible for thunderstorm propagation have been enumerated (Zehr and Purdom, 1982) but they are not fully understood and research efforts to understand them are limited. In mountainous areas the difficulties of flash flood forecasts are even more complex (Muller, 1981). A recent survey of an ad-hoc panel on mesoscale processes by the Committee on Atmospheric Sciences of the National Research Council (1981) reveals almost complete neglect of the small-scale weather processes leading to flash floods. That panel's report calls for a rather unfocused National Mesoscale Research Program without any priorities.

There has been a very notable improvement in the tracking of tropical storms. These are spotted early in their life cycle by satellites and tracked as they approach the U.S. shores. Their structure is explored by aircraft reconnaissance, but the prediction models of their future developments still leave much to be desired and their precipitation amounts are essentially a matter of conjecture. There has been some progress in the modeling of the storm surge expectations along various segments of the U.S. coast endangered by hurricanes (Jelesnianski, 1978). Only experience will show how reliable these models are. The forecasts of landfall of hurricanes are fairly good for short time intervals but rather vague for predictions of 24 or more hours. These necessitate the issuance of general alerts rather than more localized predictions. With more and more persons endangered in some coastal sectors and increasing need for longer lead times for evacuation and reduction in false alarms, present forecast abilities are clearly inadequate.

NEW AVENUES FOR RESEARCH

Observations

There is complete consensus that the flash flood component of adequate warnings is an integration of observing systems, forecasts, and communications. For the observations, further work is needed on establishing where the critical points are in various watersheds for raingage observations. These have to be reliably telemetered to both meteorological and hydrological forecast offices. There is need to develop improved interpretations of areal rainfall estimates by radar, aside from better radar coverage, in some regions of the country. There is hope that the next generation of radar devices (NEXRAD) will have improved capabilities for detection and analysis of convective precipitation systems. Efforts to study the initiation, development, and character of convective storms using GOES data alone or in combination with aircraft and synoptic observations show promise (Jolly, 1981; Sinclair and Purdom, 1982). These efforts should continue. A proposal to install a suitable radar on a geostationary satellite for use in conjunction with present infrared and passive microwave techniques for precipitation measurements has recently been made (Atlas, 1982). Although this development is still in the predesign stage, it holds considerable promise and ought to be pursued. The advantage of the indirect sensing technology for heavy precipitation measurements, especially from satellites, is its reduced vulnerability from telecommunication difficulties, which have afflicted surface raingage networks in the past during critical times.

Because intense rainfalls over watersheds can be the result of a number of different synoptic patterns, the question of forecastability has no unique answers. There are fast-moving convective storms, usually associated with squall lines or fronts, and slow-moving or stationary convective storms, often caused by stalled occluded fronts. Then there are the heavy rains caused by tropical storms, which may also move fast or slow, and often erratically. When these are moving inland in their deteriorating stages, rainfall may be particularly heavy over relatively small areas.

The prediction of most of the flood-producing situations is generally more difficult than that for the motion of and precipitation from the ordinary, less severe weather systems. These are part of the prevailing atmospheric flow patterns and amenable to the current numerical prediction models of the atmosphere. These models do not adequately cover the mesoscale, i.e., weather systems of dimensions less than 100 km (60 mi) horizontally. This deficiency calls for development of special mesoscale models. These require greater resolution in the initial data fields, on both the horizontal and the vertical scale. These models have to incorporate the diurnal variations which often control the convective activities. They must take account of the known internal structure of thunderstorms (Fritsch and Chappell, 1980) and should contain the necessary elements of cloud physics.

Although development of mesoscale numerical prediction models is imperative, there is need to systematize the antecedent synoptic conditions conducive to flash floods. These have been studied for a large number of such events in the U.S. (Maddox et al., 1979). There have been too many cases in the recent past when the potential for flash floods has been overlooked. This applies also to the prediction of excessive precipitation caused by tropical storms, whose motion close to land and after landfall is often decidedly erratic. Especially in the last stages of deterioration, particularly in mountainous terrain, exceptionally large amounts of rain can cover large areas.

After many flash flood catastrophes "post mortem" analyses are carried out, but many of them are disappointingly inadequate. They bring tables on rain amounts, casualties, and damages. They usually give some information on the macrosynoptic situation and recite warnings, if any. They often fail to address the question of critical elements for the prediction process, in particular if observations were inadequate, and what should be done to improve them. This applies both to convective storm systems (Simons et al., 1978) and hurricanes (De Angelis and Hodge, 1972; NOAA, 1975). For some of the more recent major disasters -- such as the 1976 Big Thompson Canyon flash flood and the 1977 Johnstown, Pennsylvania, flood -- re-examination of the macro- and meso-synoptic processes of the storms producing them has given helpful hints for future predictions (Maddox et al., 1977; Caracena et al., 1979; Hoxit et al., 1981).

In view of the fact that flash floods are relatively frequent events (20 to 30 per year in the U.S.) and that 3 or 4 Atlantic tropical storms move close to or cross the U.S. coastline every year, a large unexploited source of material exists (Neumann et al., 1978). These frequencies also illustrate the relatively high risks to which a steadily increasing population is exposed. Clearly one of the elements insufficiently addressed in flood-rain forecasts is the antecedent history. Not only is it notorious that rain not infrequently begets rain on subsequent days by recycled water but also true that tropical storms occasionally occur as twin events. A principal example of this was the August 1955 hurricanes Connie and Diane which caused disastrous floods in Pennsylvania and New York.

Another major mesometeorological concern deals with further studies of urban precipitation. Continuously expanding metropolitan areas have driven the flood menace from the inner cities into the suburbs. Although METROMEX (Changnon, 1981) has clarified some of the problems for summer precipitation in a relatively simple topographic setting, there remain unsettled issues. These include slow-moving fronts stalled by the friction of the urban fabric and heat island effects in seasons other than summer.

Similarly, much remains to be done to explore the effects of mountainous terrain on the mesoscale processes producing excessive rainfall. Presumably, this involves regional studies because it is quite likely that some local effects can be far more important in producing or preventing heavy precipitation than general synoptic patterns. Similarly, the antecedent weather history is a very significant parameter. There are cases when under similar synoptic conditions conducive to heavy rains, prior drought might reduce the flood hazard while prior saturation of the soils would enhance it.

Spring Flood Prediction

The orographic aspects weigh heavily in the prediction problem of spring floods. These floods develop principally as a result of snow melt. In mountainous terrain the melting process can often be precipitous, resulting in calamitous freshets in headwaters and rapid rises in the downstream rivers. There are notable inadequacies in predictions of snow melt. They start with incomplete knowledge of snow depths in mountains. Satellite information has improved vastly knowledge of the extent of snow covers (Wiesnet and Berg, 1979; Dewey and Heim, 1981). It can also survey the areal extent of snow during the melting process. But information on depth of snow and water contents is not readily acquired by indirect sensing. The use of neutron scattering from radioactive cobalt sources buried in the ground and sensed from low-flying aircraft is restricted to a few point observations.

A comprehensive study of the meteorological factors involved in snow melting in the mountains as well as in plain terrain is a major requirement for flood prediction. Snow covers can harmlessly disappear by evaporation. They can melt slowly, or they can melt explosively. Little systematic knowledge exists on these various modes. There exists only isolated observations on the role snow-albedo plays in the melting process with temporal albedo changes. The interactive effects of soil heat flux, soil temperature, air temperature, and solar radiation on snow melt are poorly understood. The time lag between the onset of above-freezing temperatures and melting of the snow cover is poorly surveyed. Other unknowns are the effect of rainfall on the melting of snow covers and the infiltration of meltwater into the soil. And the dangerous runoff of water from snow melting on frozen soil has not yet been quantitatively explored. Evidently such work has to be carried out on a regional basis.

The Prediction without Date: Maximum Expected Rain

In the past much effort has been devoted to give estimates of the maximum precipitation that can be expected in a particular area. It is axiomatic that any amount of rain once observed at a locality can be repeated again. The unanswered question is: Will it be exceeded? Much depends on the length of record at a place and the methods of statistical analysis used to determine extreme value probabilities from past records. A vast literature exists in this field. A very comprehensive manual on this topic has been compiled by the World Meteorological Organization (1973).

The prediction of extreme precipitation values is of great importance for planning and design. It is essentially a statistical expectancy, which is basic information for construction of dams, dikes, bridge supports, and other flood-control engineering structures. It will help to arrive at wise decisions on land use near streams and rivers, in conjunction with hydrological analyses.

Such predictions without date are based on analyses of maximum precipitation values in the past climatic record. In most observational records spanning any length of time, only daily totals are available, but recording raingages are now installed at many places in the U.S. Their records permit more detailed analysis of short intense rainfalls. Over the years, the National Weather Service has produced a number of studies dealing with a wide variety of these extreme values. (To cite a few representative ones: Hershfield, 1961; Cooperative Studies Section, 1962; Hydrometeorological Section, 1961; Frederick et al., 1977). Similar analyses have been performed in other countries (e.g., see Silver, 1979, for the U.S.S.R.). Several of these studies are now over two decades old and enough new data have since been obtained to check earlier conclusions.

Most of these analyses project extreme rainfall values for specific time limits, generally 50 or 100 years. They have also been extended from single station values to larger areas (Myers and Zehr, 1980). Much of this statistical work has been based on Gumbel's procedure to fit the Fisher-Tippet extreme value distribution. However, the irregularity of extreme values in time series of rainfall observations, especially those of short length, is such that in many cases other extreme value distributions provide a better fit. The selection of the most appropriate statistical model is not easy and no rationale has been established to approach this selection in an objective manner (Sevruk and Geiger, 1981). Particularly troublesome is the handling of outliers, and the process of regional rather than point aspects is yet to be satisfactorily solved. The distributions also seem to change according to whether the day preceding a large value was dry or wet (Swift and Shreuder, 1981). The same problems of treating extreme values apply to stream and river stages in hydrology. Interdisciplinary cooperation by meteorologists, hydrologists and statisticians is called for to further these essential studies in the future.

There is a major need to re-examine the validity of past procedures to determine the maximum possible storm precipitation over a watershed. As part of this review, a very detailed history of major floods on various stream and river systems is needed. This must include a synoptic re-analysis of all available meteorological information. Priority should be assigned to rivers where major population densities have caused much loss of life and damages to property in the past, such as the Susquehanna, Ohio, and Sacramento (California) rivers. The focus should be on the rare, or even singular, events exemplified by the "500-year" flood of 1937 in the Ohio valley. Existing analyses of some of these events suggest infrequent concatenation of circumstances both in the weather patterns and in other factors affecting river stages. Rather than looking only at precipitation probabilities, the statistical behavior of these other factors should be incorporated into joint risk estimates. The synoptic re-analyses should evaluate the potential of current observational capabilities and modern prediction models to judge if forecastability of such rare events has improved.

The Coastal Problem

Although tracking of hurricanes has vastly improved in the past three decades, the danagers to life and health along the coastlines of the Gulf of Mexico and the Atlantic seaboard have not diminished. The population shifts and the land use changes along these coasts have caused grave concern for the safety of large numbers of people. The problem is aggravated by the age distribution of the new inhabitants of the coastal zone that is heavily weighted toward retired persons. The director of the National Hurricane Center, Dr. Neil Frank, has repeatedly expressed his concern publicly (Sanders, 1982).

Hurricane forecasting has shown some improvement over the years, but the models for tropical storm development, their future path, their wind intensity and precipiation propensity are still inadequate for the timing and precise location of landfall (Simpson and Riehl, 1981). The lead times are inadequate for issuance of warnings to permit orderly evacuation where needed. On the other hand, unnecessary evacation, aside from stress, inconvenience, and cost must be avoided if responses to such warnings are to be taken seriously by the population.

The meteorological problem of making landfall forecasts of hurricanes with acceptable precision more than 12 to 24 hours in advance is formidable. Yet the need for such warnings is vital and urgent so that a major meteorological research effort is warranted with a high priority rating.

Communications

Even if predictions of flash floods and storm surges were perfect, the meteorologist's job does not end there. He has to convey the information to the public. The means of dissemination have greatly improved in recent years. There is the NOAA radio station network, commerical TV and radio networks, and lately also cable TV. The communication system to emergency agencies has also been strengthened. The weakest link remains the wording of the forecast. It must be unambiguous. But even the meaning of the terms "watch" and "warning," now regularly used, is not always understood by the persons to whom the communication is addressed. Here the meteorologist needs the help of other professions, especially psychologists and educators. They must explore the best ways to communicate warnings and methods that will make people act appropriately in high-risk and dangerous situations.

Other problems in the communications area are those presented by the large minorities of people residing in hurricane-prone areas who do not fully understand English. Another gap exists in some regions where flash floods occur not infrequently at night. There are various electronic means to alert people but those have found only limited entry into homes. The best forecast is useless unless it reaches those threatened by disaster. Professionals other than meteorologists will have to solve these problems.

In the post-disaster period the meteorologist, with the aid of others, has traditionally collected information pertaining to various meteorological and hydrological disturbances. The information gathered is published at monthly intervals by the National Climatic Center of NOAA in Asheville, North Carolina, under the title "Storm Data." This information is used, among other applications, for insurance, legal, and epidemiological purposes. Although this is the only pertinent documentation from an official source of damaging weather events that must be maintained, there is also a consensus that it could be considerably improved in information contents. This is, of course, not a research task, but because this publication is an essential tool for multidisciplinary research, its fate and shape has to be included in the present review.

CONCLUSIONS AND RECOMMENDATIONS

Meteorological observations and forecasts are essential ingredients for mitigating the evil consequences of floods. Their main purpose is the saving of life and prevention of injuries from the threats of flash floods and storm surges. Clearly the specific improvements of such predictions must have a high priority rating. Since they are based on auxiliary information from various observing systems, these also need research attention.

The meteorological observations and forecasts feed directly into the hydrological prediction system and hence have to be jointly explored by meteorologists and hydrologists. Meteorological warnings are also of direct concern to the public health authorities and others responsible for the safety of exposed populations. Heavy precipitation and coastal storm surges are also phenomena of primary concern to ecologists because of their impact on fauna and flora.

Other identified meteorological research needs, even though perhaps of lower priority, are needed for flood plain management, insurance, and legal purposes. Still others leading to better understanding of storm systems feed directly into those aiming to improve the forecasts.

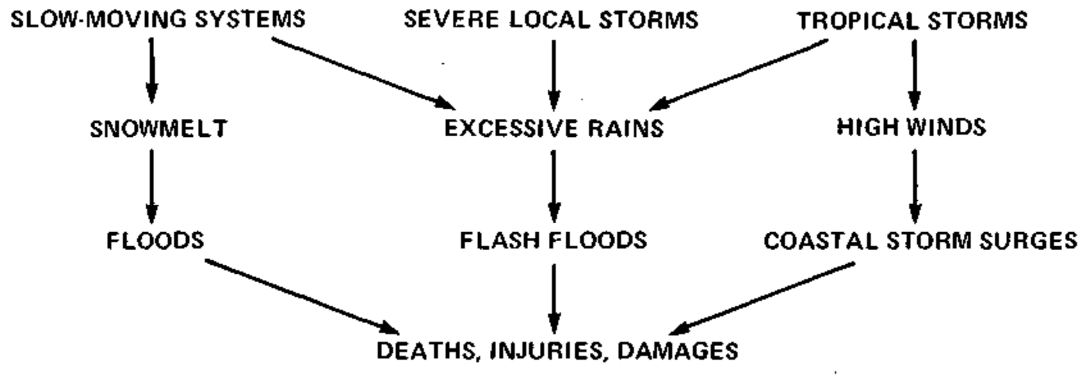
Diagrammatically the concatenation of hydro-meteorological events, the mitigation achievable by meteorological efforts, and the relations of meteorology to other disciplines involved, is shown in the accompanying figure.

The following six recommendations are presented in logical order. Of these recommendations 2 and 3 are considered to be critically important to research on floods and their mitigation. Recommendations 2, 4, and 5 are interdisciplinary with hydrology, 3 is interdisciplinary with public health.

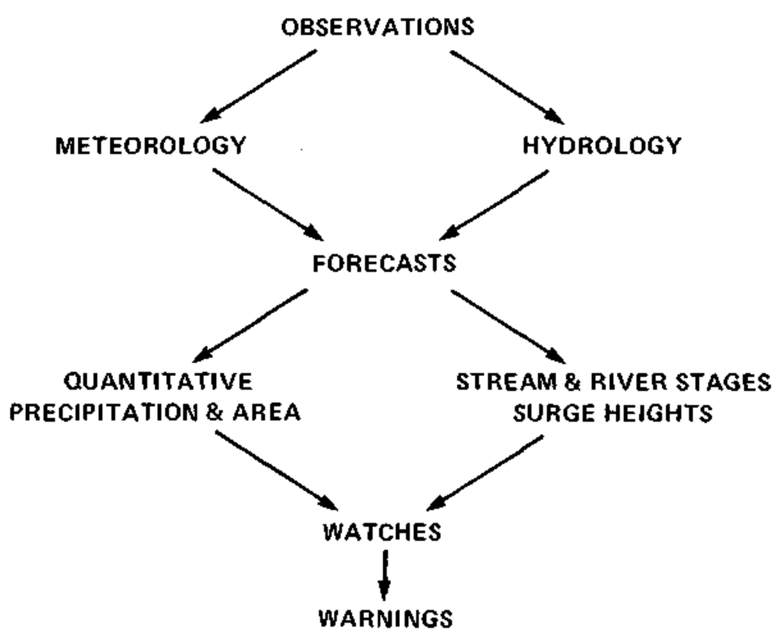
1) Improved quantitative remote sensing of precipitation for integration with conventional raingage networks. Of importance are the radar detection of heavy rain-producing storms, and exploitation of remotely sensed satellite derived information.

†* 2) Specific effort to produce reliable quantitative precipitation predictions for large amounts, including the development of numerical mesoscale models for this purpose. The models should be capable of including urban influences and adaptable to quasistationary weather systems.

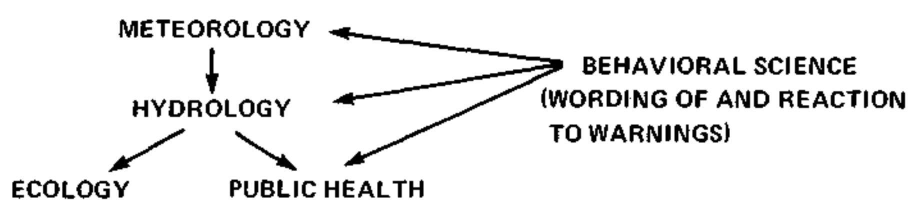
• HYDRO-METEOROLOGICAL EVENTS



MITIGATION ATTEMPTS



INTERDISCIPLINARY RELATIONS



†* 3) Improved prediction of tropical storm systems close to shore and inland with particular emphasis on improving the 36-48 hour forecast accuracy of time, location, and intensity of the storm at landfall, and on the time and location of rainfall heavy enough to cause flooding as the storm moves inland. Special attention should be given to local and regional needs for evacuation lead-time.

† 4) Examine and study snow pack release as a major contributor to flood conditions (other than flash floods), including knowledge of antecedent history of precipitation in the watershed of interest.

† 5) Re-examination of statistical procedures for estimating maximal rainfall values for different time intervals and space dimensions.

6) Re-analysis of historical cases of floods, including flash floods, the synoptic patterns which caused them, and the effect of antecedent precipitation.

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*critical priority

†interdisciplinary

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CHAPTER 3. RESEARCH PROBLEMS IN HYDROLOGY AND HYDRAULICS

CONTENTS

CHAPTER 3. RESEARCH PROBLEMS IN HYDROLOGY AND HYDRAULICS

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INTRODUCTION

Background

Hydrology is the science dealing with the waters of the Earth, their occurrence, circulation, and distribution,. . . and their reaction with their environment,. . . (Federal Council For Science and Technology, 1962). Hydraulics is the science that is concerned with the mechanics of fluids. With regard to flood hazard mitigation, hydrology is concerned with the occurrence of floods in rivers and along coastlines. Hydraulics is concerned with the performance of structures such as spillways on dams, spillway channels, gates in water control structures, and flow in artificial channels. The two fields overlap in the treatment of flood flows in rivers. Hydrology and hydraulics are therefore complementary in analyses of floods and the performance of structures intended to mitigate the floods.

Hydraulics is the older of the two fields, much useful research in the mechanics of flow having been performed as early as the 17th Century. Modern quantitative hydrology is largely a product of the 20th Century. One might suppose, therefore, that the need for more research regarding floods and flood mitigation is far greater in hydrology than in hydraulics. This is, in fact, a conclusion of this analysis and consequently this section will concentrate almost entirely on the research needs in hydrology.

Meteorology, the subject of Chapter 2 of this report, is a closely related field since it includes the atmospheric phase of the hydrologic cycle. Research in meteorology is supportive of many of the hydrologic research needs.

What Is Flood Hazard Mitigation?

Any action that decreases the likelihood of property damage or loss of life as a result of floods is flood hazard mitigation. Several techniques are available to mitigate flood losses. Flood water can be stored in reservoirs until the danger is past and then released slowly to the stream. Areas which are subject to flooding can be protected by building levees or flood walls around them to keep the flood waters out. Streams may be diverted away from an area normally subject to flooding. Regulation can control the use of the flood plain so that new properties which would suffer from flooding would be prohibited. Existing properties on the flood plain can also be acquired and the occupants relocated. Alternatively, properties in the flood plain can be floodproofed so that they suffer little or no damage during floods. Finally, insurance can compensate flood plain occupants for all or part of the damage they suffer during floods. In the subsequent text the term "flood mitigation systems" means any one or a combination of these techniques.

General Comments

Before discussing specific research needs in the fields of hydrology and hydraulics, some general comments are necessary. Hydrology is an evolving science and research is more or less continuously under way aimed at improving the techniques used in the field. Thus, the list of research areas developed in this analysis identifies areas where more work is needed. In some cases better data are required as a prerequisite to significant advances. In other cases innovative research approaches will be necessary.

The research topics discussed here are purposely broad and need not necessarily be attacked *in toto*. Discrete subproblems can be identified and researched independently of other phases of the task. There are no obvious reasons why any of the proposed research should be performed by any specific sector of the field. The goal should be to encourage research by the most capable individuals or groups, whether they be in government, academe, or private industry.

Much of the proposed work is exclusively hydrologic or hydraulic, with no special interdisciplinary aspects. However some of the topics may require participation of other disciplines or coordination with work in other fields. Some of the topics will prove useful in other disciplines, and in some cases coordination of the research may improve its utility. Specific note of the interdisciplinary aspects is contained in the discussion of the research.

In the course of developing this discussion of research needs, it has become apparent that there is a need for a comprehensive data bank of flood related information. The data needed in hydrology must be collected continuously on a regular schedule, and are the subject of a specific recommendation. The meteorologic and hydrologic data that are routinely utilized by hydrologists should continue to be stored in the data systems currently in use within the U.S. Geological Survey and the National Climatic Data Center of NOAA. Examples of the type of information which should be routinely filed in an appropriate repository include records of events such as levee failures, ice jams, and landslides, which may be useful in defining the statistical probability of such events. Also of use might be stream cross sections, records of land use and land use changes, and files of radar data showing the occurrence of precipitation in major storms. No attempt has been made to develop an exhaustive list of such data needs for hydrology, and discussions at the project workshop (St. Louis, August 1982) indicated that other disciplines could present comparable lists of their needs. The development of a plan for such a data bank is not so much research as it is a task of organizing the multidisciplinary requirements. Hence, no specific recommendations are included in this chapter, but consideration of a national flood data system could be the target of a separate project.

Three major national themes related to flood damage mitigation were noted during the workshop. These are:

- A trend away from structural flood mitigation measures toward non-structural solutions to flood problems.
- The development of the National Flood Insurance Program and Emergency Assistance Program.
- The emergence of community involvement as an important aspect of flood mitigation.

These themes must influence research needs in all disciplines associated with flood mitigation efforts, and they are recognized in the list of needed research in hydrology and hydraulics. Fortunately, the research needed for effectively designed structural flood control systems and for planning non-structural systems are essentially identical. Much the same information is required of the hydrologist for both purposes. One aspect of community involvement is found in the preparation for community action during floods. The principal hydrologic contribution to this is that of providing flood forecasts and warnings, a subject which is emphasized in the proposed research needs.

The research needs presented next in this chapter are divided into two groups: the critical research needs, or those demanding first attention (as described in chapter 1), and other important research needs that have high priority.

SPECIFIC RESEARCH NEEDS IN HYDROLOGY AND HYDRAULICS

Critical Research

Flood Risk

Complete protection against all floods is difficult, if not impossible. Certainly such complete protection would be uneconomic. Thus, all flood mitigation efforts are founded on a concept of risk. Structural measures are designed to protect against floods which occur relatively frequently, but a risk remains that a rare flood will exceed the capacity of the project. When nonstructural measures are employed, lands where the risk of flooding is acceptably low are usually excluded. The heart of any flood insurance program is the concept of actuarial premiums based on the risk of occurrence of damaging floods. The hydrologist must define the probability of flood flows and stages in order to assess these risks. Errors in the definition of probability may place persons or properties at risk when they are in fact safe and vice versa, or such errors may lead to excessively high (or low) premiums for insurance.

In recommending research in hydrology and hydraulics, emphasis has been placed on improving or replacing those hydrologic techniques which are employed in estimating flood probability and in determining the uncertainty which remains in these estimates. This calls for a comprehensive review of most of the major hydrologic procedures including the determination of flood probability from observed streamflow data, the estimation of flood probability at sites where no historic record of streamflow exists, and the definition of the flood plain having a specified probability of inundation.

Many methods are now in use for estimating flood probability at an ungaged location. Because there is no flood record with which these estimates can be compared, the reliability of the estimates is largely unknown. The Hydrology Committee of the Water Resources Council (1980a) conducted an exploratory test of some of these procedures, by asking volunteers to use them to estimate the 10- and 100-year floods at gaged locations without prior knowledge of the answers. The test was a pilot for a larger nationwide test and as such there are features of the test which were subject to question. Nevertheless, the results are important because they are the only example of a systematic test now available.

The test was applied to a few streams in the Pacific Northwest and to some basins in the Upper Midwest. In the Pacific Northwest the <u>best</u> procedure yielded errors ranging from -55% to +725% with half of the estimates between ± 20% when applied to the 100-year flood. In the Midwest the <u>best</u> procedure yielded errors from -80% to +195% with half of the errors within ± 30%. The other methods tested had much larger errors. Not only were there large errors but all methods tested showed a tendency to overestimate the actual values. Errors as large as indicated are hardly acceptable as a basis for important decisions regarding flood mitigation. A nationwide test should be conducted to identify methods which are acceptable, if any, and to indicate the degree of uncertanity in estimates which have been used in the past.

In 1968 the Water Resources Council adopted the Log-Pearson Type III distribution as a guideline for application to flood frequency estimates by all federal agencies. This decision has been subject to much criticism among hydrologists. There is no reason to believe that any one statistical distribution is appropriate for all streams in the U.S. It is not clear that the Log-Pearson Type III is superior to any other distribution. It is clear that this distribution can yield answers quite different from those of other distributions. Reliability of frequency analysis is dependent on very large samples of data, which are generally not available in hydrology. What little evidence there is suggests that records in excess of 100 years are required for reasonably reliable estimates of flood frequency. Few such records exist and, hence, research on flood probability requires innovative approaches such as record extension by use of hydrologic models. The research should also consider methods of estimating parameters for fitting distributions to the data.

Land use can have a profound effect on flood probability and upstream land-use changes may alter the risk to which downstream occupants of the flood plain are exposed. Land management practices may be one aspect of non-structural flood control. It is important therefore that we be able to predict with reasonable accuracy the hydrologic consequences of changes in land use and land management. The research on land use will be of interest in the ecological evaluation of flood mitigation measures. Public health personnel may also be interested in this research to the extent that it deals with the washoff of sediment and pollutants from the land surface.

Finally, since any flood mitigation plan leaves a residual risk of flooding, the plan should be tested in advance of implementation to be sure that the proposed system will perform as expected in lesser floods and will not leave some major hazard during extremely large floods. For example, can the residents at risk escape to safety if an exceptionally large flood occurs?

The first four recommendations under critical research in the recommendations are directed to these areas. Meteorological research workers share a similar interest in defining the probability of meteorological phenomena and findings related to appropriate statistical techniques may be transferable.

Flood Plain Mapping

In addition to the probability estimates for floods of various magnitudes, flood plain mapping requires the drawing of a continuous boundary along a stream defining the limits of the x-year flood plain. This is usually accomplished by the use of backwater computations. For straight and regular channels these computations are relatively simple, but for the usual natural channel there are many opportunities for error. These include the selection of an index of channel roughness, which must be estimated largely on the basis of judgment; the treatment of overbank flow on one or both sides of the main channel; the treatment of possible scour or fill of the channel bed or banks during the flood; the handling of the effect of obstructions such as bridges; and the handling of the effect of stream junctions and possibly other factors. Incorrect treatment of these questions can lead to errors of several feet in computed water-surface elevation alone, even if the estimate of the streamflow were exact.

Recommendations 5 and 6 are directed to the problem of flood plain mapping, with recommendation 5 directed to the hydraulic problems discussed above, and recommendation 6 looking at the consequences of combining the error in determining the flood flow of specified probability with the error in the backwater computations in estimating flood plain boundaries. This research will be of interest also in other aspects of flood mitigation, as for example, the design of flood channels, levees and flood walls.

Because the ecology of the flood plain is dependent on the frequency of flooding, ecological researchers will be interested in the research on flood plains described here and under Risk above. Their interest will be in using the results of the hydrologic research, but an ecological study of flood plains might be scheduled concurrently with the hydrologic work.

Flood Warnings

Advance warning of floods can save life and in some cases property. The techniques used to make flood forecasts have much in common with the state-of-the-art techniques in hydrology, and much of the hydrologic research proposed in this chapter may contribute to improved accuracy of forecasts. The accuracy of flood forecasting is dependent on an accurate assessment of storm rainfall already on the ground and that yet to come. The task of predicting the occurrence and amount of rainfall is addressed in the recommendations of the chapter on Meteorology. The task of assessing the rainfall "on the ground" is one of interpreting data from conventional raingages, radar, and satellites, together with streamflow response and any general information that may be available to the forecaster. Because time is usually of the essence in forecasting, the assessment of rainfall must be done rapidly and possibly automatically.

Recommendation 7 is directed to the precipitation estimates. Results of this research will certainly be of interest to hydrologists engaged in flood analysis and may contribute to hydrometeorological network design (Recommendation 9). Work under Recommendation 7 will probably require the active participation of meteorologists.

Flash floods which normally affect small watersheds, especially where subject to short but intense rainfalls, are the major cause of deaths in floods. Flood forecasting in the usual sense may be impossible because of the short time available. In some cases the time is so short that a device which triggers a warning signal as the stream rises may be the only practical solution. Where the available time is a little longer, a more sophisticated system using rainfall data and a computerized analysis may be feasible. Recommendation 8 is directed to this problem.

Data

All hydrologic research is dependent on the availability of historic data on streamflow, precipitation, snow, evaporation and in some cases other data items. These data must be collected from a nationwide network, processed and stored for ready retrieval, and, in part at least, published so as to be available for widespread use. Any immediate research can be based only on the data already in the archives. Future research should be enhanced by current research aimed at improving the sensors used in the field, devising more effective (probably computer compatible) recording devices, developing improved techniques for checking and processing data which are received, and finally studying the data storage and retrieval systems for improvement in accessibility, cost, and reliability. At the same time more research on the most efficient design of data collection networks could prove useful if it is directed to efficiently meeting the data requirements of state-of-the-art hydrologic methodology and the accuracy requirements of flood mitigation and/or management operations.

Recommendation 9 is responsive to this need. Since much of the required data are collected by or under the supervision of meteorologists and stored in the National Climatic Data Center, the active participation of meteorologists in this work is indicated.

Important Research

The critical research needs do not represent the total of the potential research needs in hydrology and hydraulics. There are several flood problems which are not covered within the critical list but are nonetheless important. Priorities are necessary in any proposal for a research plan to focus attention on those tasks which seem to be of greatest importance and these are identified in the list of critical research. The list of important but noncritical research includes topics which:

- Are regional in nature affecting only a portion of the country.
- Involve large initial capital investments to make the research possible.
- Are particularly difficult problems with little hope of immediate return in terms of useful results.
- Cannot be carried forward until a significant data base is developed.

The ten topics which are presented in the list of important research fall into one or more of these categories.

Flooding from the Sea

Low lying coastal areas are often flooded as a result of storm surges driven ashore by powerful winds. Most commonly these are induced by approaching hurricanes but can be caused by severe storms of other types. The hurricane-induced surge which flooded Galveston, Texas, in 1900 claiming a reported 6000 lives is an example which is often cited. The development of a hurricane warning service by the National Weather Service has materially reduced the loss of life from such events in the United States but major damage still results from storm surges.

A method of predicting the extent of flooding from storm surges would be helpful, both in warning of an impending event and in advance planning. Advance planning might include regulations regarding occupancy of threatened areas and/or planning for protective works where feasible. Predictive models for storm surge have been developed but their accuracy has not been tested. A report by the Water Resources Council (1980b) concludes that these models cannot be tested until a suitable data base is developed. The data required include detailed information concerning the storm which drives the surge, the extent of the flooding, and the topography of the sea bottom offshore and the land that is flooded. Thus, the primary need is the establishment of the observational network to provide the required data. These data coupled with available topographic and hydrographic maps and satellite photographs could provide the information needed for testing and probably improving a model to a level where it could be applied effectively.

Because surges do not occur every year and the location where the next surge will strike is unknown, it would be necessary to develop a program covering much of the eastern and Caribbean seaboard. This will be a costly project and many years may elapse before useful data would be in hand. When these data are available, a further research task would be that of evaluating possible protective measures and assessing the feasibility of possible actions to reduce the damage and loss of life from storm surges. Recommendations 10 and 11 are directed to the problem of storm surge. These recommendations will require the cooperation of meteorologists.

A second cause of flooding from the sea is the tsunami, sometimes misnamed tidal wave. Tsunamis are caused by undersea earthquakes which generate a long ocean wave that moves rapidly over the ocean until it strikes land where it may cause damage to installations along the coast or in estuaries. The Alaskan earthquake of 1964 generated a tsunami which was observed as far south as California. A tsunami warning service has been established to predict possible tsunami occurrence when an earthquake has been observed. A basis for predicting the probability and magnitude of tsunamis would be useful in regulating the use of coastal areas where the risk of tsunami occurrence is high. Recommendation 12 is directed to the tsunami problem. The research would involve the cooperation of seismologists.

Debris and Ice

In most major floods a large quantity of floating debris is transported by the streams. This debris often accumulates at obstructions, such as bridges and culverts or natural obstructions such as rocks, creating a dam which may back up flood waters to unexpected depths with associated flooding upstream of the barrier. Debris barriers can be a factor in bridge failures. If the debris dam is finally washed out, a surge wave of unusual proportions can move downstream exacerbating the damage from the flood alone. In some streams in the northern U.S. ice jams may cause a similar result following the breakup of the ice cover. Recommendations 13 and 14 are concerned with the problems of debris and ice jams.

Landslides

The rainfall which causes floods is often the trigger which results in large masses of earth, rock, or mud moving downslope causing damage to property and death to persons trapped in the moving mass. In the floods of January 1982 in central California almost all the deaths were caused by earth movements. In some cases a landslide may be initiated by undercutting of the stream bank by the stream. A landslide can cross a stream creating a temporary dam which ponds the flow causing increased flooding upstream and a possible surge wave downstream as the barrier is washed out by the flood waters. Research directed to predicting the probability of slides and understanding their impact on streamflow is proposed in Recommendation 15. This will obviously require interdisciplinary efforts between geologists and hydrologists.

Some Hydrologic Problems

Flood stages in the lower reaches of coastal streams which discharge into tidal waters may be influenced by the state of the tide at the time of the flood peak. Methods of effectively predicting the joint probability of high tide and flood peak would be helpful in estimating the probable stages to be expected in such situations. Work on this problem is recommended in item 16.

In the desert areas of the western U.S. streams often flow out of mountain areas across an alluvial fan, the debris deposit brought down by the stream.

Such streams often migrate laterally across the fan as the temporary channel of the stream is blocked by new deposits of sediment. Hence, the area subject to flooding varies as the stream shifts, posing a difficult problem of estimating flood probability for flood plain mapping. This research is presented in recommendation 17. The work will probably require coordination or cooperation with geologists.

RECOMMENDATIONS

Critical Research

1) Conduct a systematic test of procedures for estimating flood probability at ungaged locations, with a view to identifying procedures which can be generally accepted as reliable, and also to provide information on the extent of uncertainty which exists in probability estimates of this type.

2) Investigate the uncertainty associated with flood probability estimates based on observed streamflow records. This should consider the questions of appropriate probability distributions, statistical estimation procedures, the effect of record length, and the non-stationarity of the record caused by station moves or changes in the catchment. The use of record extension with deterministic models should be explored. Cooperation with meteorologists who are exploring methods of frequency analysis for meteorological data may prove helpful.

3) Develop and demonstrate reliable methods for predicting the effect of changes in land use or land management practices on flood peaks, flood volume, and sediment production. This work could involve cooperation with ecologists studying the ecological effect of land use changes. Public health personnel concerned with the washoff of pollutants from the land will also find this research of interest.

4) Develop and demonstrate procedures for testing the performance of proposed flood mitigation systems during extreme floods (such as the Probable Maximum Flood). One purpose here is to determine if the proposed system might in some unexpected way make floods in excess of the design flood worse than they otherwise would have been. A second purpose is to determine whether the population will be able to escape from the protected area if this should be necessary. This research should also demonstrate methods of testing performance of a flood mitigation plan on floods below the design flood level.

5) Review and improve the techniques for estimating flood flows in natural channels or predicting stages for given flow rates. This research is especially directed at more accurate estimates of flow by the slope area method, and more accurate application of backwater computations for flood plain mapping. Conditions at stream junctions and bridges should be considered in this research.

6) Investigate the uncertainty in defining flood plain boundaries for various levels of probability as a basis for planning flood plain management and for developing actuarial rates for flood insurance. This study should, where possible, identify methods which offer minimum uncertainty. This research will be of interest to ecologists studying the ecology of flood plains. Ecological indications may prove useful in defining stage probabilities.

7) Develop methods to improve estimates of precipitation for use in flood forecasting and other hydrologic studies. Interdisciplinary efforts with meteorologists may be helpful in this work.

8) Develop reliable and effective means for flood warnings to alert people at risk of an impending flash flood.

9) Investigate hydrometeorological network design (streamflow, precipitation, snow, evaporation) with a view to improving the sensors currently in use, the recording devices, data processing and storage techniques, and the design of the network. The aim of this research is to improve, within economic limits, the accuracy of the hydrologic estimates required for planning of flood mitigation systems, and other water management operations.

Other Important Research

10) Install a system for collecting data required for storm surge models, and use these data, as collected, to test the available storm surge models. If the tests indicate the need, the best model should be modified to correct model deficiences. The cooperation of meteorologists will be necessary in this study.

11) Conduct a preliminary investigation of possible measures to protect against storm surge including both barriers in estuaries and barriers on the coastal plains. The aim of this research is not to design an effective system but to define the limits of applicability, the economic constraints, the data requirements and other information that would be necessary if planning for a specific barrier were to be undertaken.

12) Review and test procedures currently in use for determining the areas which will be affected by tsunamis and estimating the probability of tsunamis of various magnitudes. This will require interdisciplinary work with seismologists.

13) Investigate the sources of large debris in streams in flood, and the mechanisms by which this debris enters the streams. Determine ways in which debris can be kept from entering the streams, methods of avoiding the formation of debris dams, and the possibility of constructing effective debris traps.

14) Investigate the formation of ice jams in streams with a view to short-term forecasting of their occurrence, defining the probability of their occurrence, and developing methods to minimize or eliminate their occurrence.

15) Develop procedures for predicting the probability of occurrence of landslides in order to permit better land-use regulation in slide-prone areas and short-range forecasts of slide hazard. This should include study of the mechanics of slide motion in order to predict the area affected by a slide. Cost-effective techniques for stabilizing potential landslides in inhabited areas are also urgently needed. This research area could also include studies on the origin and movement of mud flows and debris flows.

16) Investigate methods for predicting the joint probability of high tides and flood peaks in coastal streams.

17) Investigate the hydraulics of flow on alluvial fans to determine ways in which the area of potential flooding can be defined and the probability of flooding can be quantified. Cooperative efforts with geologists are indicated for this research.

Acknowledgments

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CHAPTER 4. AN ECOLOGICAL PERSPECTIVE ON FLOOD MITIGATION

CONTENTS

CHAPTER 4. AN ECOLOGICAL PERSPECTIVE ON FLOOD MITIGATION

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INTRODUCTION

This chapter presents an ecological view of the problems associated with flood damage mitigation. Ecologists seek to understand biological phenomena at population, community or ecosystem levels of organization. They inquire about the interactions between the components of nature. The approach to basic understanding usually involves investigation of nature that is unaffected by human activity. Applied ecology is underpinned by and complementary to this basic understanding but it is focused on human problems. Some ecologists are active conservationists or environmentalists. Most ecologists are sympathetic with such views because they understand the interdependency of natural systems, which includes the dependency of human life on natural processes.

Evaluations of environmental issues require value judgments about the way that culture or technology interacts with natural ecosystems; the goal of environmentalists is to be critical, to comment on the goodness or badness of technological activity on the environment. When ecologists become involved in finding solutions to problems such as flood damage it is more difficult to remain scientifically objective, but they ought to be more involved in the application of ecological knowledge to societal problems. The poet Milton put it this way, "I cannot praise a fugitive and cloistered virtue, unexercised and unbreathed, that never sallies out and sees her adversary. . ." This philosophical distinction needs to be understood in order to approach logically a topic that deals with both a natural phenomenon (flood) and a value judgment (damage). The burden of objectivity is greater because the potential loss of human life and property is often great. It seems to supersede science's understanding of stream ecosystems and their benefits to the point of insignificance. Nevertheless, the negative environmental impact of man's efforts to control floods is so great that the effort to evaluate the natural benefits being risked is important. Only then can they hope to be preserved.

The following is an ecological context for the flood mitigation problem. It addresses the general questions: How do streams and rivers work? How does what happens naturally in streams benefit society? How does the flood phenomenon affect those benefits? How might flood mitigation programs affect those benefits?

Ecological investigations of pristine streams and rivers in the United States are rare because there are so few such streams left. This constraint is most severe for consideration of large rivers. What ecologists have learned from the study of small rivers and streams and a few lightly impacted reaches of rivers and flood plains is significant, however, and it is useful as solutions of flood related problems are sought.

A Concept of Stream Ecosystem Function

The underlying principles of stream ecosystem function are geomorphic. The nature of bedrock and its resistance to erosion, and regional geological history such as glaciation, uplift and faulting serve as the ultimate independent variables controlling channel configuration as well as the chemical composition of the water. The energy expended by running water on landscapes is dissipated in various ways from headwater streams to the mouths of larger rivers, i.e., slope, current, turbulence, discharge, and load capacity all change along this gradient so that the channel assumes the most efficient configuration for distributing the energy.

The order system of stream classification includes some of these parameters (Leopold *et al*., 1964; Horton, 1945; and Strahler, 1971). About 75% of all stream channel lengths are first and second (low) order, but the high order channels have the highest discharge. (To a geomorphologist a stream order is specifically defined as a measure of the position of a stream in a hierarchy of tributaries. The headwater channels are first order, two first order channels join to form second order and second order channels join to form third order channels and so on.) Research that is aimed at understanding how streams and rivers behave during storm flows or floods should use this method of recording where in the watershed the research is being conducted.

Vannote *et al*. (1980) make a concise statement of the ecological function of stream systems in this geomorphic context. They recognized that biotic components ought to be adapted to the most probable state of these geomorphic changes and that the functions and the biota performing them might be expected to vary in some systematic way along the drainage network. Some biotic components, dominant in the headwaters, disappear but are replaced by others with different functions downstream.

This functional view of stream systems considers that the organic resource base, while always photosynthetic, may enter the stream either from the drainage basin or from producers in the stream itself. Depending on the source of the organic matter, the utilization of the resource and its ultimate decomposition are carried out by a changing biota along the stream course from headwaters to mouth.

The Role of Floods in Ecosystem Function

It is an axiom that organisms living in streams are adapted to the flow conditions in which they evolved. Those conditions include storm flows. The risk of being displaced by a flood is a clear selective pressure to which organisms adapt with mechanisms to maintain position, to recolonize rapidly after flood waters have receded, to adopt life history strategies that times developmental stages that are vulnerable to flooding with seasons having low probability of floods, or to otherwise survive.

As a result, streams are inhabited by a wide array of specifically adapted organisms, both plants and animals, that function to utilize organic and inorganic materials being transported by the stream or that are stored in the stream bed. The sources of the organic matter to streams is a subject of some interest; it is sufficient to say here that most of it originates in the watershed rather than in the stream itself. Naiman and Sedell (1979a) discussed the importance of organic matter stored in the stream bed and how that is related to stream order in Oregon streams. They dealt in similar fashion with organic materials being transported by streams (Naiman and Sedell, 1979b). Both discussions identified the importance of channel obstructions that delayed the export of organic matter. The efficacy with which organic material was decomposed was related to the delay. Marzolf (1978) discussed the importance of this in relation to the practice of clearing and snagging to "improve" stream channels.

It is this material in storage and in transport that drives the biotic activity in streams. Floods, in the simplest sense, have the effect of removing material from storage (erosion) and putting it in transport. The geomorphic effect of this erosional process is to readjust the capacity of the channel. As flood waters recede the material is put back into storage (deposition). Some of the material that finds its way back to channel storage is material that had been in the flood plain and, conversely, some material from the channel is redeposited on the flood plain. In either transport or storage the organic portions of the materials are decomposing due to the activities of populations of living organisms both in the stream itself and on the flood plain.

The link between the stream and its flood plain is strong. Flood flow might be viewed as a sort of "reset" mechanism that disturbs the equilibrium of base-flow biological activity. It reorders the metabolic processes that are involved in organic matter decomposition; aerobic vs anaerobic microbial metabolism, benthic infaunal dominance vs filter feeder dominance among the fauna, terrestrial vs aquatic organisms, etc. The idea of "pulse stability" (Woodmansee, 1978) seems applicable to streams subject to flooding. The dependence of stream ecosystem structure and functional responses to storm flow pulses might then be more definable and the benefits of stream processes to society better understood.

These storage, decomposition and transport processes are the basis of the stream ecosystem's utility to society and they are major benefits. Biological processes are clearly important to the control of water quality. This service function is a significant benefit to society. It seems to be in our best interest to maintain and rehabilitate the integrity of systems that enhance water quality, particularly when the continued availability of water is becoming more and more limiting. The details of how this decomposition works and how the river exchanges materials in transport with materials in storage on the banks and in the flood plains would be appropriate basic research of great value to the problem at hand.

The movement and redeposition by floods of materials such as inorganic sediments and nutrients is the mechanism of creating flood plains with enriched soils. The productivity of wetlands and marshes in flood plains is partly explained by this. Wetlands further serve to enhance water quality because they act as "activated filters" (Mitsch, 1978; Kibbeyt 1978). The use of flood plains for agricultural purposes is profitable because of this "subsidy" of nutrient materials (Odum, 1978), but tilled agriculture probably does not provide the same filtering effect on flood waters.

Recognizing flood damage is an important requirement for setting research priorities. The identification of a damage or loss often is limited to man-made structures and uses of land. It is illogical to claim that a natural system is damaged by a natural event. Only when a natural feature of streams or rivers has been identified as a particular benefit to society is it logical to say that the feature has been damaged. Natural benefits are not well defined (rather they are taken for granted). Their loss, therefore, is unpredicted and not dealt with in the accounting of losses. By the same logic, if floods are integral elements of natural systems that provide benefits, then prevention of floods can be considered in that sense, damaging.

The development of robust theory in stream ecology proceeds slowly because of the system's openness and its complexity. The number of scientists involved in stream work is increasing, however, and interest seems high. The call for further development of theoretical constructs is appropriate, especially as theory pertains to larger order streams, rivers and flood plains. This research is in the domain of stream ecologists and may be outside the scope of flood research initiatives addressed here. It is, however, a realistic need for applied research in view of the importance of water resources.

The following sections deal with the needs for research from this perspective.

AN ECOLOGICAL PERSPECTIVE ON SELECTING RESEARCH NEEDS ON FLOODS

Storm flows are natural phenomena. To ascertain the benefits to society that are associated with natural flood phenomena is an objective of research. Other objectives include sharpening our understanding of known benefits. Known benefits change along streams from headwaters to mouths. Since stream characteristics also vary geographically with hydrologic regime and ecosystem classification, flood related phenomena are expected to vary similarly.

Normal discharge of water from first order, or headwater, streams is lower than downstream and the storm flows tend to be confined to the steeper channels. The hydrograph is shorter in duration, for a given rainfall, than in the higher order streams. Most flood-related phenomena are limited, therefore, to the channel itself. The existence of a flood plain is more characteristic of higher order streams where discharges are large and the gradient not so steep. The water overflows the banks and establishes a flood plain. In the highest order streams the dominant flood related phenomena are in the flood plain (Figure 1).

This is clearly an over-simplification. Where soils are cultivated or where vegetation is sparse in the headwaters there may be serious "out of channel" or overland flows. Certainly, where these conditions contribute to suspended sediment loading, the result can become a serious problem because of

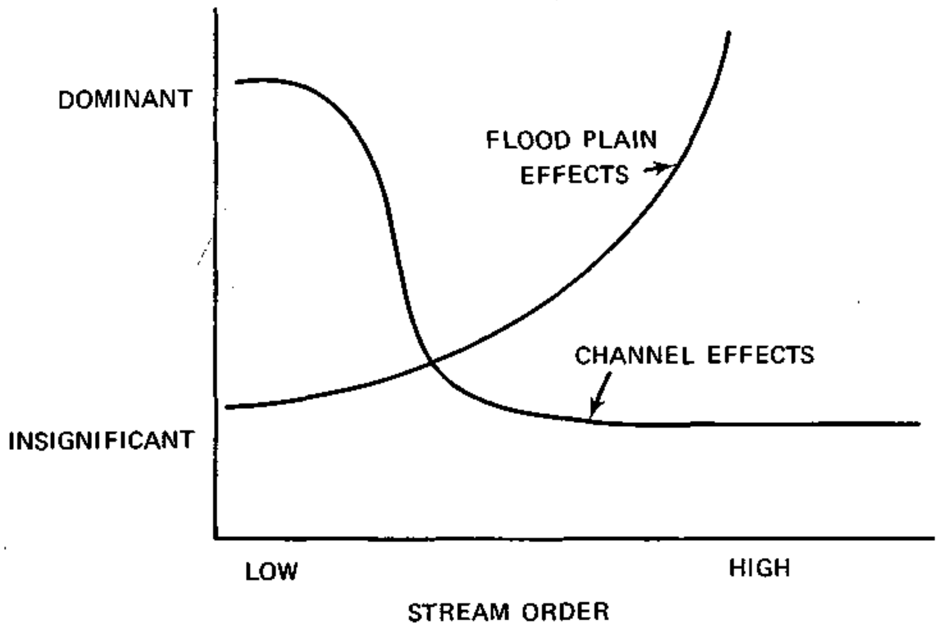

Figure 1. Hypothetical relationship between flood damage in channel or flood plain as a function of stream order in a watershed.

soil losses in the headwaters and excessive sedimentation downstream. There are also many examples of low order streams with flood terraces and flood plains. Additionally, many high order rivers were once longer than their engineered channels are now. They had meandering and braided channels that may have better contained flood flows and they may have been altered greatly by each flood. The simplification is intended only to organize or focus the statements of research need as they pertain to the effects of floods on the benefits that streams provide for society.

Hydrograph amplitudes of storm flows in headwater streams vary with the duration and intensity of precipitation (or characteristics of thaw, etc.) and the characteristics of slope, soil and vegetation that regulate infiltration and runoff. Hydrograph amplitudes in the higher order streams, while responsive to the discharge from upstream, are mostly regulated by the configuration and characteristics of the flood plains and levee systems.

Flood intensity varies geographically as well. It is more catastrophic in the desert southwest where drought and intermittent flow are characteristic. It is more muted in the humid east, where drought and intermittent flow are rare. The transition between these extremes is seen in the prairies and high plains in the central United States. Furthermore, in the temperate U.S., floods bear a seasonal relationship to thaw and seasonal precipitation that in the Mississippi River drainage is exported downstream. In the southern U.S. seasonal differences are smaller. These differences are related to climate and vegetation that are discussed elsewhere (e.g., Leopold et al., 1964; Bowman, 1936).

This brief general description suggests that: 1) ecological effects of floods on natural stream benefits in the headwaters should be sought in the channel itself, the flood plain being less significant; 2) flood mitigation strategies that regulate flood intensity and minimize losses of materials from the system might more logically be applied to the catchment basin rather than to the channel; 3) the effects of floods on natural benefits in the highest order rivers are more likely to be observed in the flood plain, a geomorphic result of floods themselves; and 4) flood mitigation strategies should be applied and flood benefits enhanced in the flood plain rather than in the channel.

1. Effects of Floods on Natural Stream Benefits in Headwaters

At latitudes, altitudes, and in rainfall regimes where headwater streams are covered by tree-shrub canopy, the input of particulate organic matter from the riparian vegetation drives the biological activity of the system. Natural stream channel configurations and obstructions retain the organic matter and it is degraded by the activities of fungi, bacteria and invertebrates. The more effectively particulate material is retained, the more of it is degraded.

This organic matter degradation is the basis of the stream system's regulation of water quality, and potentially this is the greatest benefit to be realized from stream ecosystems. Additionally, the more of the organic matter that is metabolized in the headwaters the more productive of fish and wildlife they will be; this is the basis of a recreational benefit very important in some parts of the country. Furthermore, degradation in the headwaters where turbulent flow keeps the system aerobic is, perhaps, an additional benefit; for if the material is exported downstream it adds to the oxygen demand of the flowing water, and when deposited in slow flowing reaches, the sediments are more likely to be anaerobic.

The details of the kinetics of organic matter decomposition and the relative roles of the microflora and the invertebrate fauna in this process is not well understood. Periodic flooding can be thought of as an integral control feature of some natural systems, but for the purposes of this beneficial feature of the stream as an organic matter decomposer, it may be detrimental. The productivity of streams for purposes of fish and wildlife resources may also be reduced in the short term by flooding.

The effect of storm flows on the headwaters, then, would appear to be detrimental to this beneficial stream function because materials are eroded and exported prematurely. This is not certain, however, for it can also be argued that the degradation processes in the headwaters, being carried out by organisms adapted to the pulsed input of organic matter from the watershed, are inefficient at completing the process. Further, the periodic export of the stored products of the first stages of decomposition to downstream communities is the phenomenon to which downstream organisms are adapted and upon which they have come to depend.

The subjects of soil erosion and "flash flooding" need to be better understood in relationship to natural vegetation in comparison with cultivated vegetation and tilled soils, and in comparison with vegetation that is used for grazing of domestic livestock. The erosion of soils represents the loss of an important terrestrial resource. The transport of suspended sediments in concentrations higher than might occur naturally represents a condition to which stream systems might be adapted. To the extent that this result of flood alters instream processes beneficial to society, they are damaging.

2. Mitigation Strategies in Headwaters

Consider now that the dominant effects of flooding in headwaters that are detrimental to human activity usually result from the fact that flood waters do not recede soon enough (perhaps a subjective judgment). The human response is almost always to modify the channel to carry water away more rapidly, a response that may solve an immediate problem but that heightens the detrimental effect of floods on the natural organic matter degrading function of the stream. Such practices also increase the export of water and undegraded organic matter downstream, both of which represent losses and the potential for unwanted results.

Channel modifications cause difficulty for the natural system because they create conditions for which the biota was not adapted. Organisms will, therefore, face reduced survivorship and fitness. Perhaps such changes can be viewed as neither good nor bad since adaptation to changing conditions is a characteristic of living systems. If, however, we view the natural degradation of organic matter by the stream biota, or the natural productivity of stream faunal elements such as fish and wildlife as benefits, then the change, to the extent that these benefits are lost, must be considered bad.

The strategies that are applied to mitigate flood damage will certainly be affected by land uses in the drainage basins. History demonstrates that land use decisions were not driven by ecological considerations. Ecological information might be applied to land use decisions in theory, but the implementation of this logic seems unlikely without extensive public education. The pressure to use land in the most economically productive way is very great. The gain is sought only in the short term because land use decisions are made by land owners usually responding to immediate pressure. Agricultural uses and misuses of headwater lands affect the amount of water reaching the channels and the load of materials that it carries. Land owners in the headwaters of drainage basins thus have extraordinary influence on the conditions that regulate flooding downstream. Useful research appropriate to the flooding problem should include evaluation of grazing intensity and range management, crop production and tillage methods, and riparian vegetation as a buffer between agricultural practice and rivers.

A recent example of conflict involving private ownership and incompatible land uses is the case of the Obion and Forked Deer River basins, tributaries to the Mississippi River in west Tennessee. Flood waters in these west Tennessee tributaries to the Mississippi River carried heavy sediment loads from erosion in the mismanaged upland drainages. Sedimentation of this material in the flood plain was fast enough to girdle and kill some hardwood timber, and to threaten still more and to damage cultivated crops, particularly soybeans. The Corps of Engineers, with authority in the Mississippi River flood plain, proposed to modify (clear, snag and straighten) the channels of the Obion and the Forked Deer Rivers to the extent of that authority. This, in the minds of land owners in the flood plain, would not solve the problem because the Corps' authority does not extend far enough upstream to suit them. The state of Tennessee established a river basin authority to extend the modification upstream. At this point citizens reacted negatively in defense of fish and wildlife habitat, and privately funded interests brought suit against the Corps of Engineers in the interest of these and other environmental values. The case currently awaits completion of an environmental impact statement from the Corps of Engineers, the original drafts of which have been criticized by the Environmental Defense Fund.

Legal and presumably valid interests include the Corps of Engineers, owners of floodplain forests and farmland in the lower part of the basin, fish and wildlife interests (National Wildlife Federation), the state river basin authority formed to deal with some (but not all) of these groups, the landowners in the headwaters of the Obion and the Forked Deer River (some of whom do not live on the land), the Soil Conservation Service, the U.S. Department of Agriculture, the Tennessee Department of Conservation, and the Environmental Defense Fund (Tripp, 1979). The manifestation of the problem in the headwaters was felt downstream; an example, on a relatively small scale, of what we face nationally.

3. Effects of Floods on Beneficial Features of Flood Plains

Flood plains are geomorphic features molded by floods. They are considered by ecologists to be integral components of the river ecosystem. They serve primarily to dissipate the kinetic energy of flood discharges and act as the repository for the sediment load being carried by the flooding river. As flood waters recede, they also serve as a source of materials to be returned to the channel from earlier periods of deposition. The underlying geomorphic processes operate on a longer time scale and include meandering, oxbow formation, etc. Shorter term natural phenomena characteristic of flood plains include the retention of phosphorous and other important plant nutrients. In the growing season, nutrient materials are accumulated in riparian vegetation and later released to flood plain soils. In wetlands the nutrients may be reintroduced to the main stream, though at lower rates.

Flood plain wetlands and riparian ecosystems are composed of species that are adapted to periodic flooding. These species are dependent on the river and they would not be there in the absence of a river. Flood plains are among the more productive ecosystems in the world, and they are currently the subject of intense scrutiny to uncover just the sorts of benefits that we seek to preserve in flood mitigation plans (Johnson and McCormick, 1978). Odum (1978) develops the proposition that riparian zones have their greatest value as "buffers" between human urban and agricultural development and our most vital natural resource — water. Flood plain vegetation buffers are specifically named as means for reducing sedimentation and delivery of chemicals to a water body in the "Flood Plain Management Guidelines" of the U.S. Water Resources Council (43 FR 6030, 1978) and riparian buffers are singled out for protection under the Surface Mine Reclamation Act, PL 95-87.

4. Mitigation Strategies in Flood Plains

Since the flood plain results from floods, by definition, there are no damages to them from floods. The damages that are being mitigated are all related to human use of these regions. Here, perhaps more so than in the headwaters, land uses must be considered for appropriateness to preserve the ecological benefits of flood plains and wetlands. Management of the flood plain and the river channel to reduce flood damage implies, to ecologists, management of the system as a single unit. Floods are natural and necessary elements of these natural systems, and it may follow that it will be less costly to adjust to, rather than to fight, natural forces. Ultimately an integrated program of flood mitigation must deal with the issues of land use and how various land uses affect hydrologic conditions (see, for example, Swank and Douglas, 1974) including flood frequency and intensity. Clear demonstration of the relationship between land use and hydrology in the headwaters will be required through research, and substantial public education about how the river translates that relationship to events downstream must follow.

Flood plains are some of the most fertile and easily tilled lands for crop production. Their proximity to the river makes irrigation, where necessary, a relatively simple matter. The losses to flood plain agricultural production as a result of floods needs to be compared to the benefits from flood in terms of maintaining long-term productivity of flood plain soils.

Recommendations for land use to minimize flood effects, or for any other purpose, will eventually require the coordinated accumulation of a substantial data base, one that does not exist. A long-term ecological research network for developing such data on natural ecosystems is in the initial stages of development (NSF, 1979; Marzolf et al., 1981). A protocol for managing the data is evolving (Olsen et al. , 1980; Gorentz et al., 1982). These efforts will bear most directly on land use questions in headwater regions but they will relate to a wide array of environmental problems.

Flood mitigation activity in flood plains should be integrated into flood plain management activities, though it must be kept in mind that flood plain management will not control the floods. They originate in the headwaters; management will only influence the nature of the flood effects.

The engineered structures that are employed to control various elements of flooding should be classified with a view to organizing present knowledge about potential benefits to stream, river and flood plain ecosystems. The following anecdote is an example of a structural change on an essentially pristine riverine system causing some unintended changes related to flooding.

The Glen Canyon dam has reduced the intensity of flooding in the Grand Canyon on the lower Colorado, i.e., regions that were periodically inundated are now free of flood events and the vegetation is changing. Flood vulnerable species are invading those regions and flood tolerant species are disappearing. The dam has also controlled the nature of low flow conditions in the Grand Canyon. The water that is released from storage deep in Lake Powell is colder (hypolimnetic) and freer of suspended sediments than the water that historically flowed in the lower Colorado, and the fauna of the river itself is changing. .

The point is that this change in flood regime is directly related to a technological event, the Glen Canyon dam. Whether the change, and the second order effects that it had, is good or bad, prevents or creates damages, is beneficial or detrimental, cannot be decided on scientific or engineering bases. Other judgment systems are involved, e.g., social, political, legal and economic, and all of science and engineering needs to supply information.

SUMMARY AND RECOMMENDATIONS

The ecological perspective of floods considers the role of flooding in natural stream and river ecosystems. Floods are natural phenomena and not damaging to natural systems. Quite to the contrary, they are necessary for maintaining the integrity of the natural system.

Riparian vegetation and flood plains are integral parts of the river ecosystem. Maintaining the benefits of these natural systems requires that they be managed as integral wholes rather than separate entities.

Beneficial river functions may be substantial-, taking the form of maintaining water quality, decomposing organic matter and producing fish and wildlife. Only when benefits from natural features of stream ecosystems have been identified as valuable can they be thought of as being damaged by floods, or protected from them.

The influence of flood mitigation strategies that modify channels or inappropriate land uses may have more detrimental influence on these benefits than the flooding itself.

Flood mitigation planning activities should be approached on an entire watershed basis. This is a logical landscape unit that will focus on hydrologic questions and will draw attention to geographic and land use influences.

Recent efforts to recognize the natural benefits of floodplain wetland and riparian habitats have begun to formalize conservation efforts. To the extent that these efforts lead to management, they should be incorporated into flood mitigation planning.

Recommendations for Implementation of Ecologial Information

There is sufficient knowledge and conceptual understanding to aid substantially in finding solutions to many environmental problems, flood mitigation included. The need may not be as great for additional research as it is for persuasive implementation of existing knowledge in the public interest.

This is not so much a criticism of the science that has as its goal the discovery of new knowledge, as it is a criticism of:

- Educators that do not emphasize the importance of the knowledge or who may not be alert to its potential applications,
- Legislators and decision makers who have not sought out the appropriate information or who have chosen not to incorporate it into consideration of issues, and
- A public whose expectations do not include the constraints of limited resources.

1) There is a need to develop public understanding of the river and its flood plain as a single natural unit, i.e., to redefine the public's perception of the river, so that the flood plain is included.
2) There is a need to evaluate flood mitigation proposals in terms of natural benefits in the streams and rivers themselves, in the flood plains and in the wetlands that are an integral part of these systems.
3) This amounts to a critical need for information transfer, to translate ecological knowledge into public understanding that will permit flood plain and watershed management plans to be formulated and put in place and, once in place, that will encourage enforcement.

Recommendations for Ecological Research

1) There is a need for theoretical development that includes storm flows as integral features of natural stream conditions rather than as perturbations.

   This amounts to the development of models that will help evaluate natural benefits of floods because they are related to the integrity of the stream ecosystem. How do floods reset ecosystem processes? How are floods related to the stability or resiliency of stream ecosystems? How are stream systems that experience floods at short intervals different from streams where floods are infrequent?

2) There is a need to investigate the details of organic matter decomposition processes and how they are related to water quality. It is clear that instream processes, such as photosynthesis and decomposition, are important in the control of water quality. As the quantity of water becomes more limiting, the quality of what is available will be of greater importance. It will become more important, therefore, to rely on natural processes that "treat" water in order to minimize the cost of delivering quality water.

3) There is a need to investigate the effects of flood mitigation activity on natural stream benefits.

   These activities include structural work such as dams, levees and bank stabilization work as well as "improvements" such as channeling, clearing and snagging. Instream processes that may be beneficial rarely are considered in decisions to initiate such work. Effects of the activity on downstream discharge regimes in channels and on flood plains need to be better understood. The latter is a distinct common research need also being called for by hydrologists.

4) There is a need for research to relate land uses and management practices over entire drainages to the hydrological and erosional contributions of storm flows.

It is widely held that most of the export from drainages occurs during storm flows, despite their infrequency. Soil erosion remains a serious resource depletion problem in the United States. It represents the loss of an essential agricultural resource.

The deposition of sediments downstream also threatens the integrity of reservoirs that were built for flood protection. There is furthermore an important need to investigate the details of how storm flows contribute nutrients and soil components to the flood plains downstream. The details of this important subsidy are poorly known.

5) There is a need for research to classify flood plains relative to their dependence on and tolerance of flooding.

Dependence and tolerance are concepts that must be related to the use of flood plains. There is a growing literature on the influence of flooding on riparian vegetation. The initial phases of the research may be straightforward literature review.

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CHAPTER 5. PUBLIC HEALTH RESEARCH NEEDS

CONTENTS

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INTRODUCTION

It is difficult to address public health flood hazard mitigation research needs as a specific entity because of the ultimate effect on public health of all facets of flood hazard mitigation. Flood plain management, early warning systems, and communications all play integral roles in public health, either by mitigating or compounding problems associated with floods. The extent of the impact of each of these various functions can only be assumed at present. However, anecdotal reports stemming from past flooding experiences throughout the nation appear to indicate that their individual and combined effects are of major importance to the health and safety of the public.

The major deficit in all facets of flood hazard mitigation planning is the lack of a systematic collection of data for the various types of flood events from which public health related data may be extracted. This is true regardless of the discipline involved. Fairly good records have been kept in some disciplines, but the comparability of these data from various areas of the nation and from individual flood events is limited because of the lack of a systematic approach to the actual data collection process. The object of public health is prevention, but this can be achieved only if the circumstances which place the public at risk can be defined based upon data.

The more telescopic view of public health issues to be discussed is predicated on the basis of hearsay, anecdotal evidence and probability rather than fact because of the relative absence of data. The issues include a systematic collection, tabulation, and analysis of data, emergency medical care, communicable disease control, mental health, services to the handicapped and the elderly, and environmental sanitation.

Although evacuation of residents is the responsibility of governmental authorities, the numerous public health needs that arise during evacuation make it a quasi public health responsibility. Certainly, the success or failure of the evacuation procedure determines, to a great extent, the level of public health services required within the flooded area, regardless of the type of flood. However, evacuation from coastal zones and barrier islands pose special problems because of the unprecedented increase in populations of these areas which has increased dramatically the number of people at risk as well as the level of risk in a flood event. Although there is overlap among and between these various public health issues, they are discussed individually to highlight some of the specific problems.

PUBLIC HEALTH ISSUES

Data Base

At present there is a lack of an integrated, routine, systematic collection of data before, during, and after floods. Individual disciplines do collect data. However, it appears that little consideration has been given to integrating these data from the various disciplines to determine the collective impact on each other, and particularly, on public health.

At present it is difficult to ferret out those areas of flood hazard mitigation which have the greatest impact on public health. For instance, how important is land use planning or flood plain development in public health flood hazard mitigation planning? Would more stringent building codes for homes perched on hillsides prone to mudslides or a moritorium on the development of condominum complexes on barrier islands significantly reduce the public health risk factor? What impact does the type of flood, i.e., riverine, flash or hurricane, have on public health? Are the short- and long-term effects similar or grossly different?

The type and timeliness of flood warnings issued would appear from limited evidence to have a significant effect on public health. In certain types of floods, might a warning to remain inside and avoid automobile travel result in less risk to public health? Fleeing from an area in automobiles under adverse driving conditions over inundated roads has resulted in injury and death which could have been avoided. A death in the Kansas City flood in the spring of 1982 attests to this.

The time sequence between the recognition of an approaching severe storm with impending flooding and the issuance of the public warning is vital to public health flood hazard mitigation efforts. Any delay or breakdown in communications between or among the responsible parties may lead to needless injury and death. If the weakest link in this chain of events can be identified, corrective action can be taken. It appears that only through a systematic data collection system can these basic questions be answered and reliable public health hazard mitigation plans be developed for the various types of floods.

The dearth of data relative to public health issues precludes informed planning to meet the health needs of people before, during, and after flood events. Recently it has been recognized that epidemiological methods provide an excellent approach to the study of flood related health problems. The National Center for Disease Control has dispatched teams of epidemiologists to natural disaster areas because the epidemiologist is well schooled in data collection, tabulation, and evaluation. Their medical orientation enables them to quickly evaluate medical problems and translate these into requests for aid, whether personnel or supplies. The epidemiologist is cognizant of the type and quantity of data required for statistically significant evaluation of a given situation and is accustomed to working under stressful conditions. Until reliable data on public health needs surrounding a flood event are accrued, flood hazard mitigation planning in this area is virtually impossible.

Emergency Medical Care

Floods, unlike many other natural disasters, usually produce few serious physical injuries. The proportion of people at risk requiring medical care varies between 0.2% and 2% with most of the injuries being minor lacerations and abrasions. A few burns and fractures have been reported but the most serious problem is usually exposure. Thus, a small medical cadre with relatively limited supplies should be sufficient to meet the needs of the public. Unfortunately, over-reaction has been evidenced in recent disasters. Mobile hospitals, teams of specialized surgeons, and many unprepared volunteers have been rushed to the flooded areas along with useless medical supplies which remained unused while needed supplies arrived late or not at all. This is due to both an improper assessment of needs and a breakdown in communications.

An additional problem in emergency medical care is the location and design of hospitals *per se*. In those instances when immediate hospitalization of exposure victims is required, communication with and access to a functioning hospital is a priority. Unfortunately, in many areas hospitals are located in the flood plain and their vital support systems such as auxiliary power sources and communication control centers are usually located on or below ground level. In recent years, the National Flood Insurance Program has addressed the need to floodproof new construction in the flood plain. Local governments must require floodproofing of utility and sanitary facilities and elevation of the lowest floor, including the basement, to a height at or above the 100-year flood level. Unfortunately, these mandates do not apply to existing facilities which are frequently expanded with no thought being given to incorporating flood hazard mitigation designs. Also, many existing and potential health problems have been brought about by the federal offering of insurance to homes and facilities located in flood plains.

Communicable Disease Control

Other than environmental sanitation activities, which are directed toward providing safe food and water for the protection of public health, the major activity specifically directed toward the control of communicable diseases during and after flood events is the age old medical practice of immunizing individuals against tetanus, typhoid and paratyphoid during and immediately after flood events. This practice is *passe*. It is merely busy work which diverts personnel from accomplishing more productive tasks. The protective antibody response to vaccine requires at least a two-week period, and infections, if they occur, would precede the immunization rendering it useless. Immunizations for the control of communicable diseases should be an ongoing, routine process as opposed to an emergency procedure. All citizens should be urged to utilize immunization as a part of their preventive medical routine. Unfortunately, hepatitis and numerous enterovirus diseases for which no immunizations are now available are associated with exposure to sewage-contaminated food and water. Therefore, public health protection from sewage-borne pathogenic agents must entail environmental control rather than immunization.

The major efforts in the control of communicable diseases should be operative in the refuge. The crowded conditions that exist and the lowered resistance of the refugees produce ideal disease transmission conditions. No evidence of epidemics stemming from exposures in a refuge has been documented, but this does not preclude the possibility that disease transmission has gone unnoticed because of the various emergency situations requiring immediate attention, or because the incubation period of the disease was longer than the time spent in the refuge so the illness was not associated with that exposure.

There is a real need to define the level of medical care required in refuges and the most efficient method(s) of providing that care. Could a practical nurse meet the demands for care and disease prevention or is a registered nurse or a physician required? These and many other questions remain unanswered.

Mental Health

As a result of Section 413 of the Disaster Relief Act of 1974, which included provisions for mental health counseling services in presidentally declared disasters, funds were made available to local governments and mental health agencies to provide direct service to disaster victims. This represented an official recognition of need in the area of mental health. It is of interest that no comparable recognition was given to short- or long-term physical medical problems.

In studies resulting from this impetus, an increase in emotional problems due to flood events has been documented. Two years after the Buffalo Creek flood in West Virginia in 1972, 80% of the survivors had disabling psychiatric symptoms and maladjustments (Titchner and Kapp, 1976). Most of the 224 surviving children were significantly or severely emotionally impaired by their experience during and after the flood (Newman, 1976). In another study done three years after the tropical storm Agnes flood in Wyoming Valley, Pennsylvania, emotional problems were identified in both the exposed and control groups but duration was longer in the exposed group (Melick, 1976). From these relatively limited studies, it appears that flood events may play a significant role in the onset and/or exacerbation of psychological problems, and in any case supports the need for further research.

Based on the limited research done, crises intervention is accepted as a facet of predisaster planning. Manuals are available for training of human service workers to provide mental health services to disaster victims in the temporary refuges and to disaster relief workers who may experience psychological difficulties because of the stressful working conditions. A major benefit of having counselors at a refuge is the identification for follow-up at a later date of certain individuals who might be prone to a delayed stress reaction. Thus, not only the immediate mental health needs may be met but, possibly more important, delayed needs may be met as well. Counselors at the refuge could also be available to assist in the evacuation procedure by providing counsel to recalcitrant evacuees.

Service to the Handicapped and Elderly

Early evacuation of people from their homes in the face of a flood threat may be a life saving measure but difficult to carry out under the best of circumstances, i.e., when the people are healthy, well oriented, and capable of making judicious decisions. However, the handicapped and elderly pose particularly difficult problems. Such individuals function reasonably well within their normal surroundings but may become frightened and somewhat disoriented when the decision to evacuate is forced upon them, particularly if they live alone and family members or friends cannot assist. It has been suggested that due to limited income and other factors, many of these people reside in flood prone, low rent districts, which may magnify the problems.

Unfortunately, the problems associated with evacuating and sheltering the handicapped and the elderly have not been adequately addressed. A study of mortality rates was done one to two months after the flood of the Canvey Island in January and February, 1953 (Lorraine, 1954). Increased mortality rates in February and March compared to the same months in 1952 were noted. Persons with chronic pulmonary disease and the elderly were at greater risk. Similarly, during a 12-month period following the Bristol floods in England in 1968, the elderly had a higher mortality rate in the flooded as opposed to the non-flooded areas (Bennet, 1970). Thus, it does appear that the elderly and the handicapped are at greater risk during flood events.

Environmental Sanitation

Water and wastewater treatment plants, historically, have been located in the less desirable, flood prone areas of a community. In general, treatment units are fairly well protected against flooding, but the sewers become inundated and raw sewage backs up into the streets. However, in severe flooding, even well protected treatment units may be inundated, particularly when they are located near an ocean. Population growth along coastal areas and the recent trend toward regional treatment plants serving many communities pose a severe public health hazard because lack of such services may well cover a large geographical area even though the flooding may be confined to the immediate area of the treatment plants. Hollywood, Florida, is a good example. Although only 43% of the city is sewered, contracts have been signed to supply services to several adjoining communities. The current 30 million gallon per day (MGD) plant located less than half a mile from the Atlantic Ocean and subject to tidal waves is being expanded to a 70 MGD plant. Some of the communities to be serviced are located miles inland where, if affected by the flood waters, the recovery phase would be much shorter. However, resumption of water and sewerage service could be delayed much longer because of the inundation and/or actual destruction of the only and very vulnerable wastewater treatment plant. The importance of wide-area land-use planning must be stressed in the future.

It is recognized that the cost effectiveness of regional systems may engender greater support than numerous, small plants. Unfortunately, a factor most frequently ignored in establishing the cost effectiveness of a system is that of public health. The larger and more complex wastewater treatment plants become, the more extended is the repair and start-up time. When the pumping stations fail to operate, raw sewage overflows into streets and surface waterways and the risk to public health through direct and indirect contact with contaminated food or water is enhanced and geographically extended.

The possible ramifications of environmental sanitation breakdowns that we are cognizant of today are broad indeed and may play a major role in public health. For instance, flooding frequently leads to rat and snake infestations of the higher elevations to which the residents flee, posing a public health problem. Mosquito-borne disease outbreaks such as St. Louis encephalitis are known to have occurred following flooding. In 1976, spring flooding in states located along the Missouri and Mississippi Rivers resulted in an extraordinarily high mosquito population. This facilitated extensive outbreaks of St. Louis encephalitis virus infections in these states. Mosquito control facilities were not available in some of the states, while in others the magnitude of the problem overwhelmed the existing capabilities. This accentuates the need to consider these activities within the scope of flood hazard mitigation planning.

It should be noted that in areas where untreated groundwater is used, little is known about the number of enterovirus infections which occur during the months following flood events, nor do we know the long-term effect of such infections. Virus contamination of groundwater after flood events is most probable because of possible raw sewage spills and the ability of heavy rains to desorb viruses which have been concentrated by adsorption to soils from the septic tank leachates and/or secondary effluents used for spray irrigation. This latter practice is becoming much more commonplace in the United States today and may increase post-flooding problems. Preliminary evidence of this has been accrued in Florida over the past few years in an area of extensive septic tank usage and secondary effluent spray irrigation. Asceptic meningitis cases began as flood waters receded, continued over a three-month period and appeared to be a propagated epidemic, i.e., a single source epidemic which continues over a period of time because of intermittent contamination of the source. Such intermittent virus contamination of groundwater has been demonstrated at spray irrigation sites. It is true that many enterovirus infections occur from person to person contact but hepatitis and, more recently, rotavirus and enterovirus outbreaks have been shown to be waterborne (Wellings et al., 1975; Hejkal et al., 1982).

Whether or not long-term effects of flood events can be related to environmental sanitation breakdowns is still a moot question because research into the long-term physical health of survivors has been quite generalized for the most part. Three years after the Wyoming Valley, Pennsylvania, flood in 1972, caused by tropical storm Agnes, the exposed study group of 43 males did not show any greater number of different kinds of illnesses than did the control group of 48 males, but their recovery time was extended (Melick, 1976). Conversely, five years after the flood, 407 female flood respondents showed a significant increase in physical health effects (gastroenteritis, constipation, severe headaches, bladder trouble) than did the 155 female control group (Logue, 1978). In the Bristol, England, flood of 1968 a higher surgical rate was noted in males who continued to live in their homes following the flood (Bennet, 1970). In the Brisbane, Australia, flood of 1974, the number of visits to physicians and hospitals over the year increased in the flood exposed group (Abrahams et al., 1976). There is little doubt that psychological problems are frequently expressed by physical symptoms, but on the other hand, psychological stress also lowers resistance to microbiological invaders.

Recently a more specific study has been reported (Janerich et al., 1981). In New York State following flooding due to tropical storm Agnes, a 35% rise in the spontaneous abortion rate started six months after the flood event. Approximately two years after the flood, the rate of leukemia and lymphoma showed a significant increase in towns bordering on streams compared to non-river valley towns and upstate New York. The role of viruses in the aforementioned diseases has not been demonstrated but a viral etiology is suspected. Because raw sewage may contain as many as 200,000 virus particles per liter (Nupen, 1976) of over a hundred different virus types, one must question the role of environmental sanitation breakdowns in these various illnesses.

The loss of water service during and after a flood event may or may not be less serious than the loss of wastewater treatment. First of all, if sewerage were contained during a flood, the threat of contaminated groundwater could be confined to areas served by septic tanks and those utilizing secondary wastewater for spray irrigation. Farms with livestock or livestock holding pens; landfills; and open dumps are other sources. Secondly, disease transmission via water can readily be avoided by the simple expedient of boiling the water, disinfecting it or using bottled water when available. After flood events, containerized water should be obtained from outside of the affected area to preclude the distribution of contaminated bottled water, such as has occurred in the past.

However, the length of time during which the groundwater may be contaminated with viruses after flood waters have receded and the usual precautions discontinued, has not been determined. Bacteria die off rather quickly in the absence of their vital nutrients. Thus, groundwater is usually declared to be potable within a week or so after the flood, based on bacterial tests. Unfortunately, viruses which are inert when outside of a living cell, and require no nutrients, may survive for relatively long periods of time in groundwater and thus persist after the usual precautions have been terminated.

The relatively recent recognition of chemical contamination of groundwater may prove to be even more threatening to public health than the long recognized microbiological contaminations. Bulk chemicals are being shipped throughout the nation in unprecedented volumes and stored in flood prone areas or even on barges. Industrial use and spillage of chemicals onsite pose potential groundwater contamination concern, especially when the industry is located within a flood plain. What, if any, planning has been done to protect people from these chemicals during a flood? The carcinogenic potential of many of these should serve as the impetus to inventory and insure containment during and after flood events.

Evacuation Procedures

Early evacuation is critical in flood events if loss of life is to be avoided. Evacuation of the handicapped and elderly was addressed previously because of the special problems associated with those particular groups. However, because of the unprecedented migration of the population to coastal zones and barrier islands, evacuation of residents from these areas requires special attention.

Instead of barrier islands and coastal areas serving as vacation retreats which increases the seasonal populations only, condominiums are being built for year-round residents numbering in the millions. Usually no long-term planning for the health and safety of the residents is a part of these developments. Nor is the protective effect of barrier islands considered. There is little doubt that residents of these areas are at great risk during a hurricane and its attendant flooding.

A major evacuation problem is the limited access to coastal zones and barrier islands. Usually there is a single major highway or a bridge available which thousands of people must use in evacuation of the areas. In the case of barrier islands, the lone bridge, which is itself subject to damage, may lead into the major highway crammed with coastal zone evacuees, precluding evacuation of residents from the islands.

Many coastal and barrier island communities have developed evacuation procedures but they remain untested for the most part. The critical issue is: How well have neighboring communities plans been integrated? In hurricane prone areas a regional approach to flood hazard mitigation planning is vital because of the usually wide geographic area affected by a major hurricane.

In view of the inevitable overcrowding of highways and bridges during evacuation, perhaps alternative responses should be thoroughly investigated. Are there buildings in existence in the area which could be used as on-site refuges? Would a change in building codes provide for such refuges? How would sanitary, nutrition and medical services be provided to the refugees stranded in such buildings?

If there is no alternative to evacuation, what is the minimal lead time for safe evacuation? What are the criteria for evacuation? Unlike flash floods when the event is in progress before a warning may be issued, advance warning can be provided for hurricanes. Unfortunately, the erratic nature of these storms makes land-fall prediction difficult. If safe evacuation is to be accomplished, it has been suggested that a 24-hour warning would be required in most coastal and barrier island areas. But in 24 hours, a hurricane may change direction or merely mark time. The effect on evacuation warnings of such a situation tends to decrease the public's conception of the validity of the warnings and result in noncompliance with the evacuation requests. To leave one's home unattended during a hurricane is a difficult decision at best, but after experiencing even one false alarm, many people would find it impossible to do. Therefore, a major need if safe evacuation of residents is to be accomplished is more accurate forecasting and timely warnings.

Emergency medical plans and search and rescue operations are vital components of flood hazard mitigation planning. Unfortunately^ a data base for effective planning is not available. This is probably the reason that they were not included in a very detailed and extensive flood hazard mitigation plan developed for Sanibel Island, a barrier island off the coast of Florida. There is no hospital on the island and only one ambulance with two technicians is available to meet the medical emergenices of between 5,000 and 10,000 people during evacuation. Although the need for search and rescue was acknowledged, no specific planning as to how this would be accomplished was included in the plans.

SUMMARY AND RESEARCH NEEDS

As stated in the introduction, public health is impacted by all facets of flood hazard mitigation. Thus, research which would result in improved forecasting, more timely evacuation warnings, sustained communication channels, etc., would be of distinct value to public health aspects of flood hazard mitigation. This suggests that many of the needs must be met through a multidisciplinary approach. This is particularly true for the first research need listed below. All of these research needs are deemed critical by the criteria used in this project (see Chapter 1).

1) Development of a systematic data base for the various types of floods. A multidisciplinary team should be established as soon as possible to evaluate current data and, based on deficiencies noted, to develop the components of the desired data base. Of primary concern from the public health aspect, would be to define the nature of the data base that would provide maximal probability of relevance to future flood related morbidity and mortality and to develop procedures for collecting these data most efficiently. This is the pivotal issue to which all research needs would relate.

2) Development and execution of appropriate epidemiological studies. Once the systematic data base collection procedures are established, a team(s) of epidemiologists should be established, probably under the aegis of CDC or perhaps state health departments. When a flood event is imminent, the team(s) should be dispatched to the area to take an active part in activities including analysis of data and determination of appropriate countermeasures before, during, and after the flood.

3) Determination of the appropriate land use and management measures to be used to reduce pollution, i.e., chemical, microbiological, runoff, etc., and to reduce flood hazards in general.

4) Evaluation of present methods of maintaining wastewater treatment services during floods and determining specific needs for assessing such services during and following flood events.

5) Determination of the effect of evacuation procedures on morbidity and mortality both on the short- and long-term basis.

6) Evaluation of all available flood hazard mitigation plans to determine the weaknesses and strengths of the various plans with a goal of developing a master plan for different types of floods.

7) Evaluation of the success or failure of the various mitigation plan components following different types of flood events.

8) Determination of the effect of flooding on the quality of groundwater and surface water used as potable sources, including bacteriological, virological, and chemical contaminants.

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CHAPTER 6. AN AGENDA FOR ECONOMIC RESEARCH ON FLOOD HAZARD MITIGATION

CONTENTS

CHAPTER 6. AN AGENDA FOR ECONOMIC RESEARCH ON FLOOD HAZARD MITIGATION

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INTRODUCTION

Purpose

The purpose of this chapter is to set forth an agenda for needed economic research in the field of flood hazard mitigation as part of a multidisciplinary effort to develop a comprehensive plan of research as commissioned by the National Science Foundation. After expressing concern that efficient flood hazard mitigation may not be desired as a goal of public policy, six major lines of research are outlined. First is the task of reformulation of the problem of flood hazard mitigation from an emphasis on hazard reduction *per se* to one of an efficient use of flood-prone lands and development of socially acceptable levels of residual risk. Second, there is need to specify more clearly what is the economic rationale for public action (particularly in a federal system) in flood hazard mitigation in relation to the role of markets and private choice. Third, research is needed to specify in theoretical and in operational terms the efficient level of mitigation. Fourth, the question of what constitutes a proper measure of loss is of critical importance. Fifth, economic evaluation of existing institutions and policies in the flood hazard field is clearly needed. Finally, benefit-cost studies of selected mitigation measures are proposed. An overlying concern throughout the chapter is that present institutional arrangements may act as barriers to efficient policy and obscure the rationale for other kinds of economic research.

Background

The traditional rationale for more economic research on flood problems and measures to mitigate the hazards of coastal and riverine flooding can be briefly summarized. It is usually stated that after many years of construction of flood control works and with the implementation of various programs of non-structural measures (often said to be inadequate), floods are still the most destructive of natural hazards in the United States. Economic damages from floods in 1974 were estimated at $3.5 billion (National Science Foundation, 1980). Losses are expected to rise to $4.3 billion in 2000 in 1975 dollars. It is asserted that the populations at risk are increasing and that rising flood losses in the future will cause large social and economic burdens on flood plain occupants and taxpayers alike. Sometimes it is asserted that use of flood plains is uneconomic (Water Resources Council, 1979).

These kinds of statements are often followed by a call for more innovative approaches and increased attention to the flood problems of the nation. We are then told that past efforts to mitigate the flood hazard problem are not succeeding. The presumption is that more research on the economics of flood hazard mitigation is needed to reduce the expected increased flow of damages in the future. Such arguments have been used as the reason for setting an agenda of needed research on flood hazards and their mitigation (National Science Foundation, 1980).

Three Serious Concerns

Before setting out on this task, it is important that some common notions in the flood hazard field be examined in a skeptical light. First, it should be understood that the existence of damages (actual or potential) is not proof *per se* that there is a problem of too little flood mitigation. Emphasis tends to be placed primarily on damage costs and not on the costs (which are also real) of mitigation or adjustment. Flood losses in a given situation may be too small as well as too large, but we can not know unless we compare expected costs of control with expected damages to be averted. Only if expected losses averted exceed expected costs is more mitigation warranted. By contrast, if the expected costs of adjustment exceed expected benefits, then we will have too much flood protection. Without research on this matter, it is not at all evident whether flood protection is too little or overextended. Recitation of damages from flood without such comparisons is clearly misleading. Efficient use of flood-prone lands is desirable; not hazard reduction *per se*.

A careful study of the recent flood mitigation literature shows almost no recognition of this basic logic* How much should we spend on flood hazard mitigation? What is the efficient level of risk we wish to tolerate? What is a socially acceptable level of residual risk? Clearly, economic research on the measurement of expected costs and expected damages averted is needed if we hope to define an efficient level of hazard mitigation even in an approximate fashion. Systematic statements must be available on these figures if we are to have a rational basis for policy.

Second, it should be stressed over and over that good research and good policy need a reliable data base. That there are serious problems in the quality of the existing data base for natural hazards (e.g., Wright and Rossi, 1981) has been mentioned since the late 1930 s, but little has been done about the matter. Because of poor data quality, we do not know the precise magnitude of the flood hazard problem or its relation to other problems in society.

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*It should be noted that correct economic statements about the optimal amount of flood protection appeared many years ago, e.g., James, 1965; Krutilla, 1966a; Lind, 1967; and Russell, 1970. I suggest below that the problem is that these writers have been ignored in the practice of benefit-cost analysis for flood projects in federal agencies.

White and Haas (1975), for example, point out that estimates of economic losses from disasters can be off by a factor of two or three. Such crude estimates of losses are often accepted as a basis for policy. Even the estimates of annual flood losses cited by NSF above can be sharply questioned.

Is it really possible that we have very little notion of the extent of the flood damage problem in economic terms? After reviewing the literature, I now believe that this may well be the case. The problem is not just that the data are imprecise, unorganized and lack commonality. It is even more basic than that. I will argue below that there is not common agreement on what constitutes a proper measure of flood damage. I believe that a major reconsideration of the proper measures of flood losses is needed. Current concern that we need more action to deal with expected flood losses probably should be preceded by research that we better define and measure what losses are expected before a comprehensive research policy on floods is formulated.

A third area of concern deals with the role of federal policy for flood protection and its effects on the level and mix of mitigation measures adopted. Following the Flood Control Act of 1936, federal water resource agencies have been required to evaluate proposed flood control projects using benefit-cost analysis. It has also been consistent federal policy to pay nearly the full cost of control with federal funds so that the beneficiaries see only a small part of the costs of flood protection. Correct policy requires that beneficiaries see the costs so that local contributions are required. Recently there has been a trend toward more local cost-sharing.

For many years it has been asserted among economists (e.g., McKean, 1958; Fox and Herfindahl, 1964; Krutilla, 1966b; Haveman, 1972; Cicchetti et al., 1973; Carroll et al., 1979) that the benefit-cost procedures used at the federal level systematically exaggerate benefits and understate the costs of flood control so that projects selected are not efficient. Next, these critics point out that federal project appraisals are not subject to independent, objective review. Finally, they emphasize that the failure to require extensive cost-sharing not only affects the incidence of benefits and costs (a distribution question of equity) but also the efficient level and mix of protection measures (Krutilla, 1966a; Milliman, 1969). Subsidies for structural alternatives have traditionally worked to the disadvantage of nonstructural measures (White, 1964). Subsidies (including subsidies for flood insurance) may make benefits for flood plain development appear larger than they would otherwise be, thus encouraging overdevelopment of flood plains. If this is the case, flood damages might well increase, not in spite of flood hazard mitigation policies, but because of them! Although it is widely believed that such charges are true, the evidence is more suggestive than definitive. It would seem that research by economists and other social scientists could pinpoint the role of cost-sharing and federal evaluation policy in choices among mitigation policies, and especially in the question of whether potential excess flood plain development is encouraged in part by federal policy.

If these federal barriers to economic efficiency prove to be important and if they are allowed to persist, then one might well wonder if general economic research on flood hazard mitigation should have a high priority at all. The dilemma posed here is a real one. If we assume for the moment that the "pork-barrel" and subsidy philosophy for federal flood protection is significant and not subject to change, would it make a great deal of sense to be terribly worried about the needs for additional economic research on flood hazard mitigation? In this situation it seems to me that one has to believe federal policies are subject to modification if one is to advocate a high priority for the economic research. Recently, there have been efforts at the federal level to provide for more local cost-sharing and somewhat tighter economic analysis. There has also been a trend toward nonstructural solutions which may mean less emphasis on the "pork barrel" approach used in structural measures. I will assume in the following discussion that economic evaluation of existing federal flood policies will be given high priority. It is entirely possible that the question of the efficiency of federal policies on project evaluation and cost-sharing may dominate the efficiency results of the other types of economic research on flood hazard mitigation.

In summary, it appears that sound economic concepts have not been employed in the goals of flood hazard mitigation nor in the policies followed. No credible estimates of benefits and costs of current programs exist despite the expenditure of billions of dollars. Even more worrisome is whether the achievement of an efficient flood hazard mitigation is really desired. The incentive system in terms of the distribution of gains and losses from current public policies may well work to preserve cost-sharing and relief policies that work against economic flood plain development. The weak level of concern for natural hazard mitigation at state and local levels (Wright and Rossi, 1981) may be explained in large part by these federal policies as well as by the inadequate information on expected benefits and expected costs of various measures.

GENERAL DIRECTIONS FOR ECONOMIC RESEARCH

Return to Basics: Square One

I think it is important that a discussion of an agenda for economic research on flood hazard mitigation begin with a return to basics. Before moving on to general topics and specialized technical subjects we need to consider the issues of why, what, and how in flood protection.

The need to return to basics stems from the state of the recent literature on flood hazard mitigation. In my opinion, this literature is weak in its economic underpinnings and the economic analysis tends to be superficial. This contrasts with the earlier literature cited above. Starting with the 1980 report by the National Science Foundation the only economic research cited are works by Cochrane (1975), Kunruether *et al*. (1978), Rose (1980), and Vinso (1977). The most recent work on the economic impacts of natural disasters are studies by non-economists who find no discernible long-run impacts to communities struck by natural disasters (Friesema *et al*., 1979; Wright *et al*., 1979; Wright and Rossi, 1981). Criticism of these studies in terms of their economic analysis is warranted. The extent to which the economic base is damaged is very important. The cases examined by Friesema _et al_. and by Wright and Rossi reveal that the disasters did not seriously damage the economic base of the areas hit. Therefore, their findings should come as no surprise.

The work by federal economists as exemplified by the Water Resources Council's (WRC, 1979) procedures for evaluating benefits and costs of flood control protection is limited on the one hand by federal policy constraints on benefit estimation and cost-sharing. On the other hand, the WRC evaluation procedures are confused on the relationship of physical damages (stock concept) to income losses (flow concept) and these damages to land market values. For example, in evaluation of urban flood plain protection the WRC (1979) had three benefit categories: 1) inundation benefits, 2) intensification benefits, and 3) location benefits. Using these three concepts involves double counting. In addition, WRC lists three types of damages: 1) physical damages, 2) income losses, and 3) emergency costs, with no recognition that these can not be additive. As discussed below, similar confusion between stock and flow concepts of damages are frequent in the literature (e.g., James and Lee, 1971; Cochrane, 1974, 1975). Both James and Lee and Cochrane sum up direct damages to property and indirect damages for income losses without recognition of the problem of double counting.

The theoretical and empirical advances made in environmental economics in recent years, which are closely related to the natural hazard field in terms of type of problems studied and economic methodology employed, may make them rather easy to borrow for prospective flood hazard research. For example, _The Journal of Environmental Economics and Management_ is full of excellent analyses using benefit-cost techniques for valuation of changes in environmental quality that go beyond the level usually found in flood hazard analysis. An excellent monograph reference is Freeman's (1979) review of the theory and practice of benefit measures of environmental improvement. A similar monograph on the economics of flood hazard mitigation probably would be helpful to current researchers.

Economic Rationale for the Public Role in Flood Hazard Mitigation

In the Flood Control Act of 1936, Congress took the first steps in assuming responsibility for flood protection on a nationwide basis with the declaration that "Flood control on navigable waters or their tributaries is a proper activity for the federal government" (Haveman, 1965, p. 6). This act initiated one of the greatest public works programs ever seen. In 1938, the act was amended to provide that the entire cost was to be borne by the federal government. Haveman quotes Senator Vandenburg in a prophetic warning at the time saying:

> Let it not be overlooked that this is the first time in 150 years of American history when it has been proposed to assert that floods upon practically all the rivers of the United States constitute a menace to national welfare and are a federal responsibility. The moment we have accepted that responsibility--we have accepted it for every navigable stream in 48 states of the Union; and the human imagination can hardly

encompass the total extent of the burden and responsibility which is thus laid at the door of the Treasury of the United States by the adoption of this policy." (Haveman, 1965, pp. 6-7).

In an appraisal of this policy Haveman found that:

> " . . . Congress, the Bureau of the Budget, and the Corps have acted mainly on grounds of expediency, political or otherwise, and that while paying lip service to pure economic efficiency (the benefit-cost ratio) their primary objectives have been multifaceted. The degree of distress or poverty of a particular area, the economic development of a particular area, and sheer political maneuvering are all shown to have played some role in the allocation of appropriations in the past. (Haveman, 1965, p. 10).

A review of the flood hazard literature makes it clear that the economic rationale for public action in the field of flood hazard mitigation is not well specified. The rationale, when developed, should provide justification for different policies for different types of mitigation. Moreover, we would better understand the potential role for private markets and individual choice as opposed to direct public regulation.

Definition of what kinds of market failure are present is necessary in analyzing prescriptions for improvement. In fact, a key assumption in the valuation of the benefits of flood hazard mitigation policy is the value judgment that social welfare is to be judged by individual perceptions of their own needs and wants. This assumption or value judgment needs to be discussed at the outset because it is central to the examination of the relative roles of private markets and the government in the provision of flood protection deemed socially desirable. Finally, the analysis of the public role must confront the questions of financing, cost-sharing, beneficiary charges, subsidies and price policy. Public provision of a service does not have to imply subsidized service. The rationale for subsidies should be compared with the redistribution effects. Judgments need to be made about the equity effects on those who bear the costs versus the groups who gain. At the same time the possible adverse efficiency effects of subsidized flood protection may offset, at least in part, the efficiency rationale for public action in the first place.

I will list and discuss briefly the rationale for public intervention in private decisions regarding the provision of flood protection, use of the flood plain and the bearing of risk. The discussion here is merely to illustrate the kind of analysis that needs to be performed.

1) It can be asserted that ignorance of the risk of floods causes unwise flood plain occupancy. It is possible that people have too little knowledge of the consequences of low probability-high risk events and therefore misjudge the situation. As Lind (1967) points out, flood plain zoning can be justified only because of ignorance of flood hazards. Presumably if individuals had knowledge of expected losses, location in the flood plain would be economic if the expected gains plus a risk premium outweighed the expected losses. If there is a problem of ignorance preventing efficient market decisions, then

alternative solutions such as provision of better information, compulsory insurance or flood plain zoning can be better evaluated. An important research question might be: "How can this 'ignorance' be tested versus a hypothesis that income redistribution is the motivation for flood plain zoning?" Another hypothesis to be tested is to determine whether individuals incorrectly perceive risks in decisions to locate in the flood plain.

2) Closely related to the question of ignorance of risks in low-probability events is the question of market failure by individuals in processing information of such events. Kunreuther (1976, 1978) reports that households fail to purchase earthquake insurance, even when it is in their interest to do so, in terms of the expected utility model. The Kunreuther argument can be used to justify compulsory insurance and regulation of land use and construction practices.

   Roberts (1982) has argued that the Kunreuther argument that individuals "misprocess" information (not the argument that individuals do not have correct information discussed above) is based upon the assumption that preferences depend only upon wealth. If preferences depend upon factors other than wealth such as irreplaceable objects (which seems reasonable), then the rational individual may not insure at all even when faced with "fair" insurance. Roberts also argues that the amount of insurance purchased by individuals and the amount of other mitigation undertaken along with insurance will not cause a misallocation of resources as long as the insurance is offered under competitive conditions. Research on possible imperfections in the insurance markets seems to be warranted to help deal with these issues.

3) Is the flood control protection a public good, given that it is equally available for all and that one's consumption does not interfere with others' consumption? If there is a public good aspect to flood protection, we can point to market failure as a basis for public protection. There is substantial literature on conditions under which public goods can be provided efficiently by the private market and conditions under which the private market will fail. It would appear that some kinds of structural approaches to flood control have public good aspects. Yet, this extensive literature on decision-making for public goods has not been applied to the flood control case. How do we get preferences revealed and prevent the "free rider" problem? What is the efficient level of protection and how are the investment costs to be covered?

   With the turn toward federalism in water projects and more local responsibility for flood mitigation, the question of which level of government should provide public goods rises to the forefront. Much of the new flood legislation implies that actions will be carried out and financed at the local level. The provision of local public goods will be subject to different cost constraints and to different perceptions of benefits than the older federal approach.

4) Closely related to the public good issue is the question of efficiency of large-scale of operation. Are certain aspects of flood protection to be approached in the "natural monopoly" context of a single supplier for the region as a whole. Again, the general literature on this question is extensive but there has been little application to the flood protection case.

5) Is the rationale for flood protection one of divergence of marginal private and social costs because upstream actions can have substantial effect on downstream flood plain occupants? It is true that the kind of development (and also the kind of flood protection) upstream can drastically affect the frequency and level of flows downstream. Therefore, private property decisions may not be in accord with the social welfare.

6) It may also be that the stream and its flood plain should be managed as a unit in order to maximize the total social product in a multi-purpose context. This argument would give particular justification for federal or regional responsibility when a multistate region is involved. Note, however, that this rationale is an efficiency one which does not carry with it the presumption that flood control services should be subsidized.

7) Finally, it could be argued that flood protection should be provided as a way to subsidize regional economic development or to redistribute income to certain groups. Again, the general literature for these sorts of rationale for public subsidy is quite extensive. If these arguments are applied to flood protection, it must be shown that these measures are efficient or least-cost ways of securing regional development or redistributing income to favored groups.

8) In regard to special aid given to persons and to regions following a disaster, the intent or rationale has not been well defined. Nor have the results of the aid in terms of these efforts on efficient development of flood plains been thoroughly analyzed, although Kunreuther (1973) and Cochrane (1975) have gone part way. Why is it that victims of natural disasters receive special treatment above and beyond that accorded by national welfare policies for dealing with poverty and misfortune? Is it desirable to separate disaster relief from other forms of social relief? Why are we treating the cause and not the condition? These kinds of issues have not had serious attention.

The Efficient Level of Flood Hazard Mitigation

It was argued above that the existence of flood losses is not evidence that there is too little mitigation or that the losses should be reduced. The notion that there is an efficient level of flood hazard mitigation has not received sufficient attention in the literature although the concept has been well discussed in environmental economics.

Russell (1970) was one of the first writers to define the optimal adjustment to a natural hazard as illustrated in Figure 1. Similar diagrams are now found in most text books in environmental economics. On the horizontal axis is the relative level of adjustment (A) to a given natural hazard. The vertical axis measures annual dollar amounts (they can be shown in present value terms). The curve C is the annual total cost of achieving various levels of adjustment. Usually, the costs of adjustment climb rather rapidly as the level of adjustment is increased. The curve L represents the expected total losses which often decline rapidly at first for initial levels of adjustment. The efficient level of adjustment is the one which minimizes the sum of L and C. This is shown at A*. To the left of A* the extra losses avoided are greater than the extra costs of adjustment. To the right of A* the extra costs of adjustment exceed the extra losses prevented. Note that residual losses or residual hazards persist or remain at the efficient level of mitigation. Moreover, extra benefits (losses averted) exceed the extra costs of mitigation. Most of the flood mitigation policies I have studied do not systematically compare the costs of mitigation with the expected losses to be averted.

Several comments need to be made about this diagram and its logic. First, minimization of the sum of the costs of adjustment and the damages averted should not be taken to mean that net efficiency in flood land use is neglected. The costs of adjustment properly defined should include all activities foregone by the use of the flood plain for one activity as opposed to other uses (including possible environmental benefits conferred by floods). This means that minimizing total social costs is another way of expressing maximization of the net productivity of the flood-prone land. Thus, there should be no conflict in benefit cost analysis, properly done, between maximizing net social productivity or alternatively minimizing the sum of total social costs.

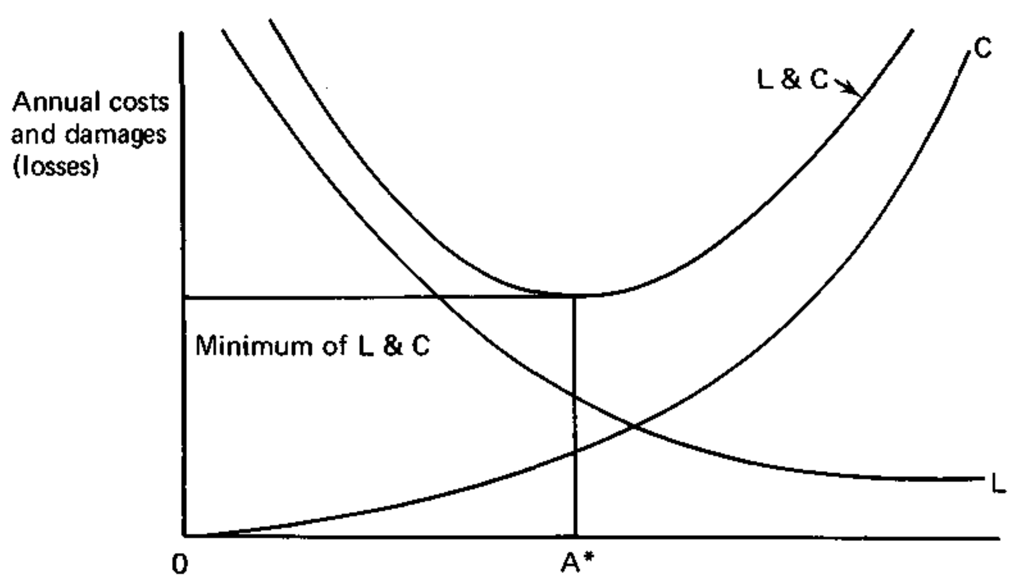

Figure 1. The optimal level of hazard mitigation.

Second, one would expect the curves in Figure 1 to shift to the right with the growth in economic activity and population. Therefore, one would expect the optimal amount of residual losses to increase over time. Thus, increases in flood losses over time should not necessarily be viewed with alarm. This point was clearly made by James (1962, p. 20) but neglected by the NSF report (1980).

To some people the notion that there is an optimal level of hazard mitigation is a very disturbing idea. Yet, it is difficult to argue that all amounts of expected residual damages from natural hazards should be eliminated despite enormous costs. Again, what is an acceptable level of residual risk? Of course, how one applies the logic developed here can be a source of controversy. Estimation of the L and C curves will always be a difficult task for which there may never be precise answers. Two sets of probability calculations are involved. First, what is the probability of a flood? Second, what is the probability of loss given an event? Neither calculation is easily defined or measured. How conservative or careful should we be?

It is also clear that the distribution of costs (who pays) and the benefits (whose losses are reduced) will influence decisions and can be a source of public debate. Nevertheless, the notion that there is a theory of optimal adjustment to natural hazards is central to policy formation and implementation. We must take care to be as precise as possible in estimation of expected losses to be averted and expected costs of various mitigation practices. Our goal should be the socially efficient use of flood-prone lands.

Proper Measures of Flood Losses

The social losses from floods include the following: 1) deaths; 2) injuries; 3) psychological trauma; 4) social dislocation; 5) property damage; and 6) the disruption and alteration of economic activity. There are also costs which may stem from particular kinds of hazard mitigation measures. For example, opportunities for use of the flood plain foregone by flood plain management are often neglected. Also, it is possible that risk-bearing can be considered a cost of flooding when individuals who are risk-adverse would be willing to pay a premium to change the distribution of losses (Lind, 1967).

Some of these losses readily lend themselves to quantification in monetary terms such as property damages and measures of the losses of regional income. Some progress in the economic literature has been made in the valuation of longevity and the marginal value of safety. Advances in state preference theory and decision making under uncertainty have been made. Use of non-market approaches, how to aggregate individual welfare functions, and the use of property values as measures of benefits have also been carefully explored. Yet few of these innovations have been recognized in the flood hazard literature.

The appropriate measures of losses and benefits and, hence, the optimal level of mitigation will depend upon individual preferences, technology, subjective probabilities of disasters, and the existence of markets for risk bearing. The conceptual framework for individual choices for hazard mitigation has been set forth by Roberts (1982). It is an extension of the state preference approach using contingent claims on economic goods and services as well as other measures that affect the individual's well being, including physical injury and irreplaceable objects.

Before turning to suggestions for research regarding these innovations it is necessary to emphasize that there is no common agreement on what the proper measures of loss should be. I believe also that much of the current discussion of measures of flood damage involves confusion between stock and flow aspects of economic activity. Adding together property damages and income losses inevitably results in some degree of double counting. Properly defined property damages should represent the present value of expected losses in net incomes or expected losses of value added in production. It is incorrect to add together property damages and income losses. It is also incorrect to estimate income losses as some fraction of property damage as is often done. Moreover, it is also incorrect to use conventional property damage estimates as a surrogate for expected income losses. Conventional property damage estimates are based upon crude estimates of book values or replacement costs and thus may bear little relation to the present worth (or capitalized values) of expected income losses.

Because of the confusion regarding which proper measures of flood losses to use in deciding upon the efficient level and mix of mitigation measures, a very high research priority should be given this matter. The very heart of evaluation procedures is involved. After agreement has been reached upon the proper measures and how they should be employed, then it would make sense to improve the collection of data on flood losses and improve systems for estimating expected flood losses under various situations. However, the whole question of what the proper measures are must be decided first. It could very well be that the damage-frequency curves so long used by hydrologists and civil engineers may need to be modified to coincide with proper or improved measures of losses! We must be assured that estimates of damages are conceptually correct and coincide with the proper economic measure of benefits! Then we can search for better data.

I believe that proper measures of economic losses stemming from a flood or threat of flood can be either a flow concept or a stock concept. In theory, the stock concept would be the market's estimate of the loss of capital value of all assets (including human capital) reflecting expected future income losses. The flow concept would involve computing the present value of the expected losses in net income (value added) over a stream of future time periods with and without the event. The expected losses could be computed for a range of probabilities. In theory, the present worth of the expected loss of net income would be equal to the estimate of total capital loss.

Adding together property damages and income losses involves a confusion between stock and flow concepts of economic activity. Therefore, such a procedure inevitably involves some double counting. References to WRC benefit and damage calculations were made above. Presumably the damage to property causes a loss of income-producing potential. Properly defined, then, damages should represent the present value of expected losses in net incomes or value added. In turn, this concept could apply to reductions in the value of human capital as well as non-human capital even though market analogues of the value of human capital are not as evident as market values for other forms of property (capital stock). Conventional property damage estimates may be based upon crude estimates of book values or replacement costs and thus may not accurately reflect the present worth (or capitalized value) of expected future income losses.

For some factors such as labor, we should use the income differential approach. For other factors, such as owner occupied housing, it is probably easier to use the stock value differential approach.

If we take the income (or flow) approach as a measure of loss we should try to measure the fall in real income caused by the event relative to what it would have been without the event. We must not fall into the conventional trap of comparing economic activity before and after; the correct comparison is a with and without an event. In other words, we would need a baseline forecast of expected income for the period without a disruption to compare with the change in income expected to result from the event. Therefore, the degree of recovery should be measured not in terms of the former level of activity but rather relative to the expected level without the disaster. In addition, the analysis of income losses should extend over successive time periods (several years if necessary) to pick up production losses that might persist into the future. Finally, the sum of the expected losses in income should be converted to present value terms.

Of the various measures of disruption of economic activity (income losses) available to economists, which measure is the proper one, and can reliable estimates of it be made? Measures of reductions in employment and the loss of wages from baseline levels are useful indicators of losses. However, they are incomplete or partial measures because losses in labor income may reflect only two-thirds of the income losses. What about changes in the Gross Product (value of all final goods and services produced). This is a familiar measure of economic performance. Gross Product is defective on several counts. Most importantly, it includes the value of intermediate goods and services imported into the region to produce the final products. In addition, allowance would have to be made for depreciation to compute net product. Also, techniques and data for estimating Gross Product at substate levels are not available on a regular basis.

The ideal measure of economic disruption would be the change in value added with and without the event. Value added is an estimate of the extra production (output) contributed by labor, capital, and land within the economy. The value added concept would be equal to the' incomes of labor, capital, and other factors of production resulting from production in the economy. By contrast, personal income of residents would count all wages, salaries, rent, interest, and profits received by individuals in the system regardless of whether the production actually took place in the economic system. Estimates of value added at the substate level are difficult to make. On the county level it is possible to make estimates of total personal income of residents on a consistent basis. If we have some notion of the portions of personal income that are transferred into the region, e.g., interest, rent, and dividends received by individuals from entities outside the region, we can come pretty close to approximating value added.

Ironically, the loss in real income which may result from displacement of persons or the inconvenience of living in damaged or temporary shelter will not be picked up in a conventional estimate of values added lost in the disaster. In practice the value added concept concentrates on the output of marketable goods and services which might be little affected by the housing inconvenience of some workers as long as they reported to work. Therefore, the value added concept as conventionally measured will understate the real income losses of disasters from damage to the housing sector.

To summarize, the proper measures of economic losses stemming from property damages and economic disruption of a flood or a prediction of one are either a flow concept or a stock concept. The stock concept would be the market's estimate of the loss of capital values of all assets reflecting future incomes or productivity lost. The flow concept would involve computing the reduction in expected values added over a stream of future time periods with and without the event. The present worth of this loss of value added should be equal (in theory) to the estimate of total capital loss. Conventional measures of loss which add together direct property damages and losses in economic activity due to disruption involve double counting.

It is clear that the theoretical equivalency of the flow and stock concepts will not be achieved in the real world. Markets for all assets do not exist (e.g., market values of human capital) or are incomplete, and equilibrium conditions may not be present. The most practical avenues to explore are ways to estimate expected income losses in present value terms. By contrast, the sum of the repair or replacement costs for physical property (assuming that the post disaster decision would be to restore the same structure of production) would at best be only a partial measure of the expected income loss depending upon the income or value added by the other factors of production. At best, frequency damage curves for physical property are only approximate measures of the present value of expected income losses.

Some Caveats

Several cautions need to be borne in mind relative to this discussion of proper measures of losses. First is the question of practicality regarding correct, but complex, measures of losses. For minor disasters, where only a small part of an economy is damaged or where the economic disruption is short-lived, it makes little sense to build a complex economic model to sort out the correct measures of damages. Many flood events are of this nature. By contrast, persistent and repeated serious flooding over a large region affecting a large economy could be a case where building an economic model is justified. It is also evident that the time and effort one should spend on benefit-cost analysis should be related to the size of the effort being considered. Crude economic analysis will often suffice for minor, low-budget efforts.

Second, the estimation of losses from natural disasters really should involve taking into account interdependencies throughout a national (or world) economic system. For practical reasons a regional economic approach is recommended because it is more manageable. But, it is clear that regional loss estimates fall short of what we would really like to know about system effects. The question is whether national losses exceed, equal or fall short of estimated economic losses from a regional point of view. To the extent that production gains in other regions can offset or substitute for production losses in a region hit by a natural disaster, national losses will be less than regional losses. I suspect that this is the most likely case.

In other words, regional loss estimates will tend to exceed national loss estimates because of the multiple substitution possibilities among inputs and outputs across regional boundaries. This implies, therefore, that the optimal level of mitigation may be less when the national view point is taken. This also implies that the economic rationale for federalism and for more local control and cost-sharing may be strengthened.

Finally, all economic analysis of gains and costs will benefit from independent review. Economic analysis can easily be skewed and abused.

Economic Evaluation of Existing Public Policy and Institutions for Flood Hazard Mitigation

As indicated above, it has been charged that benefit-cost studies for federal flood control projects systematically exaggerate benefits and underestimate costs. It is believed that correct project evaluation, reimbursement, and pricing policies cannot be separated. The failure to make adequate beneficiary charges affects the rate of output and therefore the benefit stream. The result, it is asserted, causes uneconomic development of flood plains. Finally, there is considerable concern that independent review is required because strong incentives exist for action agencies who are making economic feasibility studies to select numbers and assumptions that produce favorable benefit-cost studies.

Most reasonable persons agree that there is no substitute for external review. Therefore, it seems important that independent competent economic research be undertaken to investigate these serious charges against federal procedures, projects, and policies for flood hazard mitigation. It is possible that resolution of these questions may dominate the rationale for other kinds of economic research.

Three recent studies dealing with suggested research on mitigation of natural hazards do not directly tackle the issues just raised. The White-Haas *Assessment* (1975), the NSF *Report on Flood Hazard Mitigation* (1980), and the Wright and Rossi *Reassessment* (1981) do not speak to these questions and issues even though considerable emphasis is placed upon the need for more applied social science research relative to the perceived over-emphasis on physical science research. Model building, monitoring and evaluation are discussed. However, a full scale economic evaluation, involving acceptable techniques and estimating procedures, of various federal programs and policies was not discussed or proposed. In fact, it is somewhat puzzling that the serious charges of inefficiency and uneconomic incentives for flood plain development, said to be results of federal policy, were not carefully discussed even though such charges have been widely circulated among social scientists for many years.*

An example of the only oblique attention to the issue is the statement of economic issues for public policy found in the NSF report (1980, p. 120):

> Flood losses are often exacerbated by policies which cause inefficient use of resources and policies which shift the cost burden onto those less able to bear it.

Several observations may be made. First, if flood losses are believed to be exacerbated by public policy, this is surely a matter of study and concern. Second, shifting the cost burden onto those relatively less able to bear it appears to be more a question of equity than of efficiency. Efficiency considerations would require beneficiaries to see the cost, and an efficient pricing structure would attempt to equalize marginal benefits and marginal costs. However, no one would deny that the distributional aspects of how cost burdens are borne is also important. These three reports on needed research for natural hazard mitigation simply do not discuss these matters in explicit detail.

The time is ripe for an economic assessment of existing projects, programs, and policies. We can not seriously propose good economic analysis and economic research on new alternatives without this prior study. The evaluation is also consistent with our earlier research suggestions to develop proper measures of losses and to more carefully define the efficient level of flood hazard mitigation. This is especially important at a time when national policy appears to be changing toward more nonstructural alternatives and more local responsibility.

Benefit-Cost Studies of Selected Mitigation Measures

Damages from riverine and coastal flooding can be reduced by flood control structures, flood plain management and zoning, building codes and flood proofing, stormwater management, coastal zone management, flood forecasting, evacuation, and relocation. In addition, the costs of risk bearing of flood losses can be reduced or shifted by flood hazard insurance and post-disaster relief policies. All of these measures have been widely discussed in the literature and all of these policies have been implemented to some extent. There is not a great deal more that can be added here about the general approaches to flood mitigation.

What is needed, however, is a series of benefit-cost studies to justify the measures. Here are six general guidelines to apply to these individual benefit-cost studies: 1) The benefit-cost analysis should consider market and

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*One of my critics has suggested that similar charges apply to all federal water resource studies and have been discussed elsewhere.

nonmarket benefits and costs where both quantitative and qualitative measures can be employed. It should be conducted with theoretically acceptable measures of benefits and costs. 2) The studies should consider the relationships between cost-sharing, output, and measures of benefits. 3) Moreover, in given situations where alternative mitigation policies (such as transferable property rights) are either complements or substitutes, attempts should be made to determine the least-cost combinations for various levels of mitigation of damages and the costs of risk bearing. 4) Explicit attention should be given to residual risks or expected damages believed to remain at efficient levels of mitigation. 5) Explicit attention should be given to the development of probabilities of various levels of damage. 6) Finally, study should be given the probable distribution of the benefits and costs by income groups, by location, and by economic function. Distributional effects of alternative cost-sharing policies (including beneficiary charges) should be analyzed.

Here are some mitigation measures that deserve special research:

a) The National Flood Insurance Program. The National Flood Insurance Program with its related policies is growing rapidly and now covers approximately 17,000 communities. It is becoming the centerpiece of national flood hazard mitigation policy. Yet, the various costs of the program in terms of preparing maps, technical assistance, and local assistance are not well known. The extent and effects of the subsidy program need careful study. Moreover, the benefits of the insurance program appear to be asserted rather than measured. It is not obvious that FEMA has sufficient professionally trained staff to enable it to carry out the planning functions related to the insurance program. The costs of compliance with the regular phase of the flood insurance program on the part of local governments need documentation. Are the costs reasonable in light of the probabilities of loss? It is critical that a full evaluation be made of this program before more time has passed.

b) Land Use Controls for Flood Plains. Included in this measure are flood plain zoning, purchase of development rights, land acquisition and relocation. These measures are important in the trend toward nonstructural solutions. At the heart of the rationale for land use controls is the widely held belief among flood hazard professionals that development of the flood plain should be discouraged by public policy because the private market would encourage inefficient development. The basic assumption is that ignorance of the expected losses creates poor location decisions. By contrast, do individuals locate in the flood plain knowing that public policy will bail them out when disaster strikes? To what extent is flood plain and coastal zone development really inefficient? Is the provision of flood information to make the land market work more effectively a better alternative than direct regulation? Is it possible that zoning excludes activities that could profitably locate in the flood plain as well as some for which it would not be possible? When is purchase of development rights or outright land acquisition justified? What are the expected benefits and costs? Do the beneficiaries see the costs?

c) Forecasting, Warning and Evacuation. It is generally believed that a national system of flood forecasting, warning, and response would substantially reduce flood losses. The present system is believed inadequate. Documentation of the benefits and costs of enhanced forecasting and warning systems is greatly needed.

d) Building Codes and Floodproofing. Quantitative assessment of the benefits and costs of building codes and floodproofing is not well known. The methodological basis for such a study has been developed for seismic safety codes by Brookshire and Schulze (1980). Cohen and Noll (1981) argue that the primary economic justification for seismic building codes is that structural failures have social costs not taken into account by owners. Similar justification may exist for flood hazard building codes.

e) Relief and Recovery Assistance. The costs and benefits of flood relief and recovery assistance need careful study. Do flood plain occupants and communities assume that such assistance will be forthcoming so that uneconomic development of flood plains is encouraged? How are relief and recovery efforts related to traditional welfare and assistance measures. Is this a proper role for the Small Business Loan Program? To what extent, if any, do relief payments contribute to more rapid recovery? What are the distributional effects of flood relief policies? The federal emergency assistance program is now more closely tied to local participation. How well is it working? Research on these topics is clearly needed.

SUMMARY AND RESEARCH PRIORITIES

This chapter discusses six categories of needed economic research for flood hazard mitigation. First is the task of changing the emphasis of policy from hazard reduction *per se* to a goal of efficient use of flood plain lands. Second, the economic rationale for the public role in mitigation policy is not well defined. Third, research is needed to specify the efficient level of mitigation. Fourth, deficiencies of current measures of losses are identified and research is suggested to develop proper measures of economic losses. Fifth, it is suggested that economic evaluation of existing mitigation policies be undertaken especially in light of policy changes in the past decade. Finally, benefit-cost studies of selected nonstructural measures are proposed because earlier emphasis was on evaluation of structural approaches. Research priorities are identified in the agenda for economic research and policy analysis which follows.

Priority Economic Research and Policy Analysis

1) Work with all groups to achieve agreement on redefinition of the objective of flood hazard mitigation. There is great need for reformulation of the goal of hazard reduction *per se* to one of efficient use of flood-prone lands and the determination of socially acceptable levels of residual risk. Thus, we need to compare gains and costs of all alternative uses of flood-prone lands, the benefits as well as costs of floods, and the benefits and costs of various mitigation policies.

   Efficient use of flood-prone sites can be formulated either in terms of maximizing net social productivity or alternatively minimizing the sum of total social costs. In theory, therefore, there is an efficient level of mitigation which may imply residual risks. The problem is to define a socially acceptable level of risk. This level of risk may be expected to increase as growth in some flood-prone areas takes place.

This research is critical and should be started right away.

2) There is need to carefully spell out the economic rationale for public action within the context of individual choice:

a) We need to understand better how individual choices are made and what the foundations of value are. The emerging dispute between Kunreuther and Roberts about the theory of individual choice for low probability events is indicative of the need to re-examine utility maximization when there are multiple dimensions to wealth, in addition to nominal wealth (replaceable objects). The extension of state preference theory to utility maximization under uncertainty to disequilibrium conditions and to risk analysis can have fruitful application to the field of flood hazards.

b) Because of the shift toward more local participation, there is need to clarify the economic case and rationale for various levels of public intervention within a federal context - national, regional, state, and local governments. The case for possible non-market failure of public policies as well as the case for market failure needs reformulation in light of emerging policy trends. The economic rationale for most public policies is unclear.

This research is very important. It should be started now and subsequent theoretical advances should be encouraged.

3) It is important that a consensus among economists be developed on proper measures of flood losses and benefits of hazard mitigation policies. This consensus is needed for three reasons: a) to specify more concretely the kinds of economic data to be collected; b) to provide a better basis for economic evaluation of present and future policies; and c) to suggest areas of theoretical research on the basic theory of benefit-cost analysis for flood hazard mitigation. Particular attention should be paid to techniques for the benefit-cost analysis of nonstructural approaches.

This research is critical and should be started now.

4) Once consensus on proper measures of benefits and costs is achieved, there should be a specification of the kind of economic data to be collected in order to conduct proper economic analysis. The approach should be pragmatic and practical. Reasonable surrogates should be suggested for data that we would like to have but cannot readily obtain. Data collection could be speeded up by utilization of claim data from the National Flood Insurance Program. Special efforts at data collection might be justified for some regions where the risks are large and the probabilities of a flood event are high. All

economists who have studied flood problems are agreed that the existing data base is incomplete and unreliable.

This research also is critical and should follow the work of task #3 above.

5) Economic evaluation of existing public policies and institutions for flood hazard mitigation is badly needed. Serious charges of inefficiency have been made but the evidence is incomplete and, in some cases, out of date. This economic evaluation would not preclude a parallel interdisciplinary evaluation of institution and policies. A first-cut study should begin right away and take perhaps a year. It may then be desirable to go into more depth depending upon the results of the first-cut study and the consensus developed in tasks #2 and #3 above.

This research is very important, but should follow tasks #2 and #3.

6) Economic evaluation of selected flood mitigation policies:

a) There is immediate need to make an economic evaluation of the National Flood Insurance Program. This program is likely to be the centerpiece of future flood hazard policy and the need for careful economic evaluation is urgent because of the rapid growth of the program.

b) There is great need to critically examine the economic benefits and costs of land use controls for flood plains, including purchase of development rights, land acquisition and relocation. The use of these controls is rapidly increasing. Yet, evidence on the benefits and costs of such policies has not been developed. Do these controls lead to efficient use of flood-prone lands?

c) Cost-effective use of flood plains will require economic risk analysis of the construction of public facilities in flood plains, such as transportation systems, electrical generation plants, and sewage waste disposal facilities. In addition, quantitative assessment of the benefits and costs of building codes for flood prone structures and floodproofing is not well known. The methodological basis for some of this analysis has been developed for seismic safety by Brookshire and Schultze (1980) and Cohen and Noll (1981).

d) The economic methodology exists but the benefits and costs of flood forecasting and flood warning systems are not known. Efforts are being made to extend and improve these systems. It is timely to subject them to economic analysis.

e) The economic evaluation of emergency relief and recovery assistance is very incomplete, yet the policies are very important in scope and cost. The benefits and costs are not well defined. The rationale for relief and recovery needs rethinking in terms of its likely effects (what are they?) both upon the distribution of income and the possible effects on incentives for risk-taking in the use of flood-prone lands.

f) Alternative policies for financing and cost-recovery for flood hazard mitigation policies need to be explored in terms of effect on efficiency of flood plain use, effects upon the distribution of income, and the effects on strained sources of local, state, and federal revenues.

The research under task #6a is critical, that of tasks #6b and e are very important, and the remaining tasks are important.

Final Reflections

A great deal can be done to improve the quality of economic analysis for flood mitigation policies without calling for more economic research. The practice of benefit-cost analysis is the issue, not just the improvement of the data base and the theoretical concepts. Probably the most important suggestion is one that has been made many times before but very seldom applied. That is, economic evaluations by in-house groups and by professional consultants should be subject to independent, objective, outside review. Most all observers are agreed that the quality of economic analysis would be greatly improved by such reviews.

Next, with the movement to more state and local responsibility for flood mitigation policy, there is need for more training of middle-level personnel in the pertinent agencies to conduct competent economic analyses. Very often, economic analysis at the field level is poorly performed simply because personnel have inadequate training and guidance. Therefore, there is much to be said for special training programs and workshops to supply this important need.

The emphasis on economic analysis in this chapter is intentional because other types of social and physical research are covered in other chapters. The emphasis on economic efficiency does not preclude other social goals. After all, knowledge of the least-cost method of achieving social goals is always desirable. To assert that the benefits of flood hazard mitigation can not be measured is to say there is no rational way to make social choices about mitigation. How else can we determine whether the costs of mitigation are worth incurring? Without analysis of expected benefits and expected costs we can not chart a proper course for flood hazard policy.

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CHAPTER 7. SOCIOLOGY RESEARCH NEEDS

CONTENTS

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INTRODUCTION

The sociological dimension of flood hazard mitigation reflects a research tradition dating back to the early 1950s (Fritz and Marks, 1954; Kreps, 1981). Within the broader context of human responses to disasters of various forms, sociologists and social psychologists have made limited headway in debunking many popular beliefs. Detailed descriptions of how people in the United States _actually_ respond, in contrast to how many believed they _should_ or _might_ behave, provide the fundamental cornerstones for much of our current knowledge base (summary statements include: Barton, 1969; Dynes, 1970; Mileti _et al_., 1975; Quarantelli and Dynes, 1977; Quarantelli, 1978; Mileti, 1980).

Paralleling these developments, but reflecting a different focus -- one emphasizing human adjustments to varied types of natural hazards -- are studies by behaviorally oriented geographers (e.g., White, 1945, 1974, 1975; Burton, _et al_., 1978; Gold, 1979). Although highly relevant to many aspects of the research agenda developed in this chapter, comprehensive review of this and other disciplinary literatures was beyond its scope. While such works are alluded to periodically, this chapter emphasizes the contributions of sociological research and its rich potential for the future. For this potential to be maximized, however, sociologists must redefine the flood problem in a manner more consistent with that proposed throughout this report. Thus, more reflective of the perspective that has guided many of the behavioral geographers, sociological research must be expanded to address the flood hazard within a broader context than that permitted by a focus on human responses to flood events _per se_. Rather, efficient use of flood-prone areas must become the guiding premise, rather than an imagery limited to floods as disasters (Mileti, 1980).

We now know, for example, that flood warnings do not evoke mass panic responses by the American public. Yet, even today, fear of such responses continues to be discovered among some local officials (Wenger _et al_., 1980). A succession of systematically conducted field studies have dissected the processes of public evacuation when persons have sought escape from approaching hurricanes and riverine flooding (e.g., Moore _et al_., 1963; Drabek, 1969; Illinois Department of Transportation, 1980; Perry _et al_., 1981; Leik _et al_., 1981). Documentation of this single dimension of the human response and the restructuring of policies rooted in scientific fact, rather than myth, undoubtedly have saved hundreds of American lives and prevented injury to thousands of others.

To provide a context for discussion of sociological research needs, I will first characterize the state of the field, propose four broad developmental goals for the coming decade, and then outline the field's principal axes of organization. Priority research needs will then be summarized for each of the four phases of human response to hazards: 1) preparedness/mitigation, 2) warning, 3) emergency response, and 4) recovery and restoration. Throughout, the three different types of flood hazards will be emphasized -- flash flood, riverine, and hurricane-related.

State of the Field

Whereas much has been learned regarding certain aspects of human responses to the flood hazard, the picture in 1982 is as follows.

1) More is known than has been implemented. Mechanisms to transfer information and enhance use of research findings are not well understood. While important progress has been made during the recent past, it is essential that existent mechanisms be nurtured and new ones explored. Research findings left gathering dust in a university library will save few lives.

2) Most sociological research on the flood hazard has been conceptualized within a disaster context -- either potential or actual. As reflected throughout this report, however, a broader frame of reference is required. That is, the problem should be recast so that research reflects a more fundamental question: What is the most efficient use of flood-prone areas? This orientation contrasts sharply to a narrower perspective in which flood responses and flooding prevention are the exclusive concerns -- a view that denies the potential positive aspects of flooding or the acceptance of certain levels of risk so as to derive benefits through flood plain use. This is not to suggest that studies of flood events are no longer required. Rather, additional types of research questions must be posed -- questions that don't get raised as long as responses to flood events are viewed as the exclusive focus.

3) Data on flood victims and their losses are highly inadequate. National or regional demographic profiles are precluded (Tubbesing, 1979; NSF, 1980; Wright and Rossi, 1981). Hence, only the crudest assessments can be made regarding the magnitude of the risk associated with the flood hazard, its rate of change, or social distributions. A recent sample survey of 13,000 American households reveals, however, that family flood losses may total $2.8 billion annually (1980 dollars) (Rossi *et al*., 1982b). Victim perceptions of flood-induced losses are poorly understood, but may be more critical in ascertaining recovery responses and long-term impacts than dollar estimates. Independent of actual flood losses and the social definitions given to these, no one knows the parameters of the American population at risk, its rate of change, or social distribution. It appears, for example, that more people are building houses in mountainous areas subject to flash flooding, but available data preclude precise problem assessment.

4) The knowledge base is uneven. Critical research questions never have been addressed. A few areas -- like public evacuation behavior -- have been explored successfully. This step permits refined problem conceptualization and

far greater focus and specificity in needed research. Yet other issues, especially those related to mitigative actions, remain unexplored.

5) Most conclusions about behavioral responses lack substantive precision and specificity regarding appropriate ranges of generalization. In large part, this reflects limited and highly erratic funding patterns. Apart from a handful 'of recent exceptions, study methodologies have been limited. Rarely have research funds been adequate to permit implementation of the comparative methods required.

Developmental Goals

Those responsible for shaping social behavioral research on flood hazard mitigation during the coming decade should seek to nurture four developmental qualities.

1) Increased user-researcher interaction. A variety of mechanisms must be encouraged so that members of both communities can reinforce and inform each other. While their roles are distinctive, the performance of both researchers and practitioners is enhanced through increased interaction within contexts of mutual respect. No single model will do the job; rather, a variety of mechanisms must be employed. These range from general information transfer programs (e.g., The Natural Hazards Research and Applications Information Center at the University of Colorado provides a newsletter, user-oriented research monographs, and annual workshops), to more focused workshop series (e.g., Natural Disaster Recovery and Mitigation Resource Referral Service, The Academy of Contemporary Problems), to broad representation on research project advisory committees and the like (NSF, 1980, p. 217).

2) Improved theoretical integrations. As a strategic research site, the flood hazard requires further problem specification. Cross hazard comparisons, however, must be maintained. Knowledge about human responses to other forms of hazard enriches our understanding of adjustments to the flood hazard. From a behavioral viewpoint, there are important response commonalities across hazards, but important differences exist too. Specific social factors that differentiate these are not well understood, however.

The number and quality of sociologists conducting research on aspects of natural hazards management has increased during the past decade. Integrations of their research findings with broader theories of human behavior can be enriched greatly by studies focused on the flood hazard. Such transfer is not automatic. It too will require nurturing through several carefully selected strategies. Diversity in theoretical perspectives must be encouraged as differing questions can be pursued more effectively through conflict theory whereas symbolic interactionism or social action theory might aid more in other instances.

3) Refined data analysis and data gathering techniques. Both qualitative and quantitative data have been collected in recent field studies in which multi-system responses have been explored (Drabek et al., 1981; Leik et al., 1981). The processes under study were enhanced through use of an innovative

statistical procedure, i.e., blockmodeling. Such network analyses would be enriched by additional measurement and data analysis techniques that are more reflective of the theoretical perspectives being used. While most research questions can be pursued profitably with available techniques, some key areas, especially responses of multiagency networks, will be enhanced through further exploration of mathematical techniques that are innovative to these research issues.

Additionally, alternatives to the primary data gathering instrument — field interviews — must be encouraged. More extensive use of historical, archival, and census data, for example, could inform many important questions, especially those pertaining to longer term impacts (e.g., Aguirre, 1982) and broader societal shifts that define response contexts (e.g., Hitchcock et al., forthcoming). Also, improved data gathering strategies using systematic observational and reconstructive techniques (e.g., Canter, 1980) are required, especially in studies of flood emergency responses.

4) Development of cross-cultural data sets. Improved understanding of modal responses within American communities, as well as differential responses wherein cultural diversity may exist, require selected cross-national studies. Often, cross-national juxtapositions transform our definitions of response patterns thought to be solely reflective of elements of cultural or governmental constraint. To date, this cross-national data base on human responses to the flood hazard is limited to a handful of pioneering studies (e.g., Burton et al. , 1978; Mileti et al., 1975).

Important opportunities exist at both northern and southern borders. For example, explorations are under way with the National Weather Service to make available forecasts to Sonoran border towns as part of a bi-national search and rescue effort. Developments like this offer unique research opportunities through which cross-national data sets can be compiled. Complex organizational coordination challenges can be examined — and hopefully improved.

Recently, disaster and natural hazard research centers have been established in Australia, Japan, Sweden, Italy, England, Canada, and elsewhere. In August 1982, a permanent Disaster Research Committee was established within the International Sociological Association. These and related mechanisms must be encouraged if essential collaboration is to occur among an international collection of scholars.

Four Phases of Behavioral Responses

Human responses to the flood hazard vary. This variation is best dissected by recognizing at least four distinct phases of behavioral responses. Not all researchers use identical terminology, but most recognize these four: 1) preparedness/mitigation, 2) warning, 3) emergency response, and 4) recovery and restoration.

Also, the units of analysis differ. Depending upon the research question posed, some study designs require that comparisons among individuals be made. Yet, much human behavior is structured by group memberships, such as families, organizational affiliations and qualities of community life. Samples of each of these types of social systems are required at times because all act to constrain human responses to the flood hazard. In addition to these relatively enduring social systems are the short-lived, transitory systems. Frequently, these emerge during flood events. These emergent systems, sometimes comprising volunteers, provide essential contributions. Augmenting responses by more formalized agencies, emergent systems perform crucial functions during each of the four time phases listed above.

At this time, flood hazard mitigation is a strategic research opportunity for the social behavioral sciences. Applied study designs across the various units of analysis (e.g., individuals and groups) within each of the four response phases (preparedness, warning, emergency, recovery) can provide important new insights that are potential life savers. Simultaneously, such research will strengthen more general theories of human behavior and improve our understanding of individual and group responses to other natural hazards and social stresses.

These themes provide a context for a more focused review of research needs. The four phases of human response to hazards will order this discussion.

PREPAREDNESS/MITIGATION PHASE

In contrast to their work on warning and emergency responses (phases 2 and 3), relatively few sociologists have examined factors related to flood preparedness or mitigation actions. Hence, this area requires immediate exploratory studies to provide more focused problem definition, hypothesis specification and theoretical modeling. This priority reflects the redefinition of the flood hazard urged throughout this report -- an orientation emphasizing efficient use of flood-prone areas, rather than an exclusive focus on flood disasters. Three broad research areas merit priority designation: 1) policy formulation processes, 2) policy responses, and 3) individual perceptions.

Policy Formulation Processes

As recommended in A Report on Flood Hazard Mitigation (NSF, 1980, p.223), comparative research on flood policy formulation processes is needed. Four study areas illustrate the range and types of inquiries required.

The Process of Policy Formation

Long-term and comparative studies are needed of the actual social processes producing selected flood hazard mitigation policies. Such studies should include diverse types of communities (varying in size, locale, power structure, etc.) confronting differing types of flood hazards (flash flood, riverine, and hurricane-related). The respective roles -- both official and informal -- of varying coalitions of public interest, governmental, and private organizations should be mapped to describe and explain the policy formation process. The relative context of the flood hazard vis-a-vis other hazards and especially other types of community problems must be understood better. Within the mix of problems typically confronting communities, hazards do not rate at the top of the list (Rossi et al., 1982a). But the stability and consequence of such perceptions are not known.

Collective Behavior Analyses

Recently completed field studies by Turner et al. (1979) have penetrated the responses among various community groups to the earthquake threat in California. Parallel case studies are required for the flood hazard. These should map and explain the collective actions taken by a diverse range of public interest and educational groups. Preliminary work has begun through a recently funded study of citizen groups who have banded together to prepare for or to protect themselves from possible disasters (Quarantelli, 1981). Specific policy formulation occurs within this more general set of community processes that remain poorly understood.

Media Responses

Media organizations impact the agenda setting process for all social problems and frequently appear to impact the policy formulation process. Comparative studies of media responses to selected flood hazard policy proposals and implementation efforts are required. So too are studies of internal decision processes within media organizations -- both locally and nationally based firms. Decision processes and social networks through which media organizations produce coverage of the flood hazard generally, and specific flood events, rarely have been investigated (Committee on Disasters and the Mass Media, 1980).

Research Utilization

As indicated above, far more has been discovered by sociologists and other behavioral scientists than is being used by practitioners. Undoubtedly there are many reasons for this. Some may parallel those discovered in other scientific areas (Rice and Paisley, 1981). Thus, an immediate need is for an intensive, short term literature synthesis study to ascertain which factors appear to be most relevant to the flood mitigation context.

Additionally, field studies like those begun recently by Yin and Moore (1982) are required to identify the types of research findings that are being used by differing groups of flood mitigation practitioners. Selected sets of research findings which have been implemented shortly after their discovery should be identified and the social processes of information transfer, adoption, and implementation should be documented (e.g., see Bingham, 1978; Light, 1978). Also, studies should be made to ascertain why selected research findings have not been implemented. So too, the consequences of alternative dissemination modes should be assessed.

Policy Responses

"Long-term comparative analyses of community and state level responses to alternative mixes of flood hazard mitigation policies should be encouraged so that the dynamics of social change can be better understood, including syntheses of successes and failures" (NSF, 1980, p.223). Once policy has been adopted at any level of government, a complex social process begins. This is especially true for matters like flood mitigation, given the diversity of prime missions among the many such units whose programs relate to its differing aspects. Exploration of this process of subsystem adoption and implementation has begun (Hutton, Mileti *et al*., 1979; Platt *et al*., 1980; Williams, 1980), but the behavioral dynamics remain poorly understood. Studies of our four broad types are required. All would benefit from both disciplinary focused research and interdisciplinary study teams.

Adoption Processes

Comparative studies, focused on alternative mixes of flood hazard mitigation policies, should be conducted among state level organizations and within varying types of local communities confronting differing flood hazards. The rate and flow of adoption should be documented and key factors affecting these should be identified. Also, selected examples of non-adoption should be studied. Governmental agency and private sector actions should be included.

Implementation Processes

Once policy has been adopted formally, a complex behavioral process of implementation is initiated. Subsequently, goal displacement occurs as varying governmental agencies and private firms interact. Comparative studies are needed to describe the dynamics of multiorganizational communication and bargaining strategies during the implementation of flood hazard mitigation policies.

Managerial Strategies

Currently little is known about the types of strategies used by managers responsible for varying aspects of flood hazard mitigation. In an era of shrinking resources and governmental restructuring in the U.S., maintenance of organizational integrity (i.e., reasonable budget and staff levels) should be identified within samples of the diverse range of organizations involved in flood hazard mitigation, including federal, state, and local units. The degree to which such strategies are shared and the social processes of their diffusion should be assessed. These analyses should ascertain the impacts of and strategies for coping with altered political contexts that newly elected officials may bring. The implications for subsequent managerial training should be a prime focus of such studies.

Planning Process Variations

While numerous ideal versions of generalized planning methodologies may be relevant to flood hazard preparedness and mitigation, little is known about the behavioral dynamics of actual planning efforts. Comparative studies in urban and rural settings of varying types of planning efforts are required. Potential variations reflecting community differences and major barriers are poorly understood.

Individual Perceptions

Research indicates that individuals generally distort and typically underestimate the risk they confront from hazards and lack much relevant knowledge (Burton *et al*., 1978; Slovic *et al*., 1977). Also, many adjustments such as flood insurance and land use planning remain unpopular and poorly understood even among those at risk (Kunreuther *et al*., 1978; Palm, 1981). Basic work completed makes possible rather precise hypothesis testing studies. The social processes whereby individual and official perceptions are formed, the range of variability nationally, and the degree of stability lack adequate specifica-' tion. Researchers with alternative theoretical orientations (e.g., bounded rationality, symbolic interaction, and social learning) should be encouraged. Special emphasis should be placed on the behavior of primary groups such as families, in contrast to individuals. While more precise specification of the processes of formation and change in individual and official perceptions of the flood hazard is required, virtually nothing is known about the social dynamics within family groups wherein most decisions are reached regarding many flood hazard adjustments, e.g., adoption or renewal of flood insurance. This assessment suggests three study areas.

Hazard Perceptions and Knowledge

Hypothesis testing studies are required to delineate the precise interrelations among a large number of social and individual characteristics which seem to structure perceptions and knowledge of the flood hazard. Many factors have been identified, but their relative contributions and interaction effects are not known. Public perceptions of urban influences on precipitation intensities (e.g., NSF, 1980; Farhar *et al*., 1979) await careful examination, however, as does delineation of the potential impacts of blame assignation of varying forms, e.g., dam design, failure to warn adequately, or modification attempts such as cloud seeding or hail suppression (Farhar, 1977). Diversity in theoretical orientations among researchers conducting such investigations should be encouraged, as should multihazard comparisons. Explorations of the relative stability of these perceptions over time and the identification of factors causing change merit priority. Additionally, the roles and impacts of the mass media should be assessed. Impacts among populations with differing social characteristics should be determined (Baumann and Sims, 1974). Finally, important differences may exist, regarding both the content of risk perception and factors influencing their formation and stability, among flood events of different causal bases (e.g., dam failure vs riverine overflow) and locations (e.g., urban vs rural settings).

Adoption of Adjustments

As noted above, little is known about the social processes whereby families decide to adopt various mitigation measures, including insurance against loss or such emergency planning measures as a family evacuation plan.

Given the rapid growth of the number of communities participating in the National Flood Insurance Program (see Chapter 1), assessment of family decision making processes regarding this mitigation strategy must command a top priority. As indicated in the economics chapter of this report, such factors may constrain aspects of individual behavior. But the social processes of decision making require much further study by researchers specializing in family studies since group processes may be more predictive of behavioral outcomes. Certainly, individual willingness to support such adjustments as land use planning varies as do those occupying flood plains (Dexter et al., 1979; James, 1968). Yet, the stability, intensity or behavioral consequences of such views are not well understood. Group processes are even less well mapped. Research suggests, however, that these variations can be used to assess the probability of success for alternative implementation strategies (James, 1975; Andrews et al., 1978).

Efficacy of Educational Change Efforts

Research suggests that merely increasing knowledge and/or awareness of natural hazard risk levels does not produce sweeping behavioral adoption of damage mitigation measures. While the exact processes are not well understood limited attitude and behavioral changes do occur following some programmatic campaigns. Broadly based, non-focused appeals appear to be least effective, but the research base is thin for evaluating even these (Illinois Department of Transportation, 1980). Priority should be given, therefore, to several demonstration experiments in which social behavioral researchers participate with local and state agencies to design various educational change programs intended to increase public adoption of damage reduction and mitigation adjustments. These experiments should be highly varied in content and target populations. Variations in program content should reflect research conclusions regarding the importance of such factors as community variations, characteristics of the threatened population, physical appearance of the flood plain and recent flood history (James, 1975). Each should be evaluated rigorously and selected cases should be followed up to ascertain longer term effects.

FLOOD WARNING PHASE

As indicated above, the past two decades of behavioral science research has produced much insight into the social processes that constitute the warning phase, both public responses and organizational systems. Widespread dissemination of these findings and implementation of multiagency networks have saved American lives, especially in coastal areas. In contrast to such killers as Hurricanes Audrey and Camille, for example, Bob and Frederick took few lives. Although other factors were relevant, this result stemmed largely from moderately effective warning systems that evoked orderly evacuation by thousands. High death tolls during flash floods in Rapid City and the Big Thompson Canyon, however, underscore that much remains unknown. Two core areas pinpoint the more pressing agenda: 1) operational constraints, and 2) public evacuation.

Operational Constraints

Four research areas require attention. To date, the few behaviorally oriented researchers studying such phenomena appropriately have directed their efforts toward other issues -- topics like age and sex differences in warning responses, consequences of variations in message content and source, and the like (see Mileti *et al*., 1975, and Perry *et al*., 1981, for research summaries). These studies provide solid footing from which to proceed.

Flood Warning System Implementation

As pointed out in *A Report on Flood Hazard Mitigation* (NSF, 1980, p. 94), a posture of blaming victims no longer is acceptable. Instead of asking why victims didn't leave before the flood waters arrived, the more appropriate question is: "Why don't local officials use existing technologies and scientific understandings to elicit the desired evacuation behavior?" "A key research priority should be to improve understanding of constraints and incentives related to the implementation of response systems based on what is known about human behavior" (NSF, 1980, p. 94).

Comparative study of communities confronting similar flood threats will unveil networks of both incentives and constraints. Through comparative case study methodologies and more quantitatively oriented community analyses, sociologists must assess the social processes which culminated in implementation of effective flood warning systems. Also, clusters of social factors must be identified that depict those communities in which the mixes of incentives and constraints are such that effective operational systems are not in place. Additionally, aspects of this topic are exceptional candidates for interdisciplinary research, since composite mixes of social, economic, and political processes require assessment.

Flood Warning System Composition

Recent completion of a multiyear study by a University of Minnesota research team (Leik *et al*., 1981) provides the first *multicommunity comparisons* of operating flood, hurricane, and tornado warning systems. This data base, consisting of less than three dozen communities, precludes many types of comparisons. The alternative configurations of the operating flood warning systems in communities of varying size and confronting different types of flood hazards (e.g., coastal vs mountain terrain) remain unknown. Indeed, detailed cross-community comparisons of even planned systems await study. These must be completed, but should not distract from an emphasis on the more critical, but more difficult, analyses of actual operating systems.

Beyond describing a fuller range of these operating systems are the next tasks of precise measurement of the modes and patterns of multiagency communication found within them. After these two elements are assessed with greater precision, researchers can begin to dissect the respective levels of multiagency coordination. Then the relative effectiveness of the public responses generated can be related to alternative network configurations.

Such research must be comparative in at least two different ways. Samples of communities differing in such social characteristics as size, must be juxtaposed with differing flood hazards, e.g., proportion of population at risk, warning frequency, probable length of forewarning. It is likely, although not known, that alternative design configurations will be required for differing social environments. No single design may prove to be universally effective.

Case Studies for Managerial Training

Practitioners ranging from employees of the National Weather Service, to county sheriffs, to personnel of all media firms, to those specializing in physical science aspects of flooding (e.g., hydrology) represent a diverse array of agencies with highly varied day-to-day responsibilities. Sociologists should produce an ongoing set of flood warning case studies that document the functioning of exemplary warning systems in communities of varying size. A parallel series should document failures and identify key operational problems. Special attention should be given to cases in which flood water crosses political jurisdictions, including city, county, state and national boundaries. These studies should be made available for managerial training.

Integration of Warning Systems

Local communities confront many different natural and man-made hazards. They cannot construct separate warning systems for every type of hazard. Yet, the degree of multipurpose functionality among warning systems is not well understood (see Perry, forthcoming). Obviously, many subsystem elements differ. For example, measurement and projection of floods differ from the assessment of a cloud of toxic gas produced by a fertilizer plant. Yet, many toxic substances may be spread by flood waters, and emergency responses to flooding may be inhibited by the presence of toxic materials. Adequately integrated warning systems must encompass such cross-hazard effects and complications. Further, integrated systems should use procedures for message formulation and diffusion that have been developed and tested across hazards. These criteria for "integrated" systems are in addition to the usual implication of a system that effectively unites and uses diverse agencies and organizations at the community level. But the limits and principles of such integration are not well understood even among floods with varying causal bases (e.g., flash flood due to intense rain vs dam failure) and locations (urban setting vs rural).

Public Evacuation

Perhaps more than any other aspect of human response to flooding, public evacuation has been dissected in numerous research studies (e.g., Perry *et al*., 1981; Quarantelli, 1980, 1982). Hence, the research needed can be identified with much greater specificity than most other behavioral response areas. Investigations focused on four problem areas will provide practitioners with important new tools that will greatly enhance their management capability.

Adverse Conditions

Without question, the implementation of hurricane warning systems has saved hundreds of American lives (Simpson and Riehl, 1981). Though not perfect, existing systems are being improved through a variety of new technologies. Nationally, riverine flood warning systems are less developed, although exemplary localized systems do exist. At present, areas at risk due to flash flooding are the most vulnerable. The short lead time available for adaptive response in these events is but one of several factors identified by researchers for which innovations are required. Other adverse conditions include: 1) when quick actions are required late at night; 2) when the population at risk is unfamiliar with area, e.g., tourists; 3) when family members are physically separated; and 4) when the locale has minimal flood experience. Demonstration experiments, linking behavioral researchers and local officials, should be funded for the design and testing of innovative flood warning systems by which these and other adverse conditions can be neutralized. Death tolls in canyons like the Big Thompson need not be repeated.

Special Populations

Every community has various concentrations of citizens with special evacuation requirements if they must be evacuated. Among those identified in the research literature are: 1) the elderly, 2) children, 3) the handicapped, 4) some ethnic minorities, and 5) the institutionalized, e.g., prisoners, mentally ill. The degree to which this matter has been considered in the design of existing flood warning systems is unknown. A few case studies, e.g., Rapid City (1972) and Big Thompson Canyon (1976), have documented disproportionate death rates among these special populations. The range of adjustments required and the degree to which these have been preplanned have not been studied. Hence, even the crudest parameters of this problem have not been ascertained.

Evacuation Facilitators/Inhibitors

The effectiveness of public evaucations and the levels of disruption and trauma experienced by evacuees could be reduced substantially through implementation of a series of facilitating mechanisms. While several have been proposed, none has been subjected to scientific testing. For example, Perry *et al*. (1981) concluded that family message centers, especially for use by evacuees *not* housed in public shelters, might be an important incentive and would reduce the level of trauma. Sociologists should be encouraged to propose such facilitators to local officials in samples of communities, assist in their planned implementation, and then evaluate the effects. In contrast to this focus, study needs to be made of samples of non-evacuees. What are the inhibitors which preclude a certain percentage of families from leaving? Relatively little is known about this population or the barriers that constrain them from taking what others perceive to be adaptive action.

Shelter Requirements

Contrary to widespread belief, most American evacuees do not seek public shelter except when very special circumstances prevail, e.g., access routes to safe areas are limited as described in the public health chapter regarding barrier islands. Typically, most evacuees take refuge within homes of relatives or friends. Comparative studies are required, however, to narrow the estimation ranges. Depending on such factors as anticipated length of stay, geographical isolation of the community, level of community preparedness, and other variables, the reported percentages of evacuees actually taking refuge in public shelters vary between 3 and 30 percent. It now appears feasible to design a series of comparative studies that would provide practitioners with a precise estimation formula. Given a particular threat with specific values on selected social dimensions, the public sheltering needs could be predicted with reasonable accuracy. Such a tool could increase efficient use of resources. This research area has very high payoff because of its widespread application potential and relatively low cost. Finally, studies of the attitudes and behaviors of host populations are germane since their actions influence family responses. Evacuations are encouraged through an invitational process that has been documented in several flood warning responses (Drabek, 1969; Perry _et al_., 1981).

EMERGENCY RESPONSE PHASE

Until recently, most sociological studies focused on this phase. Thus, many issues have been explored so as to permit more precise problem definition. Three core study areas merit priority.

Multiorganizational Response Systems

As identified in _A Report on Flood Hazard Mitigation_ (NSF, 1980, p. 223), comparative research should be conducted on multiorganizational response systems to flood events. While some basic exploratory work, e.g., Drabek _et al_. (1981), has been completed recently, it is clear that four types of research foci merit further study.

Volunteer Groups

The efforts of paid emergency organization personnel are augmented by a diverse cadre of volunteer groups who reflect varying organizational domains and levels of authority (Dynes and Quarantelli, 1980). Field studies have found that these groups are poorly integrated within the overall response set. Priority should be placed on studies designed to determine the barriers and incentives altering the degree of volunteer integration within the core emergency response system.

Field studies have documented important actions taken spontaneously by individuals who sometimes form shortlived emergent task groups. While these actions have been noted in numerous case studies, the processes of their formation, composition, and contributions await systematic mapping. Mechanisms through which these groups might be integrated better with core emergency organizations require study, also. Special attention should be given to assessing perceptions of aspects of the legal system; e.g., "Good Samaritan" laws, as recent field data have indicated uncertainty among helpers. "It will be unfortunate if fear of litigation erodes the scope of voluntary helping responses in post-disaster settings, which reflect an important core of American values" (NSF, 1980, p. 128).

Emergent Multiorganizational Networks

Large-scale disasters exceed the capacities of any single emergency organization. As multiple agencies respond, the degree of interdependence among them becomes much tighter and new relationships are required. Thus, emergent multiorganizational networks spring to life to meet disaster demands. In one sense, the problem is how to manage this complex system of diverse organizations which may be autonomous units (e.g., neighborhood self-help groups), components of regional or national private organizations (e.g., insurance companies, Red Cross), or divisions of local, regional or national governmental organizations (e.g., police, National Guard, Army Corps of Engineers). Obviously, "manage" is too strong a term given the decentralized quality of American society. But clearly, increased local capability to coordinate emergency efforts is required.

There are no mapping techniques for ascertaining the relative response effectiveness of emergent networks with varying shapes and composition. Studies should be initiated immediately to develop such tools. Cross-agency communication patterns and network decision making and control structures are critical variables that should be included in study designs.

Studies in which responding organizations are viewed as multiple activity centers must be initiated. Research to date has relied primarily on perceptions of agency heads. In some cases these may be consistent with experiences of other subsystem managers, e.g., communication supervisors. Frequently, however, relationships with other organizations may vary at different vertical levels. Improved management of emergency responses requires that these matters be given top priority by the research community.

Media Relationships

Unplanned media relationships adversely affect many disaster responses (Drabek et al., 1981). Case studies have documented a wide ranging set of problems, such as unauthorized release of victim names, and both victim and managerial harassment. A series of studies should be initiated to explore these and other dimensions of media-emergency manager relationships and changes in public responses (Waxman, 1973).

Emergency Operations Center

Probably no other structural addition to local and state emergency agencies has increased response effectiveness as much as the construction of local emergency operations centers (Quarantelli, 1978). EOCs are often poorly managed and frequently augment rather than coordinate cross-agency responses. Comparative research is needed to document the techniques for EOC management in locales with differing social characteristics (urban vs rural) and confronting varying types of flood hazards. Relatively effective EOC responses should be identified and the managerial strategies used in constituency building should be mapped.

Simulation studies of EOCs should be encouraged so that alternative design structures can be tested by local agencies considering EOC construction or replacement. Technological imitation occurs, rather than design specification reflecting community needs and differences. Additionally, training in EOC management should be assessed through a simulation experience study. In a national, or several regional simulators, samples of local community managers (i.e., the agency representatives designated for EOC assignment in an actual disaster) should participate in highly realistic emergency exercises. Performance in subsequent floods, and other disasters, should be evaluated.

Emergent Group Processes

In contrast to the organizational focus just outlined, research rooted in the collective behavior framework recommended by such scholars as Kreps (1982) and Quarantelli (1978) is needed. Studies should be initiated on selected post-flood tasks, e.g., search and rescue, handling of dead, and security. Given the highly destructive quality of flash floods especially, aspects of these tasks often are very difficult, e.g., identification of badly mangled bodies located within debris piles. Field observations should focus on physical locations within disaster stricken communities where these tasks were performed. Using a situational and task process focus, in contrast to an organizational orientation, researchers should document participant behavior.

Different concentrations of organizational personnel, such as National Guard, local police or fire personnel, comprise operational teams with relatively high degrees of autonomy. Relationships within these emergent field locations have never been mapped systematically. Such documentation will augment our understanding of the overall response. Additionally, this information will provide case materials for managerial training that are not now available. Descriptive field studies in varying locales' confronting differing flood hazards are in order given the near void in knowledge.

Helping Behaviors

A wide variety of helping behaviors have been documented through numerous case studies completed during the past two decades (Dynes and Quarantelli, 1980). Hence, more precise problem definition is possible. Three priority topics demand attention.

Family Recovery Processes

How do families recover from flood-induced tragedy? Drabek and Key (in press) and Bolin (1982) have explored the recovery mechanisms following tornado damage and provide a base for subsequent study. The capacity for families to recover varies according to social constraints, e.g., age, ethnicity, and socioeconomic status. The recovery process is complex; a wide variety of social and economic groups participate.

Among these participants patterns of neglect involving both emotional and financial assistance appear to delay recovery among some. The precise mechanisms involved and policy implications await specification. The symbolic and social aspects of recovery must be integrated with the economic dimension. Emotional and psychological dimensions of recovery merit focus. Certain aspects of this study area, especially insurance use patterns, temporary and long-term housing relocation decisions, and roles performed by financial institutions, would benefit from interdisciplinary study teams.

Therapeutic Communities

The rise and demise of post-flood therapeutic or altruistic communities have been documented. These are composed of a wide-ranging mix of helpers, varying from kin and friendship groups to formal relief agencies. An elaborate theoretical modeling of the mechanisms affecting the speed, extensiveness and duration of such responses was published over a decade ago (Barton, 1969). To date, comparative studies, or even a single empirical test of this model, have not been published.

Because of the potential importance of these phenomena for assessing long-term impacts on micro social systems, comparative research should be encouraged immediately. Relevant questions are: 1) Based on field data, what factors structure the relative speed of emergence, intensity, extensiveness, and duration of post-flood therapeutic communities? 2) Who participates in these, in what ways, and for how long? 3) Who must benefit from these, how, and for how long? 4) In what ways do existing relief agency policies nurture or neutralize the growth and impacts of therapeutic community development?

Assessments of Agency Interventions

Since the 1974 Disaster Relief Act, and earlier in a less preplanned manner, large amounts of federal dollars have been funneled into communities stricken with natural disasters. The majority of these disasters (i.e., those evoking a Presidential Declaration) have resulted from flooding. This assistance comes in many forms. It augments that provided by private agencies like the Red Cross, the Salvation Army, Interfaith groups and many others. Public Assistance funds aid communities and states in reconstruction and repair of roads, bridges, schools, libraries, and the like. Individuals are aided through a specialized program. Also, as detailed in the public health chapter, many innovative services, like mental health counseling, and programs for special populations, like the elderly, have been implemented (e.g., Taylor *et al*., 1976; Tierney and Baisden, 1979). Consequences for recipients, assessments of the sequential administrative process used, or even the perceptions held by local officials, remain unstudied through comparative research designs (Baisden and Quarantelli, 1981). Scientific studies of these and related topics could offer empirical bases for policy review.

RECOVERY AND RESTORATION PHASES

Prior to 1975, few researchers had examined the behavioral responses during the recovery and restoration phases (Baisden and Ouarantelli, 1979). Following a pioneering work by Haas et al. (1977) two major projects have been completed (Friesema et al., 1979; Wright et al., 1979). These permit specification of three core study areas which merit priority designation within a much broader set of unknowns pertaining to behavioral responses during this phase.

Community Decision Making

"The dynamics of post-disaster community decision making and flood mitigation policy formulation requires further research which is interdisciplinary and comparative" (NSF, 1980, p. 223). Comparative field data available are limited to three studies (Haas et al'., 1977; NSF, 1980, p. 204; and Rubin, 1981). Given this near void, exploratory case studies should be initiated in differing types of communities following flood events of varying characteristics. These will permit subsequent hypothesis formulation and greater precision in problem definition than is possible now.

Improved understanding of the social dynamics by which some communities initiate major alterations in subsequent risk levels such as rezoning or more stringent enforcement of previous zoning plans within flood prone areas, and the constraints precluding others from taking such actions, are essential knowledge. The complexity of this research problem will require several studies; some will require interdisciplinary teams. Comparative case histories will provide information immediately useful for managerial training. In such studies, the responses and impacts of media organizations should receive special attention. Little is known regarding the long-term treatment of such matters by the media. Nor have the effects of these treatments on public perceptions of the flood hazard or mitigation strategies been documented adequately.

Long-Term Impacts on Micro Social Systems

Do flood events have long-term impacts on macro or micro systems? The two major studies of macro system impacts (Friesema et al., 1979; Wright et al., 1979) focused on limited sets of social and economic variables. These are discussed in more detail in the economics chapter of this report. Despite the general conclusion that no long-term impacts of certain kinds were evident, many scholars remain unconvinced. Numerous criticisms, including selection of additional dependent variables unavailable to these researchers, clearly indicate that this issue is not resolved and subsequent research should be encouraged (Aguirre, 1982).

Of greater urgency, however, are assessments of long-term impacts on micro systems, including individuals, families, and other primary groups. Currently, the literature is divided sharply reflecting differing theoretical orientations, study designs, and types of events selected for study (see Drabek and Key, in press). For example, intense psychological impairment reportedly persisted following the Buffalo Creek flash flood (Erikson, 1976; Gleser et al., 1981). Reviewing similar data from other disasters has led some researchers to generalize such pathological effects, thereby justifying various types of intervention efforts, especially for children.

In contrast to this individual trauma perspective, others report selective adaptations within families and primary group configurations that may neutralize many pathological consequences for individual victims. Some of these adaptations actually may strengthen some of the support systems in which victims participate, e.g., increased family solidarity. It is possible that the impact variations reported in the literature reflect differences among the events, victims, or helping responses evoked (Leik et al., 1982). The extreme pathologies reported after the Buffalo Creek flood may have reflected the terrifying nature of many victim experiences and cultural traditions unique to Appalachian life. Other community characteristics such as extensiveness of primary group networks and event qualities such as blame assignation processes have been discussed too. Hence, comparative designs are required to ascertain interaction effects.

Past research, though limited, provides a solid foundation for the design and implementation of a program of comparative research using rigorous methodologies now available. Given the policy relevance of these issues, previous studies as a foundation, and the sharply divided opinions among experts within several disciplines, micro system impacts merit top priority designation. While limited exploration should be encouraged for subsequent study of macro system impacts, micro system analyses of three types should be emphasized. These flood event impact studies should be paralleled with a series of studies completed on other hazard types — both natural and man-made. Only through such a comparative base can the limits of appropriate generalization begin to be specified. Finally, cross-national data bases focused on these types of analyses merit priority.

Primary Group Impacts

Post-flood alterations in such primary group systems as neighbors, friendship groupings, and voluntary associations have important consequences for victims. Researchers have documented some instances wherein these processes have been affected in negative ways through unwitting actions taken by relief agency personnel (e.g., Erikson, 1976). Such impacts probably vary across communities with alternative social compositions and among events with differing analytic qualities (degree of victim horrification, scope of damage). Thus, studies must be comparative and long term to isolate these and other interaction effects.

Family Impacts

Tornado studies (e.g., Bolin, 1982) like recent assessments of the trauma produced by Mount St. Helens eruption (Leik et al., 1982) indicate that family impacts persist although they are not uniform. Families headed by younger and older individuals and those with lower socioeconomic status register far greater impacts than others. No study has been published reporting data on long-term or cross-national family impacts across several flood events.

Specific variables now identified in the literature (internal role differentiation, kinship solidarity) provide a solid foundation for the type of comparative designs required. Especially critical here are cross-national data. To date, only a very few studies of disaster impacts on families based on cross-national data sets have been published (Bolin and Bolton, 1983).

Individual Impacts

As noted above and emphasized in the public health chapter of this report, comparative data bases on long-term flood victim impacts do not exist. Requisite study designs including specific measures of individual functioning (physical and mental health) are available now so that a carefully monitored program of comparative studies is feasible. The foundation has been laid so that precise answers can inform the current controversy among experts of differing persuasion. This area has highest payoff potential and the greatest policy relevance at this point.

Study designs combining assessments of alterations within all three system levels (individual, family and primary group) merit a priority designation given the high potential for interaction effects. Integrations with research on other forms of social stress and life events should be encouraged, also. Finally, comparative study is required of the impacts of flood events on victim perceptions of this hazard. Impacts are likely dissimilar across events with differing qualities and among victim populations with differing social compositions. The decay curve characterizing the impacts of flood events on these perceptual sets should be ascertained through comparative studies.

Processes of Community and Organizational Change

Following the 1964 Alaskan earthquake, Anderson (1969) concluded that certain organizational changes already in motion were accelerated. Also, new patterns of change appeared. Organizational and community systems may register a wide variety of short-term coping actions that create new patterns of constraint or alter predisaster change patterns. For example, a police department involved in implementing a more decentralized decision making structure might accelerate that work substantially.

Yet, following Anderson's initial field study, most of these matters have remained unexplored (Ross, 1978). Subsequent developments in organizational and administrative theory construction and methodologies now make this research area ripe for comparative study of system change and stress responses, especially among emergency organizations. Also, selected cases of blame assignation, such as class action suits filed following the Buffalo Creek flood, should be studied and the impacts on subsequent mitigation policies assessed.

Given the minimal research base, however, a limited series of longitudinal and comparative studies should be encouraged so as to produce more focused problem definition. These should be followed by larger samples of units using available quantified measures of organizational and community system properties. Priority should be placed on organizational studies of social dimensions, although interdisciplinary teams should be encouraged as well.

CONCLUSION

The sociological research agenda on flood hazard mitigation is broad, multifaceted, and urgent. Future mitigation efforts and policy formulation will remain highly constrained until significant progress has been made toward completing this research agenda. Four developmental goals should be nurtured: 1) increased user-researcher interaction; 2) improved theoretical integrations; 3) refined data analysis techniques; and 4) development of cross-cultural data sets. To ensure fiscal and scientific accountability, however, it is essential that only the most highly qualified researchers be encouraged. Furthermore, it should be recognized that despite their professional qualifications, persons employed within state or federal mission agencies may confront important constraints especially when policy impacts and processes are the research focus. Thus, both mechanisms of peer review and a requirement of close involvement with user agencies in the planning and execution of the research, must be maintained.

If the nation's flood-prone areas are to be used more efficiently, we must improve our understanding of several social behavioral dimensions. This conclusion is shared by all of the writers of chapters focused on physical science research needs. They recognize explicitly that improved flood forecasting technology, for example, is not enough — the human dimension must be faced.

The sociological research agenda that I have outlined in this chapter is summarized in Table 1. Upon applying the three criteria (importance, probability of solution, and cost) used throughout this report, nine study areas attained a "critical priority" designation. These are highlighted in the table.

Certainly, our present absence of knowledge regarding the social processes by which flood mitigation policies are formulated (study area 1A in Table 1) and implemented (study area 1B2) greatly reduces the effectiveness of those wrestling with this hazard. Furthermore, their leadership ability will remain dulled until the sociological research community has synthesized existing knowledge regarding research utilization strategies (study area 1A4) and the social processes defining individual and group hazard perception formation and change (study area 1C). These syntheses will have immediate application for practitioners and will structure the hypothesis-testing research that must follow.

Despite these and other application efforts, however, some flood events will occur. By improving our response capability lives can be spared and personal trauma reduced. Thus, the remaining recommendations identified in Table 1 will enhance our capacity to cope more effectively when flooding occurs. Each is cost-effective and theoretically additive. Integration of warning systems (study area 2A4) and evacuation facilitators/inhibitors (study area 2B3) are potential life savers. Both are highlighted in the meteorology and public health chapters. Similarly high payoffs can be expected from further study of the multiorganizational networks (study area 3A2) that too often flounder in times of emergency.

Table 1. Summary of Sociology Research Needs

Response phase	Major study areas	Key research topics
1. Preparedness/ Mitigation	A. Policy Formulation Process	*1) Process of policy formulation 2) Collective behavior analyses 3) Media utilization *4) Research utilization
	B. Policy Response	1) Adoption processes *2) Implementation processes 3) Managerial strategies 4) Planning process variations
	*C. Individual Perceptions	1) Hazard perceptions 2) Adoption of adjustments 3) Efficacy of educational change efforts
2. Flood Warning	A. Operational Constraints	1) Flood warning system implementation systems 2) Flood warning system composition 3) Case studies of management planning *4) Integration of warning systems
	B. Public Evacuation	1) Adverse conditions 2) Special populations *3) Evacuation facilitators/ inhibitors 4) Shelter requirements
3. Emergency Response	*A. Multiorganizational Response Systems	1) Volunteer groups 2) Emergent multiorganizational networks 3) Media relationships 4) Emergency operations
	B. Emergent Group Processes	
	*C. Helping Behaviors	1) Family recovery processes 2) Therapeutic communities 3) Assessments of agency intervention
4. Recovery and Restoration	A. Community Decision-Making	
	*B. Long-Term Impacts on Microsystems	1) Primary group impacts 2) Family impacts 3) Individual impacts
	C. Process of Community and Organizational Change	

* = Critical Priority

Until these responses and various forms of helping behaviors (study area 3C) are understood better, the long-term impacts of flooding on families and other types of micro social systems (study area 4B) will remain unknown. Today, various interest groups stand poised, yet unsure of when their aid is needed most and what its consequences might be for those receiving it. Relevant organizational policy — like that focused on other phases of flooding — will remain uninformed by scientific knowledge until these studies are completed. Consequently, the nation's use of flood-prone lands and recovery from flood events will remain far less effective than it need be.

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CHAPTER 8. POLITICAL SCIENCE RESEARCH ON FLOOD MITIGATION

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CHAPTER 8. POLITICAL SCIENCE RESEARCH ON FLOOD MITIGATION

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INTRODUCTION

Floods cause problems that are perceived as calling for political action to mitigate their effects. Principal problems are the destruction of private and public property, disruption of business and other activities, and the loss of human life. The Flood Control Act of 1936 and subsequent acts authorizing flood control projects of the Army Corps of Engineers, the Flood Insurance Act of 1968 and the Flood Disaster Protection Act of 1973 are major examples of political actions by the federal government to help solve flood problems. State and local governments have taken related political actions.

Political action involves politics — which can be defined as the processes by which a society makes authoritative decisions about the allocation of value (Easton, 1965). Accordingly, the output of politics can be seen as public policies and the significant values that result from their implementation. In the United States the mitigation of floods has been highly valued. The billions of dollars spent by the federal government alone on flood protection, subsidized flood insurance and disaster relief is indicative of such public valuation.

Public policy with respect to flood mitigation has changed over the last fifteen years from reliance almost solely upon flood control by dams and levees to a complex of measures. This changed national perspective emphasizes national flood insurance and emergency assistance programs, nonstructural in preference to structural solutions, and local community responsibility and action. A widely held norm, among professionals involved in determining the mix of measures that should be utilized in each particular situation, is "efficient use of flood-prone lands."

Implementation of this basic policy change — that assumes close cooperation and coordination of federal, state and local governments for its success — is far from complete. Political knowledge derived from research is needed by the practitioners involved. Study is needed of administrative progress and the political problems encountered in implementation. Also, evaluation of the impact of the change, largely calling for interdisciplinary studies and providing feedback for policy-change processes, has hardly begun (NSF, 1980).

The contribution of the discipline of political science to the study of flood mitigation up to this time has been fragmentary. Relative to other disciplines, such as hydrology, economics and law, political science research has been scarce.[1]* Many, possibly most, academic political scientists, focus their research upon problems looking toward advancement of the discipline, rather than utilizing the discipline in research to provide political knowledge of use to practitioners. The opportunities for research identified in this chapter are set forth to encourage involvement of political scientists in applied political science.

On the basis of the author's perception of political knowledge needed with respect to flood mitigation problems and of the applied research contributions that political scientists are equipped to make, an initial political science research program on flood mitigation has been formulated, as set forth below.[2] When more political scientists become involved in research on flood mitigation, this initial program will need revision on the basis of a wider range of perspectives and expertise.

The initial program includes three types of political science research: political behavioral, policy analysis (formulation/legitimation, implementation and impact) and intergovernmental relations. In a number of flood mitigation problems identified with these three types of research, research from the perspective of public choice theory could be undertaken, independently or in conjunction with related items in the economic research chapter. Also, several of the research problems included in the initial program could, or should, be addressed by interdisciplinary teams. These problems are so identified. All research problems deemed to be <u>critical</u> have been identified by an asterisk.

POLITICAL BEHAVIORAL RESEARCH

Political behavioral research here includes statistical analysis of relationships among political variables; sample survey of opinions, their intensity and actions; and political analysis more generally. Related social research is included in the chapter on social behaviorial research needs. The potential for interdisciplinary research is apparent in several instances.

<u>Catastrophe and Political Action</u>

Political scientists specializing in natural resources/environment have long perceived that catastrophe, or well recognized threat thereof, is a major independent variable in natural resource/environmental policy establishment and implementation. More particularly, floods have been so perceived. Nevertheless, the correlation between flood catastrophes and political actions has not been studied rigorously. Definite knowledge of such correlation among professional personnel and political actors, for example, might instigate more

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*Superscript numbers refer to the Endnotes of this chapter.

substantial pre-disaster planning and then improved post-disaster action. Under what circumstances do political actors (public and private) take advantage of catastrophe?

This research problem is deemed to be critical because lapses in political and administrative concern with flood mitigation is evident between flood events. It is hypothesized that greater progress in policy development and implementation could be achieved if full advantage is taken of the political and social focusing effects of catastrophe, particularly in local communities.

*Research Problem

> Determine for one or a sample of rivers the correlation between major flood events and changes in public policy and levels of implementation with respect to flood migitation measures.

Ideological Involvement

Ethical principles and other ideological positions are involved in formation of public opinion regarding public responsibility for flood hazard mitigation and in the inspiration of political action. Some of these ideological positions are supportive of public responsibility for flood hazard mitigation and some are in opposition. For example, in our culture human life is highly valued and its loss, or threatended loss, inspires community concern. On the other hand, liberty in the use of one's real property is also highly valued and results in resistance to community interference in its use. The full range of these ideological positions has not been clearly identified and their relative political importance has not been determined. Risk assessment research, involving individual and community assessment of risk, could be a part of this research.

Research Problem

> Identify the various ideological positions on flood hazard mitigation within defined publics and determine their relative political importance.

Flood Mitigation Constituencies--Federal, State and Local

The initiative for change in flood mitigation policies and levels of implementation in the federal government during the last 20 years has come from professional experts and leaders within the Executive Branch plus a few leaders in Congress. Similar initiatives have been undertaken independently by a few states (e.g., Wisconsin) and localities (e.g., metropolitan Denver). Academic research, largely by geographers spearheaded by Gilbert White, has inspired much of this change.

Government programs without active political constituencies outside government tend to weaken or die. Well organized interest groups (e.g., the National Water Resources Association and its constituent groups) promoting flood control measures have been the dominant political constituency. Constituencies supportive of nonstructural mitigation measures and of comprehensive planning and community action (e.g., the League of Women Voters and some environmental groups) need to be identified and studied. This information would be particularly useful to political actors including flood plain managers.

Research Problem

> Identify the groups outside government — at federal, state and local levels — that support or oppose particular types of flood mitigation measures and comprehensive planning and action; and specify their activities and effects.
>
> Identify groups that, a *priori*, might be expected to be such groups but are not actively interested; and determine why they are not actively interested.

Authority and Funds--State and Local

Planning and action on flood mitigation measures should be largely a local government responsibility, except for the possible flood control structures which continue to be of direct concern to the federal government. The federal government has initiated "carrot and stick" measures to encourage local planning and action and state support thereof. Both local planning and action and state support require local and state authority and funds.

Research Problem

> Identify instances of successes and failures of state and local governments to obtain authority and funds for planning and action related to flood mitigation and determine the reasons for success and failure via correlation with public opinion, interest group activity, organizational arrangements of the flood mitigation unit, application of federal leverage, etc.

Strategies for Management and Resolution of Conflict

Management and resolution of conflict are generic societal problems, which have been the subject of substantial research, particularly in labor-management relations. Mediation, arbitration, cooling-off periods, legislation, etc. have been utilized.

Major conflict problems are involved in most natural resource/environmental programs including flood mitigation programs. Mediation has been attempted in a few highly confrontational river basin planning situations. Currently, in California's Lake Tahoe area, a widely representative advisory committee, with markedly diverse opinions among members, is operating under decision rules which force extremists to compromise or have no direct effect on decisions.

Research Problem

> Identify successes and failures in management and resolution of conflict over flood mitigation measures and the methods that were utilized; determine the specific economic, social and political factors involved and their relative importance; and suggest strategies for management and resolution of conflict that have a likelihood of success.

Regulation of Private Land and Public Land Acquisition

Individual and political liberty in the United States are closely associated with the private ownershop and control of land. Land-use regulation and public land acquisition are major institutional means of flood hazard mitigation. Intensive study of these conflicting public interests is needed at all levels of government.[5]

Research Problem

> Study public attitudes involved in these conflicting public interests with a view to discovery of means to resolve conflict.

Private Institutional Impacts on Flood Mitigation

The insurance industry, real estate agents, land developers and lending institutions play major private and institutional roles impacting on public flood mitigation efforts.

Research Problem

> Identify the interests of each of the private institutions with respect to their positive and negative impacts on public flood mitigation efforts; and evaluate means by which their impacts might become more supportive.

PUBLIC POLICY RESEARCH: FORMULATION/LEGITIMATION

Pre-Flood Planning of Post-Flood Measures

A major problem in improved flood mitigation efforts is conducting disaster relief programs in such a way as to reduce future flood losses. On the one hand, flood plain occupants often want to reoccupy the flood plain. On the other hand, catastrophe tends to establish the political conditions for reform. Reform, however, requires pre-flood planning of post-flood mitigation measures in accord with the National Flood Insurance Act (Public Law 90-448), as amended, and the closely related Flood Disaster Protection Act of 1973 (Public Law 93-234), as amended. One of the purposes of the Hazard Mitigation Teams under the FEMA-led Interagency Task Force, discussed later in this chapter, is to conduct pre-flood planning, but in most instances they have been organized after a disaster was declared. Such pre-flood planning, however, might breed much local hostility with negative political repercussions.

This research problem is closely related to the problem discussed above under Catastrophe and Political Action and is deemed critical for the same reasons. Moreover, as noted in the Introduction to this chapter, the present national perspective on flood mitigation emphasizes both national insurance and emergency assistance programs as well as local community responsibility and action. Effective post-flood mitigation action, particularly by the federal government and local governments, is critical to lessening the adverse effects of future floods. Lack of pre-flood planning by federal, state and local governments substantially lessens (presumably) the efficiency and effectiveness of post-flood mitigation action.

*Research Problem

> Identify alternative public policies and programs for handling pre-flood planning, on the basis of case studies or hypothetical conditions; and evaluate these alternatives in terms of their political and administrative advantages and disadvantages.

Alternatives to Direct Land Regulation

Alternatives to direct governmental regulation are being studied in many areas of public policy. The results of this general research interest need to be considered with respect to direct regulation of private land use as a means of flood mitigation. Relevant alternatives might be tax penalties or incentives; public acquisition of specific property rights, but not all such rights, by easement; and mandatory insurance paid by a property owner to protect those adversely affected by his freedom to use land as he chooses.

Research Problem

> Identify alternatives to direct governmental regulation discovered or considered in other areas of public policy; evaluate their applicability to flood mitigation; formulate technically feasible policy proposals; and determine their political feasibility.

POLICY ANALYSIS RESEARCH: IMPLEMENTATION

Implementation of Local Flood Plain Regulation

The federal "carrot" of subsidized flood insurance is conditional upon the "stick" of local adoption and enforcement of flood plain regulations upon land owners in both coastal and riverine areas. Little is known generally and systematically of the quality of these regulations in comparison to a general standard (or comparatively among them), and of the degree of their enforcement.

The Community Assistance and Program Evaluation Program of the Federal Emergency Management Agency now monitors local government compliance with minimum federal standards and seeks to obtain compliance.

Research Problem

> Determine the quality of local flood plain regulation in comparison to a standard (e.g., the minimum standards of the Federal Emergency Management Agency) and comparatively among localities.
>
> Determine effectiveness of enforcement in terms of administrative action, local political support, use of variances and judicial actions.

Enforcement Role of Lending Institutions

Certain types of lending institutions have been given an enforcement role by the federal government with regard to the purchase of flood insurance. They are expected to deny mortgages under most circumstances for structures in flood plains not covered by flood insurance. The self-interest of these institutions would seem to be importantly involved, too, in view of their own requirements for fire insurance by mortgagees. Recent flood events in Illinois indicate that lending institutions have been performing their role very poorly and steps are being taken to correct this particular situation. However, little is known systematically of the successes and failures of this means of enforcement.

This research problem is critical because of the important strategic role that thousands of lending institutions play in enforcing the purchase of flood insurance. The results of this research are essential if measures need to be taken to make this decentralized enforcement role fully effective as soon as possible. The long run goal of the flood insurance program, it should be noted, is to shift the burden of flood damage to flood plain property owners and to lessen disaster assistance costs now borne by the public at large.

*Research Problem

> Determine the policy and administrative response, with respect to this enforcement role by lending institutions, of federal instrumentalities (e.g., Federal Reserve Board, Federal Home Loan Bank Board, Comptroller General, etc.) that control the activities of lending institutions.
>
> Determine the policy and administrative responses of lending institutions to this public responsibility and private opportunity by type of hazard zone (i.e., riverine, coastal, and mudslide) and degree of hazard.

River Basin vs Localized Flood Mitigation Efforts

The Delaware and Susquehanna River Basin Commissions have substantial river basin regulatory and other authority. Local governments in the basins have authority, too. There is little systematic research on the utility of these commissions, in cooperation with local governments, in planning and implementing comprehensive sets of flood mitigation measures or individual measures.

Research Problem

> Determine the utility of federal-state compact commissions, in cooperation with local governments, in planning and implementing flood mitigation measures. In this connection, studies comparing commission vs non-commission basins could be made.

Interagency Task Force

The Office of Management and Budget in July 1980 directed creation of an interagency task force at the national level to promote use of nonstructural and other measures. The Federal Emergency Management Agency (FEMA) was designated as lead-agency even though this assignment was hotly contested by other agencies before the decision was made. Two levels of activity have stemmed from this assignment. First, Hazard Mitigation Teams are in the field largely working on post-flood measures, but they can be authorized to undertake pre-flood planning of mitigation. Second, top agency representatives, under leadership of the top FEMA representative, are to provide overall policy coordination and promotion of mitigation measures. Conventional wisdom in Washington would say that no agency will succeed in a coordinating leadership role that has an operational stake with respect to the functions involved. Alternative interagency arrangements include leadership by a successor to the Water Resources Council, a task force led or supervised by White House staff, a Cabinet council or committee arrangement, or a task force led by a representative of the Office of Management and Budget.

Research Problem

> Determine what the task force has done or not done; factors involved in successes and failures; and evaluate this FEMA-led task force in relation to the strengths and weaknesses of alternatives.

Implementation of Presidential Executive Order 11988

Presidential Executive Order 11988 directs many federal agencies to carry out their functions in such a manner as to help enhance riverine and coastal flood hazard mitigation through exercise of their regulations or other powers. Recently, 0MB has directed FEMA to conduct a review of this executive order.

Research Problem

> Review the literature on Presidential executive orders with respect to their substantive, as distinguished from their

symbolic, utility as a basis for examining the probable utility of a particular executive order.

Determine and evaluate federal agency responses to Executive Order 11988.

Local Community Responsibility

Local communities need to have a local sense of responsibility, it can be hypothesized, if flood mitigation measures are to be successfully and permanently implemented in both riverine and coastal areas. In this connection, is federal and state "carrot and stick" behavior supportive of development of local responsibility or does it subvert or preempt local responsibility? In some governmental programs, it would appear, state and/or local action is taken and continued only because of federal pressure and the threat of direct federal action.

This research problem is critical because success or failure of present national policies for flood mitigation critically involve local community responsibility and action. Priority attention, therefore, should be focused upon the community role.

*Research Problem

Formulate hypotheses concerning, and undertake case studies of development of local assumption of responsibility (i.e., political regulatory and financial) for flood mitigation measures in the context of state and/or federal pressures. Case studies involving apparent successful and unsuccessful assumption of responsibility should be undertaken. Comparative studies testing particular hypotheses should also be made.

Implementation of WRC's Unified Program

In 1976 and 1979 the Water Resources Council (WRC, 1976, 1979) published a Unified National Program for Flood Plain Management. With the demise of WRC, the responsibility for the Unified Program has been assigned to FEMA. The apparent intention of the two program statements was to encourage all governmental participants to follow the directions of the programs. The 1979 version strengthened, but did not contradict, the 1976 version. The reception and response to governmental participants — federal, state, and local — is not known.

Research Problem

Review the literature on the substantive utility of presidential messages and policy statements, executive orders, policy commission reports, departmental policy, program reports and other high level official educational documents.

Determine the nature of the reception and degree of response of governmental actors to the Unified Program and compare these results with expectations derived from the literature review.

Implementation of Land Acquisition Policies

The WRC's handbook on State and Local Acquisition of Land of Flood Plains and Wetlands (WRC, 1981) summarizes experience with implementation of land acquisition policies, as follows:

> "Many federal policies now recognize that (land) acquisition can play a useful role in floodplain management programs. Still, experience with acquisition projects has been mixed. While sponsors consider some projects highly successful, others have been marred by inefficiency and frustration; still others have failed entirely. In many cases, available funds are insufficient to make floodplain acquisition a viable floodplain management technique. States and localities have frequently tried to obtain needed funds by 'packaging' state, local, federal, and private resources" (p. 27).

The Handbook gives analyses of successes. No analyses of failure are set forth. Bloomgren and Kusler (1982) in their Strengthening State Floodplain Management and Kusler (1982) in his Innovation in Local Floodplain Management--A Summary of Community Experience have dealt with this matter. A more selective, intensive and analytical research effort would be very useful.

Research Problem

Formulate hypotheses and determine through intensive studies the political and other factors responsible for successes and failures of land acquisition as a mitigating measure; and evaluate the case studies comparatively.

Policy Analysis Research: Impact

The Flood Hazard Mitigation Report (NSF, 1980) recommended that the Water Resources Council "develop a plan . . . for analysis of the impact of riverine and coastal flood hazard mitigation policy . . ." (pp. 220-221). Such analyses would be indicative of success or failure in actually mitigating the hazard and would of necessity be widely interdisciplinary.

Development of an official plan for impact analysis (which is desirable because of the needed broad scope of such analyses and the need of governments to know impact) does not, and should not, preclude independent academic research.

Research Problems

Design a plan study of policy impact for a successor to the Water Resources Council or FEMA and test the design in limited geographical areas.

Conduct independent impact analysis of particular policy elements in the total mix of mitigation measures or of all elements as they impact a particular river basin or river segment. Particularly useful would be research on political blockage of the utilization of impact information for policy . change.

INTERGOVERNMENTAL RELATIONS[6]

State Organizational Arrangements

States vary substantially in their complex of organizational arrangements pertinent to flood hazard mitigation. Comparative studies of these arrangements are not available and could be made within the context of more general comparative state studies that already have been made. Bloomgren and Kusler (1982) and the Association of State Flood Plain Managers, Madison, Wisconsin, could provide help formulating a research design.

Research Problem

Develop hypotheses and evaluate states comparatively, assessing strengths and weaknesses of their organizational arrangements, based upon comparable state data.

Local Organizational Arrangements

Cities, counties, and special districts vary substantially in their complex of organizational arrangements pertinent to flood hazard mitigation. Comparative studies do not exist and could be made within the context of more general comparative local-governmental studies that already have been made. Kusler (1982) could provide help in formulating a research design.

Research Problem

Develop hypotheses and evaluate local governments comparatively, assessing strengths and weaknesses of their organizational arrangements, based upon comparable local data.

New Federalism and Flood Mitigation

The new federalism of the Reagan Administration (as well as preceding proposals) call for reallocation of responsibility for water matters, generally, between the federal, state and local levels of government. Flood plain management is a part of this large domain of reallocative concern (NRC, 1981). It is also a part of multi-purpose river basin development and of multi-hazard responsibilities of FEMA and other governmental agencies.

This research problem is <u>critical</u> because of current public efforts, widely supported in principle, to devolve more responsibility to states and local governments. Research is needed to inform these public efforts.

*Research Problem

> Identify the presumptions of fact and value that underline the existing allocation of responsibility for flood hazard mitigation.
>
> Identify alternative allocations of responsibility and their presumptions of fact and value; evaluate these alternatives among themselves and as compared to the status quo.

<u>Flood Mitigation Management and Scarce Resources</u>

Accountability and responsibility for implementing flood mitigation measures is not diminishing but the needed personnel and financial resources are becoming increasingly scarce at all levels of government. Strategies to handle this situation also involve, or affect, all levels of government. Alternative strategies, responsive to different normative criteria, need to be developed to inform management of the alternative strategies available to them.

This research problem is deemed <u>critical</u> because of increasing scarcity of resources with little if any promise that the situation will improve.

*Research Problem

> Develop alternative strategies, responsive to different normative criteria, to cope with increasing scarcity of resources to implement flood mitigation policies.

<u>Urban and Rural Regional Districts</u>

Urban and rural regional districts have been formed with direct authority and responsibility for flood hazard mitigation as an alternative to no formal means of coordination of city and county governments and to coordination by Councils of Governments. No intensive assessments of this alternative now exist.

Research Problem

> Compare one or more urban or rural regional districts with regional areas that have no such district and evaluate the strengths and weaknesses of each organizational arrangement.

INTERDISCIPLINARY RESEARCH

Flood Insurance Rates

Research on flood insurance rates, actuarial and subsidized, should involve more than one discipline. The chapter on economic research proposes research on this subject. Following is a suggested component of study for political scientists.

Research Problems

Study of implementation of flood insurance law in FEMA and is predecessors to ascertain how rate issues have been handled and decisions made.

Perform political feasibility analyses of one or more rate policies alternative to that being implemented by FEMA in accordance with extant law. Studies could include sample opinion surveys of insurance policy holders, agents, insurance companies and the financial insitution enforcing the purchase of flood insurance under the National Insurance Program.

Performance Standards for Local Governments

The Flood Hazard Mitigation Report (NSF, 1980) recommended that FEMA develop performance standards for local governments broader than current regulations with respect to the efforts of these governments to mitigate flood hazards (p. 221). Minimum performance standards are now in existence and are used in application of federal "carrot and stick" policies. During the last two years two local jurisdictions have been suspended, with the consequence that no flood insurance is available to these areas. Other jurisdictions are said to be responding now to the threat of suspension. Adequate performance standards are essential to obtain an acceptable level of success in flood mitigation. Research is needed on the adequacy of current standards.

Research Problems

Design alternative standards for possible use by FEMA in judging adequacy of the performance of local governments, indicating their pros and cons.

Field test these alternative standards as regards "fairness," etc.

Flood Mitigation and Social Goals

The Flood Hazard Mitigation Report (NSF, 1980) recommended that "flood hazard mitigation strategies should be examined to determine the extent to which social goals, such as equity, conflict with other goals, such as efficiency and environmental preservation, with an eye to reducing conflicts."

Research Problem

Examine these strategies in both normative and positive terms, from the perspective of several disciplines including political science.

Political science could contribute normative analysis, political and administrative feasibility analyses, means of conflict management and resolution, etc.

Risk-Benefit Analysis

Risk assessment involves scientific as well as normative elements. If only property were involved in flood damage, benefit-cost analysis might be viewed as sufficient. But human life and other "intangible" values are also involved. The rapidly developing literature on risk assessment in general, to which political scientists are contributing, should be utilized to provide context and comparisons. Both individual and community risk should be addressed.

Research Problem

Undertake risk assessments relating to the flood hazard including residual risks after mitigation. Compare risks from floods with other forms of risk as an aid in public policy judgment.

CONCLUSIONS

The knowledge derived from research by political scientists is pertinent to improved governmental action with respect to flood mitigation. Relatively little such research has been undertaken up to now by political scientists. Three types of political science research (together with interdisciplinary research proposals) are proposed as an initial program: political behavioral, policy analysis (formulation/legitimation, implementation and impact) and intergovernmental research. The knowledge gained could be useful in advancing the effectiveness, equity and efficiency of current practice of flood mitigation. The research problems identified are believed to be important. They relate to the following, with an asterisk indicating that they are deemed of critical importance.

*Catastrophe and political action
Ideological involvement
Flood mitigation constituencies — federal, state, and local
Authority and funds — state and local
Strategies for management and resolution of conflict
Regulation of private land and public land acquisition
Private institutional impacts on flood mitigation
*Pre-flood planning and post-flood measures

Alternatives to direct land regulation
Implementation of local flood plain regulation
Enforcement role of lending institutions
River basin vs localized flood mitigation efforts
Interagency task force
Implementation of Presidential Executive Order 11988
*Local community responsibility
Implementation of WRC's Unified Program
Implementation of land acquisition policies
Policy analyis research: impact
State organizational arrangements
Local organizational arrangements
*New federalism and flood mitigation
*Flood mitigation management and scarce resources
Urban and rural regional districts
Flood insurance rates
Performance standards for local governments
Flood mitigation and social goals
Risk-benefit analysis

CHAPTER 8 REFERENCES

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ENDNOTES

1. An incomplete but suggestive examination of bibliographical sources indicates the relative scarcity of applied political science research on flood mitigation. Of some 3600 water resource abstracts covering flood control and flood mitigation and included in the computer access system through July 14, 1982 of the Water Resources Scientific Information Center, less than 200 explicitly concern public policy. Many of the researches covered by these abstracts were not performed by political scientists. One reference was identified, explicitly involving flood control, the principal author of which is a political scientist: F. Munger, Politics and Organization in Water Resource Administration: A Comparative Study of Decisions, Water Resources Research, Vol. 1, No. 3, pp. 337-347, Third Quarter 1965. Another reference with the third author a political scientist is: L. D. James, E. A. Laurent and D. W. Hill, The Flood Plain as a Residential Choice: Resident Attitudes and Perceptions and Their Implications to Flood Plain Management Policy, (Environmental Resources Center, Georgia Institute of Technology, Atlanta), a completion report of September 30, 1971 under OWRR Project No. C-1786, Grant No. 14-31-001-3167. Abstracts for the research of political scientists with known interest in water resources, H. Ingram and D. E. Mann, do not relate explicitly to flood control or flood mitigation.

   The only paper by the author concerning floods was prepared when he was Executive Director of the U.S. Water Resources Council: Flood Plain Management Policies in the Proceedings of National Conference of State or Federal Water Officials, Denver, Colorado, September 6-8, 1967 (Published by the Interstate Conference on Water Problems and the U.S. Water Resources Council, Washington, D.C.).

   This lack of interest by academic political scientists, however, may be changing. The Annual Meeting of the American Political Science Association, September 1982 in Denver, Colorado, included papers on "Risk and Uncertainty in Policy Making" and "Disaster Analyses in Theoretical Perspective." Also involved in the meeting was a Disaster Policy Group, organized by Douglas Nilson of the University of Redlands.

2. An early draft of this chapter has benefitted from review by Helen Ingram, Department of Political Science, University of Arizona; colleagues in the Department of Political Science, Colorado State University; and by a number of non-political scientists who are familiar with flood mitigation problems. Time and resources were not available to obtain more widespread review by other professional colleagues.

3. Known exceptions to this statement is the research, noted above, by L. D. James, E. A. Laurent and D. W. Hill, which only covered Peachtree Creek watershed in metropolitan Atlanta, Georgia; and H. C. Hart The Dark Missouri (The University of Wisconsin Press, Madison: 1957) pp. 92-97.

4. L. C. Dodd and R. L. Schott Congress and the Administrative State (John Wiley and Sons, New York: 1979) pp. 98-99. The importance of interest groups in contemporary American society is clear from this citation, as well as much other work that might be cited.

5. . Sociologists and other social scientists have already done some research on this topic. See J. R. Hutton and D. S. Maletic et al. Analysis of Adoption and Implementation of Community Land Use Regulations for Floodplains (Report to NSF by Woodward-Clyde Consultants, San Francisco, California: 1979) pp. II-46 to II-64.

6. Intergovernmental relations as a field of study in political science involves relations vertically between three levels of government and horizontally between major units at the same level. It includes the study of federalism.

CHAPTER 9. LEGAL ASPECTS OF MITIGATING FLOOD DAMAGES

CONTENTS

CHAPTER 9. LEGAL ASPECTS OF MITIGATING FLOOD DAMAGES

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INTRODUCTION

Our legal system deals with floods both prospectively and retroactively. It provides the means for planning to reduce the consequences of flooding and for assigning liability for damages that inevitably follow floods. These features of the legal system can be directed toward increasing the efficiency with which we use flood-prone lands — that is, toward maximizing the net social benefits.

The pervasiveness of the law is amply demonstrated by this report. Each of the other disciplinary chapters deals directly with substantive and procedural legal issues, as illustrated by the following examples:

Meteorology and Climatology--Regulatory procedures by which data are reported and standardized.

Hydrology and Hydraulics--Legal effects of alternate ways of mapping and classifying flood plains for regulatory purposes.

Environmental Sciences--Legal considerations surrounding proposals to modify stream channels, water levels, and rates of flow.

Health and Sanitation--Implementation of local, state, and federal regulations for the health and safety of persons living in flood-prone areas.

Sociology--Delineation of authority to encourage or require human actions in accordance with broader policies for public health, safety, and welfare.

Economics--Transformation of economic principles into public policy.

Political Science--Organization and allocation of governmental authority over a broad range of flood mitigation measures.

The recommendations for legal research at the end of this chapter were chosen with due regard for how they might help resolve the research questions raised in the other chapters, particularly with reference to the three major national themes embodied in this report: 1) the National Flood Insurance Program and related emergency measures, 2) the trend from structural to non-structural mitigation measures, and 3) the emergence of involvement by local communities in mitigation planning.

This chapter is intended to provide the non-lawyer with an overview of the relevant legal issues and the rationale for the research recommendations. A vast legal literature of case law, statutes, articles, and other sources is available for lawyers and others who wish to pursue any of the points raised here. Kusler and Platt (1982) provide an excellent volume of source material and commentary.

SURVEY OF LEGAL ISSUES

What follows is a listing of legal issues that might arise during the chronology of a flood, using the chronological sequence developed in the chapter on sociology research needs: preparedness/mitigation, flood warning, emergency response, and recovery/restoration. Some of these issues will be covered rather cursorily, while others are described in greater depth. The space allotted to each issue is not necessarily proportional to its importance: some issues need to be explained so that legal questions raised in other chapters in this report might be understood more clearly.

Preparedness/Mitigation

Many of the mitigation efforts are initiated long before the flood-prone area is in danger of being inundated by a particular flood. Indeed, both the percentage and the intensity of efforts undertaken at this stage are increasing steadily.

1) Land-Use Planning. An obvious way to prevent damage by flooding is to keep things of value off the flood plains, or at least to restrict land uses to those that are least affected by flooding. This indeed would be simple — legally but not politically — if all flood plains were publicly owned, but obviously they are not, and the public's interests do not always coincide with those of private landowners. These differences create both geographical and intellectual zones of contention. As a result, we must address the constitutional limits to public regulation of private property.

Private property rights never have been absolute. Even at earliest common law, the benefits gained by ownership of real property were accompanied by obligations not to use it in ways detrimental to other property owners. Examples are the duties to maintain lateral support for neighboring property, to allow diffuse surface waters to flow upon one's land from higher elevations, and not to produce contaminants on the property that unreasonably affect use of other property.

Public limitations on use of private property are imposed under authority of a state's inherent police power to further the public health, safety, and welfare. This power is delegated by statutes to subordinate units of government, not only to counties and municipalities, but also to special use districts (e.g., irrigation and drainage districts, urban development authorities, and natural resource conservancy agencies). As might be expected, the legislative and judicial definitions of "public health, safety, and welfare" expand in response to society's needs as reflected by increasing human populations and greater burdens that can be imposed by modern land uses on surrounding property.

The ever-increasing reliance upon governments to control floods has forced consideration of land-use planning within flood plains as a way to limit losses. Many major urban areas are located on the approximately 7% of the United States that comprises flood plains, and jurisdiction over them is fragmented among thousands of state, county, local, and special-purpose governments. The main idea of flood plain planning is to allocate land use among districts with respect to anticipated flood conditions. For example, those districts where routine flooding is expected would be zoned to prohibit uses (such as residential and business) that would sustain unreasonable losses. Fine examples are provided and discussed in Association of State Floodplain Managers (1982) and Bloomgren and Kusler (1982).

The constitutionality of land-use regulations is well established and need not be considered in detail here. The legal literature on the general topic of land-use planning is extensive, both in breadth and depth, and hundreds of individual regulatory and judicial decisions concerning it are made every week in the United States. Indeed, land-use planning has become a well-established area of legal specialization, as evidenced by a number of legal periodicals and treatises.

A central concern can be stated simply: How to restrict private uses on flood plains to reduce damages that might result from flooding. The various criteria that are used to judge whether a land-use restriction is constitutional with regard to the lessening of property rights are not applied in all circumstances, but the following three frequently are cited as being the most important.

1) Whether a rational relationship exists between the restriction and a legitimate state objective (with a strong presumption in favor of the statute or regulation),
2) Whether the allowable uses are compatible with uses of neighboring property, and
3) Whether the resulting reduction in value of the affected property is reasonable.

In essence, the decision involves a balancing of all benefits and burdens created by the land-use restriction, with the affected property owner bearing the onus of proving that the burdens clearly exceed the benefits to an unreasonable degree. When courts are called upon to examine the constitutionality of land-use laws, they proceed on the initial presumption that the legislation is valid.

Other land-control procedures at federal, state, and local levels include governmental purchase of flood-prone areas for public open space, public acquisition of various types of easements to allow public use while controlling flood-plain development, property tax incentives to encourage open space use, strict sanitary and health codes to preclude undesirable land uses, and building and housing codes that take into consideration the anticipated conditions to be encountered on flood plains.

The need for better land-use planning is a recurring theme throughout this report, and it obviously will be a topic of subsequent studies by legal scholars and practitioners, as well as provide a fertile source of litigation. See Bosselman et al. (1973) for a thorough explanation of the issues.

2) National Flood Insurance Program (NFIP). This program is analyzed in some detail in other chapters, particularly the one on economics, but it might help to explain some of its features here as well. In the National Flood Insurance Act in 1968, Congress created a federally subsidized plan to provide low-cost flood insurance in the absence of private coverage. An important qualification was that flood insurance would be available only where specifically identified flood-prone areas were managed by local communities through appropriate regulations.

This program, however, proved insufficient to attract the desired degree of participation by local governments. Congress subsequently passed the Flood Disaster Protection Act of 1973 in response to a strong public policy favoring a national flood insurance plan. This statute increased the incentives for local governments' enrollment in the insurance program. Communities in flood-prone areas must participate in the NFIP to receive federal funding for flood-control projects, and property owners in those participating communities must be covered by flood insurance to receive mortgage money from a federal agency or a federally related financial-lending institution.

The land-use planning features of the National Flood Insurance Act of 1968, the Flood Disaster Protection Act of 1973, and the National Environmental Policy Act of 1969 were amplified by Executive Order 11988 in 1977 for the purpose of avoiding to the greatest extent possible the adverse effects associated with use of flood plains. Under this Executive Order, each federal agency must act to reduce the risks and effects of floods and to restore the natural and beneficial values served by flood plains. These actions are to be performed by the agencies as they fulfill their responsibilities for managing federal lands and facilities, providing federal assistance programs, and conducting federal "activities and programs affecting land-use, including, but not limited to water and related land resource planning, regulating, and licensing activities." The Executive Order provides some specific guidance on how the agencies are to proceed and determines its scope by defining flood plain as "the lowland and relatively flat areas adjoining inland and coastal waters, including flood prone areas of offshore islands, including at a minimum that area subject to a one percent or greater chance of flooding in any given year."

The NFIP, now administered by the Federal Emergency Management Agency, was held constitutional in Texas Landowners Rights Association vs Harris, 453 F.Supp. 1025 (1978), aff d 598 F.2d 311 (1979), and has prompted much commentary in the legal literature. Helpful accounts of the program's history and probable future role are provided by Holmes (1980) and Baram and Miyares (1982).

In many instances, legal consequences can arise only after a threshold determination has been made of what hydrologic event actually occurred. Thus, the definitions of common terms can have legal significance. Among these are annual flood, average annual flood, banks, bed, channel, flood plain, natural channel, ordinary flood, and peak flood. To prevent unnecessary confusion, the use of these terms must be carefully coordinated in the related federal, state, and local procedures related to the use of flood plains. Closely related, and of at least equal importance, is the need to coordinate the manner in which flood plains are to be mapped, with particular reference to the NFIP.

3) Enforcement of Flood Plain Regulations. Enactment of laws and promulgation of regulations under them usually are necessary but not sufficient to solve the problem they address. Enforcement is needed in nearly all instances, and it certainly is necessary when the laws and regulations concern limitations on land uses. For a number of reasons, land-use regulations are not enforced as uniformly or as aggressively as they might be. Civil liability normally is relied upon to enforce property laws and land-use regulations, with the prime deterrent being the possibility of having to alter or abandon the illegal land use.

Perhaps some appropriate criminal sanctions could be added to the enforcement provisions. These would allow the levying of fines and in some instances the deprivation of personal liberties. If enforced even-handedly, these additions would enhance the current enforcement efforts.

4) Equitable Relief. The use to which property can be put is limited by the law of nuisance to those activities that are reasonable under the circumstances. Thus, any land use that imposes a legally unreasonable burden on the enjoyment of surrounding land can be prohibited. Significantly, the burden needn't actually be experienced if a proposed land use would clearly violate the "rule of reasonable use" in light of all surrounding circumstances. The proposed activity then can be enjoined — that is, judically prohibited from being initiated. This equitable relief, then, precludes problems from arising rather than dealing with the monetary damages that would result because of their existence.

Planned or actual diversions of water can create conditions that cannot be tolerated under the law of nuisance. A common example is alteration in drainage patterns as a result of topographic changes during development of new subdivisions. A related problem can arise when stream channels are changed in an effort to reduce flood damages along one portion of the stream, thereby imposing greater burdens elsewhere. What follows is a brief overview of the state of the law concerning the respective rights of landowners along watercourses.

Riparian landowners share reciprocal rights and obligations among themselves to protect land from inundation and to secure the benefits of naturally occurring overflows. Details of the relationships vary from state to state. A common provision — the "civil law rule" — is the imposition that all landowners accept natural floodwaters on their property, thus denying them the right to divert the water onto other lands unless the flood is so extraordinary that its occurrence could not be foreseen. Under the "common enemy doctrine," each landowner can take whatever measures are necessary to protect property; downstream landowners who might be affected by actions upstream then have the right to protect their own property by all reasonable measures. This doctrine might apply also under the civil law rule but only if the flood truly was extraordinary. In a leading case involving diversion by levees of the Mississippi River's normal flow, Cubbins vs Mississippi River Commission, 241 U.S. 351 (1916), the Supreme Court of the United States traced this rule back to Roman Law. The Court stated that the law in this country prohibits unnecessary deflection of floodwaters by construction of works for individual benefit but that this is qualified in the event of extraordinary floods. The "reasonable use rule" is an option available to states that prefer greater flexibility in dealing with floodwaters.

As a corollary, riparian owners are entitled to the beneficial use of floodwaters caused by ordinary or predictable flooding. Thus, the Supreme Court held that owners of riparian grassland that benefited from the seasonal overflow of the San Juaquin River were entitled to compensation for deprivation of this right due to construction of a dam as part of the Central Valley Proiect in California. United States vs Gerlach Live Stock Co., 339 U.S. 725 (1950).

Floodwaters before reaching a watercourse (that is, not within well-defined bed and banks) and overflows from flooded watercourses that do not return to the channel are treated differently. These surface waters are considered by one rule as a common enemy that may be diverted from land in any reasonable manner onto any other land, thus casting the burden on other landowners to deal with them. The more common rule in the United States imposes a servitude on lower-lying lands to accept naturally occurring overflows from higher lands, with the corresponding right to have even lower-lying land accept the water from them.

Landowners also have a property right not to have the hydrologic balance on their property unreasonably altered by construction of downstream dams and other works. Lands that are permanently flooded are considered to be "taken" by the responsible governmental entity and thereby become subject to the constitutional provision that just compensation must be paid for them. This well-established rule was extended in 1917 by the Supreme Court to apply to lands that are only partially or periodically inundated, thus requiring compensation from the government for an easement allowing overflow as often as necessary for efficient operation of the public works downstream. United States vs Cress, 243 U.S. 316 (1917).

Watercourses frequently serve as boundaries between private landowners or between states or other units of government. In the normal course of events, soil is eroded from one stream bank and deposited on the other bank (accretion). This ongoing process gradually shifts the boundary, whether it be the middle of the watercourse or one of the banks. However, floods frequently alter the stream bed itself, as in the creation of ox-bow lakes. These avulsive changes do not alter the original property lines. The boundary remains the abandoned stream bed, and one of the landowners now owns the land on both sides of the new channel. This distinction between accretion and avulsion is of more than academic interest, and courts every year are called upon to settle the resulting questions of property ownership.

5) Tax Policy. Various provisions of federal and state tax laws can be used to encourage or to discourage certain uses on flood plains. These "carrot and stick" approaches can deter industrial development, for example, on sites that in the public interest should not be developed. A broad spectrum of human activities and behavioral patterns are influenced directly by tax policies, including land development in several contexts, but we have very little experience with this in regulating the uses of our nation's flood plains. Properly conceived, tax laws could promote sound planning for flood-prone lands with a minimum of public expense and legal uncertainty.

6) Liability for Flood Control Structures. The design, construction, inspection, and maintenance of flood-control structures raise possible questions of liability for negligence in fulfilling legal duties. Undeveloped flood plains incur little or no economic damage during normal flooding. Rather, they provide beneficial geological, hydrological, and ecological functions. As population and commercial pressures along waterways developed historically, a greater percentage of our flood plains was shifted from natural to man-made uses. (Of course, the individual investors presumably kept in mind the probabilities of flood damage when deciding where and how much to invest for any particular purpose.) Because of social disruptions caused by flooding, it gradually became a legitimate concern of state and local governments to restrict flood plain development, and they for many years have embarked upon various flood control projects.

It soon became evident that major man-made structures intended to control floods also diverted flood waters onto other lands. This inevitably resulted in lawsuits by the persons upon whose land the water was diverted. However, since 1928 the federal government has been immune from liability by a statute that reads in part, "No liability of any kind shall attach to or rest upon the United States for any damage from or by floods or flood waters at any place." 33 U.S.C. 702c. In addition, most cases conclude that the Federal Tort Claims Act (FTCA) precludes suits against the United States under these circumstances. Congress enacted FTCA in response to unreasonable arguments that suits against the federal government were barred under all circumstances by doctrines that evolved from the familiar "The king can do no wrong" rule. Still, the Act, while stating that "the United States shall be liable. . . . in the same manner and to the same extent as a private individual under like circumstances. . . .," went on to exclude from this provision "Any claim based upon an act or omission of an employee of the Government, exercising due care, in the execution of a statute or regulation, whether or not such statute or regulation be valid, or based upon the exercise or performance or the failure to exercise or perform a discretionary function or duty on the part of a federal agency or an employee of the Government, whether or not the discretion involved-be abused." Jayson (1964) offers continuing commentary on FTCA issues. For example, the landowner in Coates vs United States, 181 F.2d 816 (1950), was denied damages when land and crops were inundated by an unusual overflow of the Missouri River caused by changes in the river by a federal program to control floods.

In some circumstances, the law attaches strict liability to certain actions that have potential major consequences; this means that a person would be liable for any consequences regardless of whether the person dutifully tried to meet the legal standards of care. (Perhaps the most common example is storage of explosives, for which the possessor is liable for accidents regardless of efforts to prevent them.) If construction and maintenance of dams met the criterion of being ultrahazardous or abnormally dangerous activity, strict liability might apply.

A more recent concern is the potential liability of governmental officials for issuing construction or operating permits to private developers for projects that subsequently result in damages. How the law allocates the responsibility for these activities can determine how well prepared a river basin or coastal area might be in event of a flood. Great uncertainty about who might bear much liability easily could dissuade persons and governments from undertaking flood mitigation activities. On the other hand, this might be less of a question in the future in view of the trend toward efforts to reduce flood losses by means other than physical structures.

Flood Warning

In our chronology, we now are at the stage where there is at least a reasonable expectation of flooding, thus raising a set of legal issues concerning the rights and obligations between those persons who know of the impending flood and those persons who might be adversely influenced by it.

1) Duty to Warn. The question here is simply stated: If a person knows that a flood (or other natural hazard) is about to occur, does that person have any legal duty to inform others? Barring some contractual agreement to do so, the answer is "No." Regardless of philosophical or moral arguments to the contrary, that person does not have a legal duty to fulfill, and no legal actions can be taken merely because that person remained silent. This legal question has been answered uniformly under many factual circumstances.

2) Liability for warnings. Closely related to the question involving a duty to warn is the question whether any liability will be imposed for issuing a false, inaccurate, or belated warning. This question is not nearly as easy to answer. Statutory or regulatory requirements for issuing warnings might exist, and these almost always would be subject to governmental immunity that would relieve the agency or person responsible for the warning. As indicated above, the Federal Tort Claims Act would preclude a suit against the United States under most circumstances. For example, in Bartie vs United States, 216 F.Supp. 10 (1963), aff'd 326 F.2d 754 (1964), a man was denied recovery for the loss of his family's lives to flood water that accompanied Hurricane Audrey in 1957 in Louisiana, the losses being caused by faulty federal reporting on the intensity, path, and speed of the hurricane and the existence of a resulting tidal wave.

However, it is not clear whether liability might surround warnings that are issued by private individuals or nonfederal agencies. The "Good Samaritan" rule, as discussed below, might be relevant in this situation, also. How this question is resolved could influence the inclination of a person with knowledge of an imminent flood to assume the responsibility of issuing a warning, even though no duty might exist to do so. The total financial costs of responding to an erroneous warning could be enormous.

3) Evacuation Authority. The more comprehensive mitigation plans include procedures for evacuating the population that would be influenced by the flood. Some questions might arise concerning the liability of a government for requiring a person to evacuate against that person's will or for refusing to offer assistance to evacuate under extreme circumstances. These questions are not likely to arise frequently and thus are less important than those related to possible liability for issuing warnings.

Emergency Response

Floodwaters now have arrived, and individuals and governmental authorities are trying to reduce loss of life and property damage.

1) Good Samaritan. What happens when a person comes to the aid of another and the rescue is not as successful as possible? This question typically arises when the rescued person later claims injuries as a result of the rescuer's actions. Statutes in some states relieve certain individuals — e.g., physicians — from liability when acting under emergency situations in the absence of willful or wanton negligence. The "Good Samaritan" issue arises in so many contexts that it probably is not worthwhile to pursue it on a nationwide basis with particular reference to floodings. Still, it remains a genuine concern during emergencies. Ratcliffe (1966) presents wide-ranging views of the legal implications.

2) Public Necessity and "Taking." The classic example of this situation arises during an urban conflagration when it becomes necessary to destroy private property to create a fire break. Quite obviously, legitimate questions are raised, both when making that decision and when examining it after the emergency has passed. Why was the fire break constructed here? Why was that particular dwelling destroyed? Who is to pay for the damages? As explained above, the taking issue is raised whenever public authorities act to deprive private owners of their property, even in the name of the public health, safety, and welfare. This issue certainly will arise should the public authorities destroy or damage privately owned property in the course of their actions during a flood, as when creating an emergency floodway. The law is applied from state to state in response to experiences accumulated over the years in emergency situations.

3) Diversions of Water across Boundaries. As noted above in the discussion on legal consequences raised by diverting waters from their normal channels, physical barriers on one side of a flooded watercourse frequently will increase damage on the other side. If emergency-control structures are erected on both sides of the stream, greater damage might result upstream. Some questions might arise if the water was diverted across state boundaries, thus raising questions correctly related to our concept of federalism, but liability is only a remote possibility unless the actions taken were blatantly unreasonable.

Recovery/Restoration

The flood waters have subsided, and the main concern has shifted to returning the affected lands to productive uses. Some of the issues that now would arise have been addressed previously in this flood chronology (such as liability for various actions before and during the flood), but several of them occur here for the first time.

1) Recovery of Financial Losses. The income tax or property tax laws might allow deductions or credits for flood-related losses, and in some circumstances it might not be clear whether the actual losses are covered by these provisions. Which losses are covered by private insurance would be an obvious issue, but these questions usually are settled on a case-by-case basis, and many have received adequate attention already. Whether private or public entities might be liable for monetary damages also would come up for consideration, as discussed above.

2) Moratorium on Rebuilding. Local governments with the authority to restrict land uses might wish to delay reconstruction of damaged facilities or redesignation of other land uses. This delay would allow an opportunity to reconsider the permissible uses on the flood plain and to accommodate them with new planning measures to mitigate flood damages. (This is a different issue from that raised by a governmental prohibition against persons returning to an area immediately after flooding, because of potential dangers.) Two problems arise in this context.

a) The duration of the delay cannot be so unreasonable that it becomes an unconstitutional deprivation of private-property rights. What might be a reasonable time depends upon all of the surrounding circumstances, and we do not have sufficient guidelines based upon experiences in different situations to suggest what time limits might be permissible for various planning purposes.

b) When new land-use regulations are enforced, uses that do not conform to the new plan typically are allowed to remain for some length of time to avoid the constitutional prohibition against taking of private property. These nonconforming uses are not allowed to remain indefinitely, and we have sufficient experience in all of the states to suggest how long certain uses might be allowed to remain under various types of land-use regulations. However, we might need to examine whether a nonconforming use could be reestablished if it were destroyed by flooding a very short time after the restrictive land-use plans had been enacted.

Overview

Several considerations underlie all of the above legal aspects during the chronology of a flood.

1) Many of these issues must be raised or addressed on a state-by-state basis because they are controlled by state law. It is possible to provide some guidance that would be valuable to all states, but the specific application of legal actions or remedies often must be based upon the law of a particular state in which the flood occurred or is anticipated.

2) Although we might not have much experience with some of these issues as they are keyed directly to flooding, we do have experience with them under other situations, including other natural hazards. Lawyers are accustomed to drawing analogies between factual circumstances under a unifying set of legal principles. Thus, an inability to cite case law in a particular circumstance does not mean that the legal system cannot respond to it forthrightly.

3) Some legal precepts cut across the entire flood chronology. An example is the constitutional provision that all parties similarly situated receive the equal protection of the law. This would apply, for example, to planning for the protection of property, to the issuance of warnings, to the execution of evacuation procedures, and to the allocation of assistance following the flood. Obviously, not every person and every parcel of land will receive identical treatment under the law, but the equal protection clause of the United States Constitution prohibits unreasonable variations from that norm.

A survey conducted for this project reveals the prevalence of land-use questions that arise during litigation concerning our nation's flood plains. Of the 21 most recent cases involving flood plains reported by federal courts through April 1982, 15 primarily concerned the adequacy of environmental impact statements under the National Environmental Policy Act (effects of construction projects, need for stream channelization, and the like). Two cases involved land ownership that was questioned due to changes in river channels, two concerned liability for depositing refuse into navigable waters, and two involved the National Flood Insurance Program, one being the challenge described above to its overall constitutionality and the other a challenge to the appropriateness of allowing buildings on a flood plain. Of the 43 most recently reported cases concerning flood plains that were resolved by state courts, 18 dealt with questions of land-use planning and two with disputed land ownership due to changes in river channels; the remainder covered a variety of issues not directly related to flooding.

RESEARCH NEEDS

Mere uncertainty in how a legal issue might be resolved does not raise a need for legal research. Most questions that arise between private property owners, or between a property owner and the government with land-use planning authority, can be resolved without much difficulty. These problems do not require prospective analysis. On the other hand, uncertainty about how law might promote new public policies for mitigating flood damage could justify the expenditure of research funds. This not only would expedite implementation of sound policies, but also might preclude expenditure of time and money in devising plans that would encounter intractable legal obstacles. We are in the fortunate position of having enough experience to formulate sound research plans to address the main legal issues now facing us.

The following five research recommendations are based upon the importance of the problem to be addressed, the probability that the results would directly assist in mitigating flood damages, and their high economic and social benefit-cost ratios. These five are ranked in order of decreasing priority. None is deemed to be "critical," but all should receive "high priority." All five are multidisciplinary to some extent.

1) Tax Policy. The tax policies of federal and state governments do more than raise revenues. They influence how individuals, partnerships, corporations, and others allocate their resources and efforts. These policies similarly can influence how flood plains are used. For example, providing tax deductions or credits can encourage construction of flood-control structures and of buildings that are designed to withstand flooding. Abolition of casualty deductions can discourage construction of high-risk structures by denying tax relief when they are damaged by floods that can be foreseen. We routinely couple financial incentives and disincentives with a number of land-use regulations, but we have not explored adequately how tax policies can be used best to mitigate flood damages. Importantly, the tax policies can be used to promote sound nonstructural measures for this purpose, including the installation and operation of flood warning systems.

   This multidisciplinary project could be undertaken best by a bar association, where the necessary talents could be assembled (e.g., tax lawyers, economists, and land-use planners). National, state, and local bar associations frequently undertake this type of research project through existing or new committees or task forces.

2) Enforcement. Enacting laws is but one step in restricting uses on flood plains. Enforcement often is weak for any of several reasons, such as lack of motivation or insufficiency of personnel and financial resources. An empirical study of the mechanisms and success rates of different enforcement proceedings would allow more effective procedures under future laws and regulations. The study should include an analysis of how criminal sanctions could be used to strengthen the law.

   A research institute could manage this project most effectively, because of the need for empirical surveys and multidisciplinary coordination.

3) Limitations on Reconstruction. Governments can impose moratoria on reconstruction on flood plains following floods to allow time for implementation of new regulations. These limitations on use of

private property cannot last indefinitely without violating constitutional prohibitions on interference with private property rights. This topic includes the question of whether uses that do not conform to current land-use regulations can be reestablished following flooding.

A law school would be the logical site for conducting this research, primarily because of the need to research the law in each of the 50 states in addition to addressing the several inherent constitutional issues. The availability of research assistants to undertake portions of the work is another reason for recommending a law school.

4) Warnings. It is uncertain whether liability exists for issuing incorrect prediction of flooding. It is clear that the federal government is not liable (Federal Tort Claims Act), but many questions remain with respect to private individuals, partnerships and corporations, and state and local governments.

   This research could be conducted at a law school or a law firm. The scope of inquiry probably is too limited for a bar association or research institute, and the work primarily entails library research.

5) Floodplain Mapping. Obviously, flood plain regulations must be keyed to specific land areas, but these can be defined (mapped) in different ways for different purposes. Some conflict (perhaps latent) might exist between federal mapping requirements for the National Flood Insurance Program, for example, and local mapping requirements for zoning and related land-use purposes. The extent to which any differences might frustrate federal or intergovernmental programs should be assessed and corrected.

   A research institute perhaps would be the most suitable setting, because of the need to coordinate empirical and library research.

Legal research conducted in isolation tends to remain isolated and thus of limited value. Lawyers might be able to provide some correct answers to multidisciplinary questions, but they not always are able to pose the right questions. In each of these five research recommendations, professionals other than lawyers should be actively involved from the outset to ensure that the research design is comprehensive and the probable results of greatest social utility.

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CHAPTER 10. INTERDISCIPLINARY RESEARCH

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CHAPTER 10. INTERDISCIPLINARY RESEARCH

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INTRODUCTION

People at local, state and federal levels who are responsible for coping with trends outlined in the introductory chapter rarely rely solely upon the findings from one research discipline. When confronted with decisions about preparedness, emergency warnings and response, disaster relief, and long-term reconstruction related to flood plain use, they draw upon a variety of information and experience.

As indicated in the preceding chapters, many of the flood-related, studies pursued by scientists in one discipline use data, analytical methods and judgments generated in other fields. The economic aspects of a flood-warning system or the community response to a floodproofing standard are examples. On a larger scale, there are few problems in coastal zone management that lend themselves to solution by the work of one discipline alone.

But for reasons discussed later in this chapter the research enterprise finds it much easier to carry out its work largely within disciplinary boundaries. Here emerges one of the persistent dilemmas in research on floods, flood plains and their management. Wise management decisions generally need to use findings cutting across several disciplines, while the basic research work is done within disciplines for the most part. In these circumstances the users must either themselves undertake to integrate the findings from several studies or depend upon others to do so in a convenient package or plunge along without applying all that is known and relevant.

To minimize the latter practice, the effort to improve the quality of flood plain management through research can follow three different though complementary lines. Wherever practicable the traditional disciplinary research can be encouraged to incorporate relevant methods and data from other fields. Measures to speed up and strengthen the interpretation of research findings to users can be facilitated. And explicitly interdisciplinary research can be initiated where the need for answers is especially urgent and where there is prospect for a successful inquiry leading to direct application.

This chapter in its later sections points out the principal directions of flood plain research which might benefit from taking account of possible contributions from other disciplines. It next comments on studies or study components whose outcome would be to improve the conditions in which research findings are applied in flood plain management. Finally, it suggests three research programs of high priority that should be undertaken from the outset as interdisciplinary ventures. As background for those recommendations it reviews in the early sections the principal modes of interdisciplinary activities in the province of floods, comments on salient problems in trying to carry out such investigations, and notes several theoretical constructs that may offer assistance in organizing new studies.

MODES OF INTERDISCIPLINARY RESEARCH

There are numerous ways of classifying interdisciplinary research, and there is little to be gained from reviewing all of them. It may be helpful to point out four modes of work that commend themselves in the field of floods and flood mitigation.

The least complicated and most common mode is where one investigator in seeking understanding of a process can draw upon findings from another discipline but need not engage in joint investigation. The use of hydrology in stream biology, of demography in public health studies, and of geographic classifications of land use in investigations of the public administration of land regulations are examples. The linkages deserve recognition and do not present special issues of method or organization. However, it cannot be assumed that all investigators will take the trouble to look across a fence separating them from an adjacent field. Encouragement often needs to be given when projects are initiated.

A second and far more complicated mode is involved in tracing and evaluating the effects of a technical or policy intervention. Here, valuative judgments are required and, as in most policy analysis, the study may probe hydrologic, engineering, geographic, economic, sociological and political facets of a flood problem. For example, an examination of the social effectiveness of a community flood warning system might look into the cost and operational feasibility of alternative equipment, the likely economic benefits from operation, the circumstances in which appropriate individual and corporate response to a warning can be anticipated, and the political conditions for funding and managing the various possible types of systems. Similar examples might be outlined for flood insurance, land-use planning, integrated storm drainage, and numerous other public interventions. Sometimes they can be achieved by one insightful and experienced observer (Galloway, 1980) but usually they require teams.

In practice, this mode of study is segmented either through independent investigations, as recommended in the preceding chapters on economics, sociology and political science, or as components in a joint study in which workers from different disciplines are members of the same team with varying degrees of central management. The way in which the several parts are fitted together may be more than a matter of taste or administrative convenience. Unless the components contribute to a joint product fashioned so as to be intelligible to and respected by the legislators, administrators or fellow technicians who shape policy and program, the studies have a low probability of affecting the course of events. Planning to do so and to involve the users from the outset may foster but not guarantee a sympathetic reception.

A basic judgment which should be made in recommending new research with a strong orientation toward policy analysis is whether or not collaboration among disciplines appears to be a condition for undertaking it. The process is different from the kind of administrative policy reviews carried out by the Water Resources Council. The latter have sometimes been long delayed or emasculated by inter-agency rivalry.

It should be remembered that in a field where federal programs are shifting as they are with respect to floods, the target of a policy analysis may change rapidly while the study is under way. In those circumstances a short-term group assessment, like the Jason studies in the physical sciences, may be in order. These typically bring together a highly skilled group of scientists to work intensively for a period of weeks, drawing upon materials assembled in anticipation of the study sessions.

A third mode has to do with certain methods of eliciting and presenting information. It would be desirable, for example, to employ demonstrably sound methods of surveying opinions and attitudes in studying response to an insurance offering or in finding out what kind and extent of use is made of a flood insurance rate map. The concern here is not with joint investigation, but with assuring that the appropriate skills from other disciplines are brought to bear in the investigation. Perhaps the more common failures against which to guard are the disposition of economists to judge the constraints and suitability of institutional devices affecting consumer behavior, the inclination of sociologists and political scientists to judge the economic feasibility of activities, and the tendency of all to feel that in a common sense fashion they know how consumers will use new information. Where opinions or overt behavior is being canvassed, it is to be hoped that survey procedures will yield comparable results from place to place or over time.

Important experience is accumulating as to ways of promoting open and understanding responses on the part of users in both the government and private sectors to the results of research projects. Research workers on flood plain problems have come a long way in this direction during the past nine years. The participation of users in advisory committees on new research projects is a vital provision and has become commonplace. The advisory committees facilitate the dissemination and adoption of the resulting conclusions. A number of national organizations such as the American Planning Association and the American Public Works Association have provided special opportunities for their members to learn the latest and appropriate research findings. An annual workshop brings together many of the researchers and administrators. A bi-monthly newsletter, also under the auspices of the Natural Hazards Research and Applications Information Center, reaches a much larger audience. A special information center is available to local officials, and the Association of State Floodplain Managers reaches out increasingly to municipal and county officials. Case studies are under way on successful applications. All of these activities are interdisciplinary in character.

Finally, interdisciplinary collaboration is essential to the design of the improved data systems recommended in this document. Twenty years of effort to develop a more precise system of data collection and storage for flood plain information have so far been fruitless. Some observers doubt that it will ever be attained because the principal users with their special needs have little incentive to change their ways (Tubbesing, 1979). Activities of the Corps of Engineers, Soil Conservation Service, Federal Emergency Management Agency and its Federal Insurance Administration, and American Red Cross are likely to continue with little change. Considerable additional data are being collected by state and local agencies. Meanwhile, research aimed at sharpening and extending the data base, either for the nation as a whole or for urban areas, with digitized data and mapping facilities probably will have no major effect until the needs of the concerned disciplines are presented in integrated fashion and are accompanied by a practical plan of action. The current shortages of operating funds may provide incentives to consider improvements and collaborations. Unless there is to be an all-out effort to reform the data base, such as suggested later in this chapter, it may be wise to let individual investigators chip away at a small improvement here and there.

PROBLEMS OF CARRYING OUT THE WORK

Perhaps the key maxim to follow in undertaking research with strong interdisciplinary features is to avoid specifying such collaboration unless there seems no feasible way of achieving it through traditional disciplinary channels. However attractive the concept of joint and interactive studies, the obstacles along that path are sufficiently formidable to raise sobering cautions.

Funding generally is more difficult to arrange for interdisciplinary studies. Academic traditions and departmental promotion policies discourage faculty participation. The administrative troubles of handling expenditures and personal appointments in several units can be formidable.

Investigators often have difficulty talking to and understanding each other when they are from different traditions. They are uncomfortable with methods from bordering fields, particularly if they are obliged to confront practitioners from those fields. Managed collaboration in a joint project is viewed by some as constraining innovation.

To be sure, there are shining examples of research projects that clear all these obstacles and end the race with intellectual prizes exceeding the simple sum of what would have been gained by a collection of individual investigators. Those may be viewed as exemplary and as demonstrating what can be done in the right circumstances. If the management is ingenious and administratively astute and if suitable leading scientists can be recruited, the results may abundantly warrant the extra time and stress.

Relations Among Disciplines

To a large degree the theoretical constructs of the disciplines within which new research is proposed are independent or overlap either slightly or harmoniously. The boundary zone between meteorology and hydrology is one of generally easy cooperation. Likewise, the merging of stream hydraulics and aquatic ecosystems. Social behavior and public health approaches are often separate and cooperative. Much of the suggested work has both economic and political aspects. These, however, present different theoretical orientations that are difficult to blend. And neither is closely linked with sociological and psychological theory. Geographers have sought synthesis with an approach that examines the range of adjustments to floods and seeks to understand why particular adjustments are adopted and what would be the effects of changing one or more elements in the situation.

When a major interdisciplinary effort is proposed, an early question will be in what construct the investigation may be expected to proceed. It would be unwise to specify at this stage the framework to be used: that decision properly rests with the investigators. It may nevertheless be helpful to note the availability of several orientations bridging or offering the possibility of merging the research efforts of two or more disciplines.

One is the body of organizational theory encompassing contributions from political science and sociology. As indicated in those chapters, a number of the problems selected for study are concerned with how organizations respond to and prepare for crisis situations.

Another construct is the loose aggregation of study that incorporates economics, decision making and policy analysis. This is emphasized in the economics chapter and has been exemplified in studies of flood insurance.

Much of the proposed research appears to call for systematic examination of the geographic, economic, social and political aspects of how public choices are made with respect to floods and of the effects — past or prospective — of particular public policies. Insofar as the aim may be to facilitate decisions at the local level with respect to flood plain use, any one of the constructs noted above — geographic, organization, or policy — might serve the purpose. There is somewhat encouraging experience with each.

PRIORITY INTERDISCIPLINARY RESEARCH

A considerable number of the studies proposed in the foregoing chapters would be likely to benefit from methods and data originating in other fields, following the first mode. Their execution might be strengthened by encouraging the careful use of those sources. The chief opportunities are noted in the list of topics developed from the disciplinary chapters, in Table 1 of Chapter 11.

In addition to all of the research recommended in the chapters on disciplines, three studies of a major interdisciplinary character are proposed for early action. They are directed at 1) an evaluation of the implementation and effects of major federal policies, 2) the design of a minimal system for data collection, and 3) an analysis of the special problems raised by barrier islands along the hurricane coasts.

Evaluation of Major Policies and Programs

The overall situation in the flood plains of the nation has not been examined in a detailed and comprehensive fashion in recent years. The data are difficult to assemble but the major obstacle has been the division of authority among at least five agencies having responsibility for particular sectors of activity. Through the Water Resources Council two inter-agency policy statements have been prepared since 1970, and a new Executive Order has been issued. The new policies in FEMA, as noted in Chapter 1, are coming into effect.

Thus far, it has not been practicable for the federal agencies to mount a critical appraisal of the consequences of these policies and programs at the county and municipal level. Given the administrative commitments to programs and the burdens carried by experienced personnel, it is unlikely that such an appraisal could be completed in an impartial manner within any reasonable period of time. Yet, without an overall appraisal, the grounds for continuing or shifting the present policies are splintered and often anecdotal. A number of evaluations have been made of individual programs or parts thereof, and new ones on the functioning of state and county agencies are under way. Thus, a good deal has been learned and is available in disparate pieces.

It would be a mistake to initiate a 2- or 3-year investigation: by the time it was complete the program probably would have changed again. A short-term appraisal, taking 4-6 months, could provide highly insightful observations on the actual course of events, the effects of prevailing policies, and the ways in which programs might be made more effective.

The procedure, following the Jason activities, might be to establish a team of experienced scientists and users who would agree to set aside a period of weeks for preparation of a critical appraisal based upon their knowledge and a digest, to be prepared in advance, of the relevant studies and data then available. It seems likely that a competent team could be brought together for that purpose, and that the cooperation of concerned agencies would be assured.

The appraisal team would be obliged to look at how programs and policies have been carried out as well as their effects. Much of the debate about the efficacy of several programs turns upon how thoughtfully and assiduously they have been administered, and on the interpretations made of broad legislative or executive directives. Time would not permit an exhaustive inquiry for the country as a whole, but judicious samples could be selected, and the results of studies by independent scholars and by the General Accounting Office could be of use.

Design for a Basic Data System

It is evident from the discussions in all the foregoing chapters that the nation lacks a comprehensive base of information about a number of parameters of floods, flood plain use, and the consequences of floods. Even the most widely quoted set of data on flood losses is prepared from three separate agencies — the Corps of Engineers, the National Weather Service, and the Soil

Conservation Service — and they have never been carefully reconciled as to valuation criteria and coverage. The data on injuries and loss of life are even less satisfactory, and the Center for Disease Control has only recently begun to evaluate them.

Since the national flood control policy has launched in 1936 there- have been repeated attempts to provide for a unified and consistent set of data on losses, land uses, and structural and nonstructural measures. Administrators knew it would not be an easy goal to achieve, and found it easier to continue their separate ways. Some observers hoped that the National Water Assessment might furnish the groundwork for a system, but it has not yet realized those aspirations. Meanwhile, a massive new drive for data collection on flood risk zones, flood insurance policies, and community land use and permitting activities has come into being under the National Flood Insurance Program.

The challenge immediately ahead is to see whether or not a unified system could be designed which would yield results meeting most or all of the following general specifications:

- A valid measure of property losses from floods;
- A valid measure of impairment of health and loss of life due to floods;
- A record of expenditures for flood control, flood relief and reconstruction, and mitigation of losses including insurance;
- A record of the status of local and state land use regulations and plans;
- A valid record of the numbers of structures and people at risk;
- By means which would not impose heavy additional costs of data collection and dissemination.

It will be argued that additional parameters would be desirable, but it must be recognized that earlier, more ambitious efforts always foundered on the rocks of complexity and expense. It is possible that a simplified system could serve to monitor major trends without being bogged down in supporting highly specific aims. The time may be right to try for a relatively simple design utilizing the data collection facilities of federal agencies.

In addition to the advent of the large new data processing system of the Federal Insurance Administration, two other developments lend support to study of the design at this time. Interest has grown in the possibility of a system of data on a range of natural hazards, including earthquakes and landslides (Tubbesing, 1979). Coupled with this is the rapidly growing capability to prepare maps from digitized data. Municipalities and counties as well as the U.S. Geological Survey and other federal agencies are experimenting with such mapping at a large scale for a wide variety of phenomena. The possibility of incorporating flood data should be explored while the new systems are taking shape. Indeed, the flood data system might provide a framework for incorporating data for other hazards.

The design effort would require contributions from numerous technical and scientific groups. It would seem to lend itself in the first instance to the mode of investigation suggested for the evaluation of major policies and programs. No effort of that character has been tried in the past, and an initiative now might end in utter failure. At best, it could lay the groundwork for a relatively simple and modest system. Even if it were not to arrive at that outcome, it might be expected to instigate a few improvements in data reporting, such as in recording property losses, loss of life, and flood plain insurance coverage. Advances along any or all of those lines would seem to warrant the attempt.

The Barrier Islands

Arguments can be made for stimulating investigations of the special conditions and problems encountered in a number of geographic areas having common characteristics. Flood plains on peripheries of growing cities, mudslide areas, and subsiding coasts within the reach of tropical storm surges would be on the list. Reviewing all such combinations of physical and human circumstances, the type of area which now appears to have highest priority is the barrier island along the hurricane coasts of the Atlantic and the Gulf of Mexico.

Large national value and scientific merit attaches to understanding the issues created by flooding in barrier islands. New legislation would guide or prohibit their further development. This is coupled with recognition of the intense development in already-settled barrier islands where major disasters loom. Rapid growth and development prevails on barrier islands along the East and Gulf Coasts at risk from tropical storms where high economic values are at stake, evacuation is difficult, and there are substantial numbers of older and often handicapped people.

There have been a few detailed studies of land use and evacuation needs in such regions as Tampa Bay, and the environmental implications have been probed in several areas, chiefly those still free from settlement. Building on these investigations, a broader review is in order. Assistance would be sought from economists, lawyers, health-sanitation experts, social behavioral scientists, biologists, land use planners, meteorologists, and a variety of others concerned with appropriate policy in fast growth areas.

Acknowledgments

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CHAPTER 11. SUMMARY

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CHAPTER 11. SUMMARY

Stanley A. Changnon, Jr., William C. Ackermann, and J. Loreena Ivens

Problem

From a national economic viewpoint, floods are the most destructive natural hazard in the United States. Flood losses amounted to $3.8 billion in 1975, and floods cause the loss of more than 100 lives per year and untold psychic trauma. Losses have been increasing at a rate of between 4 and 7% per year, in real dollars, with the losses increasing most rapidly in urban areas. If certain conditions prevail, it is estimated that flood losses by the year 2000 may exceed $4.3 billion (in 1975 dollars).

The nation has invested billions of dollars in flood hazard mitigation and control over the last 60 years, but the trend in flood damages continues to increase, particularly in urban and developed coastal areas. Review of the flooding problem in the United States brings forth three salient points:

- Flooding is the major natural hazard of the nation.
- Flood losses continue to grow despite our national investments.
- Our approaches for controlling and mitigating flooding have not fully succeeded.

Recent Assessments of Flood Problems and Issues

The National Academy of Sciences issued a report in 1981 entitled "Federal Water Resources Research: A Review of the Proposed Five-Year Program Plan." This assessed a report on the federal water resources research planned for 1982-1987, a report developed by Interior at the direction of the Water Research and Development Act of 1978. In its 1981 review, the Academy panel identified 31 critical research areas, and 7 related to flood hazard mitigation.

Congress also directed the National Science Foundation to prepare a broad assessment of flood hazard mitigation. The Foundation's report, issued in 1980, identified 27 broad research topics.

These two recent reports became the foundation for a comprehensive assessment of the research needed relating to flooding and flood mitigation. To this end, the Illinois State Water Survey sought funding from the National Science Foundation in 1981 to develop a national blueprint of research to address two audiences: 1) the scientific and engineering communities, and 2) the federal, state, and private organizations who fund flood research.

A Real World Context

The assessment of the research needs, largely done by experienced researchers on floods, was performed in the context of current and future policy issues affecting flood mitigation activities. It was recognized that the research recommendations must be relevant, in terms of national policies and major issues, if the recommendations were to be properly prioritized and subsequently funded.

There are four new major national issues or trends that were accounted for in this research assessment. The first of these was the new federalism, as reflected by the shift in responsibilities from federal to local and state entities. This ongoing shift currently affects answers to basic questions about who has the authority and justification for flood-related actions, and who pays for the flood mitigation activities.

The second issue considered in this research assessment was the policy of the National Flood Insurance Program. This is considered the dominant national element in both current and future flood plain activities and hence has a major influence on research thinking.

The third issue recognized in the research assessment was the ongoing shift of emphasis from structural approaches to nonstructural approaches for flood mitigation. This includes activities such as flood plain management and zoning, coastal zone management, flood warning systems, evacuation and relocation, flood insurance, and land acquisition. This reflects a belief that the future success of flood mitigation rests in public perceptions and behavior and hence is now more of a social issue than an engineering issue.

The fourth major issue considered in this research assessment was recognition of the major new and developing national programs in emergency assistance. It was important to understand that flood assistance done by the federal and state agencies fits within a host of multi-hazard assistance activities.

An interesting and important aspect of these four major national issues, which provided the stage for helping to choose flood research needs, is that all four are "moving targets," ongoing shifts with the difficulties that this condition potentially represents. We find major ongoing shifts 1) in the responsibilities from federal to state-local entities, 2) in federal insurance policies, 3) from structural to nonstructural approaches to mitigation, and 4) in the emergency assistance programs. It seems likely that the policies and programs emanating from these shifts will persist into the foreseeable future and we believe that research needs based on them will be meaningful and applicable for the next 20 years or more.

The Design and Performance of the Flood Research Study

This study and other recent national studies have established that: 1) floods are the nation's most serious natural hazard, affecting all of the United States; 2) major expenditures involving a myriad of approaches have not resolved the flood problem with continuing growth in flood losses; 3) most flood-related research has been limited and too heavily focused on physical or structural solutions; and 4) recent general assessments of water research and floods have identified the need for an in-depth research assessment of floods and how to mitigate them.

A review of the magnitude and complexity of the flood problems in the United States leads to the conclusion that much flood-related research must be interdisciplinary in nature. Many of the problems crosscut several traditional disciplines that can only be successfully addressed by a mix of scientists and engineers from various disciplines. Hence, this research assessment focused on interdisciplinary research, as well as on traditional disciplinary research.

The age-old hope for relief from flood problems by flood control has given way to a realization that a more realistic national goal is flood hazard mitigation. Thus, this research assessment chose to address and resolve the question about how to view and define flood hazard mitigation, as a part of the identification of the research needs. We have adopted a broad view of flood hazard mitigation, and not one of just flood loss reduction. Where possible, we addressed research needs within the context of mitigation attempting to enhance the total productivity of flood-prone lands. This orientation helped identify the research needs and to set priorities for the recommended research. The assessment considered both riverine and coastal flooding.

The research assessment was done by a consensus approach involving the best possible national expertise in floods. Senior researchers in eight disciplines (meteorology, hydrology, ecology, public health, economics, sociology, political science, and law) were selected along with a national leader in geographic and interdisciplinary research, and they each prepared a "paper" addressing the problems and the research needs. Their draft papers were intensively reviewed by more than 100 other flood researchers with a series of three revisions of the papers after each set of reviews. This consensus approach culminated in a 3-day workshop of 45 persons including the 9 authors, 22 national experts, 5 of our Water Survey staff, and representatives from 9 federal agencies. This interactive process led to this report, and the papers became chapters in this report.

The Products: Research Recommendations

In the assessments, both disciplinary and interdisciplinary, the chapter authors set forth the major problems and unknowns, as the basis for identifying the research needs. After initial deliberations about-classifying and prioritizing research needs, it was decided collectively that the research needs identified herein would be those considered "high priority," reflecting the need to begin research immediately. The authors and the reviewers used three criteria for assessing whether research needs met the high priority recommendations. These included: 1) the importance or severity of the flood problem (based on effects on human health and life, on the environment, quality of life, on economics, or on the irreversibility of the damage); 2) the probability that research within reasonable limits of time, talent and money, would improve knowledge and lead to solution of problems; and 3) judgments as to the general cost of the proposed research in relation to the possible benefits. After reviews and discussions involving many national experts, we further concluded that certain high priority research areas were "critical," basically defined by the need to address these first, either due to a limited funding situation, or for a proper time-ordered sequence of attention.

We recognize that the research priorities expressed herein will shift over time as problems are resolved and as policies change. However, those established and presented in this report represent our best collective judgment as to where the emphasis should be placed in programming flood research, both now and in the foreseeable future.

The following portions of the summary present and review the research recommendations. These research recommendations are sorted under varying classifications and the national issues they relate to.

High Priority Research

As a result of this study, 115 high priority research tasks were identified. These are listed, according to disciplines, in Table 1. Also shown for each research recommendation are the other disciplines involved in the task if interdisciplinary research is needed. The description of each research recommendation is of necessity abbreviated in this table. A longer explanation and justification for each research recommendation can be found in the relevant preceding nine chapters. The 115 high priority research recommendations in Table 1 are also identified by number for cross-referencing in the other tables of the summary.

Table 2 presents the frequency of the research tasks by disciplines. The disciplinary totals vary from as few as 5 recommendations in ecology and law to a high of 32 under sociology. The number of high priority research tasks in the four disciplines that would be labeled as physical sciences (meteorology, hydrology, ecology, and health) totaled 36, as compared to 79 in the social sciences (economics, sociology, political science, and law). These differences help illustrate one general conclusion of this flood research assessment. That is, there is a much greater need for flood mitigation research in the social sciences and nonstructural approaches than in the physical sciences, which tend to focus on structural approaches.

Also shown in Table 2 is the frequency of interdisciplinary research tasks identified within disciplines. In all, 79 research tasks have an interdisciplinary character; that is, they involve at least two or more major disciplines. This helps reveal that many of the problems needing resolution through research exist across more than one discipline. It further suggests that interdisciplinary research groups or teams need to be gathered or developed to perform flood research.

Critical Research

The review of the chapters conducted at the 3-day workshop in August 1982 led to a decision to identify, from the list of 115 high priority research tasks, those that were "critical." All 115 tasks met the criteria of importance of the problem being addressed, the probability that research will lead to solutions, and that the cost of the research was justified by the benefits.

Table 1. Recommendations for High Priority Research for Flood Mitigation

Research Needed	Interdisciplinary with
Meteorology	
1) Improved Remote Sensing. Develop improved methods of remotely sensing of precipitation (radar, satellite) and their quantitative interpretation for integration into conventional networks and forecast and warning systems.	
2) Predictions-Large Amounts. Develop reliable quantitative precipitation predictions for large amounts, including use of numerical mesoscale models.	Hydrology
3) Predictions-Tropical Storms. Develop improved prediction of tropical storm systems close to shore and inland, with emphasis on heavy rainfall, to improve evacuation lead-time.	Public Health
4) Snow Pack Releases. Study snow pack release as a major contributor to flood conditions, including antecedent history of rain in the watershed.	Hydrology
5) Statistical Procedures. Re-examine statistical procedures for estimating maximal rainfall values for different time and space dimensions.	Hydrology
6) Synoptic Patterns with Floods. Re-analyze historical floods, including flash floods, the synoptic patterns that caused them, and effect of antecedent rain.	
Hydrology and Hydraulics	
7) Flood Probability-Ungaged Areas. Conduct a systematic test of procedures for estimating flood probability at ungaged locations.	
8) Uncertainty-Flood Probability. Investigate the uncertainty associated with flood probability estimates based on observed stream flow records.	Meteorlogy
9) Methods for Predicting Effect of Land Use on Floods. Develop and demonstrate reliable methods for predicting the effect of land use/management on flood peaks, flood volume, and sediment production.	Ecology Public Health
10) Mitigation Performance with PMF. Develop and demonstrate procedures for testing the performance of proposed flood mitigation systems during extreme floods (Probable Maximum Flood).	
11) Improve Flood Flow Estimates. Improve the techniques for estimating flood flows in natural channels or predicting stages for given flow rates.	
12) Defining Flood Plain Boundaries. Investigate the uncertainty in defining flood plain boundaries for various levels of probability as a basis for planning management and developing insurance rates.	Ecology, Law, Land-Use Planning, Geography

Table 1. Continued

Hydrology *(Continued)*

	Research Needed	Interdisciplinary with
13)	Methods to Improve Precipitation Estimates. Develop methods to improve estimates of precipitation for use in flood forecasting and other hydrologic studies.	Meteorology
14)	Reliable Flash Flood Warnings. Develop reliable and effective means for flood warnings to alert people at risk of an impending flash flood.	Geography, Sociology, Public Health, Psychology
15)	Hydrometeorologic Network Design. Investigate hydrometeorological network design (streamflow, precipitation, snow, evaporation) with a view to improving the sensors, recording devices, data processing and storage techniques, and the design of the network.	Meteorology
16)	Data for Storm Surge Models. Install and test a system for collecting data required for storm surge models, and use these data, as collected, to test the available storm surge models.	Meteorology
17)	Storm Surge Protection. Conduct a preliminary investigation of possible measures to protect against storm surge including both barriers in estuaries and barriers on the coastal plains.	
18)	Tsunamis Prediction. Review and text procedures currently in use for determining the areas which will be affected by tsunamis and for estimating the probability of tsunamis of various magnitudes.	Seismology
19)	Large Debris in Streams. Investigate the sources of large debris in streams in flood and the mechanisms by which this debris enters the streams, determine ways to keep debris from streams to avoid the formation of debris dams, and study the possibility of constructing effective debris traps.	
20)	Ice Jams in Streams. Investigate the formation of ice jams in streams with a view of forecasting their occurrence, defining the probability of their occurrence, and developing methods to minimize or eliminate their occurrence.	
21)	Prediction of Landslides. Develop procedures for predicting the probability of occurrence of landslides to permit better land-use regulation and short-range forecasts.	
22)	Predicting High Tides and Coastal Floods. Investigate methods for predicting the joint probability of high tides and flood peaks in coastal streams.	
23)	Flow Hydraulics on Alluvial Fans. Investigate the hydraulics of flow on alluvial fans to determine ways in which the area of potential flooding can be defined and the probability of flooding can be quantified.	Geology
Ecology		
24)	Floods as Natural Phenomena. Develop theory including models that treat storm flows as integral features of natural stream conditions rather than as perturbations.	

Table 1. Continued

Ecology (Continued)

Research Needed	Interdisciplinary with
25) Organic Decomposition Processes. Investigate the details of organic matter decomposition processes as a benefit because they are related to water quality.	
26) Effects of Flood Mitigation on Natural Stream Benefits. Investigate the effects of flood mitigation activity on natural stream benefits including structural work such as dams, levees and bank stabilization work as well as non-structural "improvements" such as channeling, clearing and snagging.	Hydrology
27) Effect of Land Use Management on Storm Flows. Relate land uses and management practices over entire drainages to the hydrological and erosional contributions of storm flows.	Hydrology, Geography
28) Flood Plain Classification. Classify flood plains relative to their dependence on and tolerance of flooding.	
Public Health	
29) Public Health Data for Floods. Evaluate current data and, based on deficiencies noted, develop the components of the desired data base that would provide maximal probability of relevance to future flood related morbidity and mortality, in addition to other needed data.	All Disciplines
30) Epidemiological Studies. Establish team(s.) of epidemiologists, probably under the aegis of CDC or state health departments, that would be dispatched to an imminent flood area to take an active part in activities before, during and after the flood.	
31) Land Use Management to Reduce Pollution. Determine appropriate land use and management measures to be used to reduce pollution, i.e., chemical, microbiological, runoff, etc., during and after floods.	Hydrology, Law
32) Methods of Wastewater Treatment during Floods. Evaluate present methods of maintaining wastewater treatment services during floods and determining specific needs for assessing such services during and following flood events.	
33) Effect of Evacuation Procedures. Determine the effect of evacuation procedures on morbidity and mortality both on the short- and long-term basis.	
34) Master Plan for Flood Mitigation. Evaluate all available flood hazard mitigation plans including communication systems to determine the weaknesses and strengths of the various plans with a goal of developing a master plan for different types of floods.	All Disciplines
35) Successes and Failures of Flood Plans. Evaluate the success or failure of the various components of flood plans following different types of flood events.	Sociology
36) Effect of Flooding on Groundwater Quality. Determine the effect of flooding on groundwater quality including bacteriological, virological, and chemical contaminants.	Groundwater Hydrology

Table 1. Continued

Research Needed	Interdisciplinary with
Economics	
37) Redefinition of Objective of Flood Mitigation. Redefine the objective of flood hazard mitigation, from a goal of hazard reduction *per se* to one of efficient use of flood prone lands, and determine the socially acceptable levels of residual risk.	All Disciplines
38) Economic Rationale for Public Action. Spell out the economic rationale for public action in the field of flood hazard mitigation to understand better how individual choices are made and what are the foundations of value.	Sociology
39) Economic Case for Various Levels of Public Intervention. Clarify the economic case for various levels of public intervention -- national, regional, state, and local governments -- including the case for possible nonmarket failure of public policies as well as market failure.	Political Science
40) Proper Measures of Flood Damage. Develop a consensus among economists on proper measures of flood losses and benefits of hazard mitigation policies, with particular attention to techniques for the benefit-cost analysis of nonstructural approaches.	Sociology
41) Collection of Economic Data. On the basis of proper measures of benefits and costs, specify the kind of economic data to be collected in order to conduct proper economic analysis, with suggestions for reasonable surrogates for data not readily obtainable.	
42) Evaluation of Existing Public Policies. Make an economic evaluation of existing public policies and institutions for flood hazard mitigation, starting with a 1-year first-cut study.	Political Science
43) Economic Evaluation of National Flood Insurance Program. Make an immediate economic evaluation of the National Flood Insurance Program, since this program is growing rapidly and is likely to be the centerpiece of future flood hazard policy.	Law
44) Benefits and Costs of Land Use Controls. Critically examine the economic benefits and costs of land use controls for flood plains, including purchase of development rights, land acquisition and relocation.	Law
45) Economic Evaluation of Construction in Flood Plains. Make an economic risk analysis of the construction of public facilities in flood plains (transportation systems, electrical generation plants, sewage waste disposal facilities) and assess the benefits and costs of building codes for flood prone structures and floodproofing.	

Table 1. Continued

Research Needed	Interdisciplinary with
Economics (Continued)	
46) Economic Evaluation of Forecasts and Warnings. Examine the economic benefits and costs of flood forecasting and flood warning systems.	
47) Economic Evaluation of Relief and Recovery Assistance. Make an economic evaluation of emergency relief and recovery assistance policies, in terms of likely effects both upon the distribution of income and the incentives for risk-taking in the use of flood prone lands.	
48) Economic Evaluation of Alternative Financing Policies. Explore alternative policies for financing and cost-recovery for flood hazard mitigation policies, in terms of effects on efficiency of flood plain use, the distribution of income, and on strained sources of local, state, and federal revenues.	
Sociology	
49) Process of Policy Formation. Make long-term and comparative studies of the actual social processes producing selected flood hazard mitigation policies, with the studies including diverse types of communities confronting differing types of flood hazards.	Political Science
50) Collective Behavior Analyses. Make case studies to map and explain the collective actions concerning the flood threat taken by a diverse range of public interest and educational groups.	
51) Media Responses. Make comparative studies of media responses to selected flood hazard policy proposals and implementation efforts, including studies of internal decision processes within media organizations.	
52) Research Utilization. Make an intensive, short term literature synthesis study to ascertain factors most relevant to the degree of use of research findings of sociologists and other behavioral scientists in the flood mitigation context. Then make field studies to identify the types of research findings that are being used by differing groups of flood mitigation practitioners.	
53) Adoption Processes. Conduct comparative studies, focused on alternative mixes of flood hazard mitigation policies, among state level organizations and within varying types of local communities confronting differing flood hazards.	Political Science
54) Implementation Processes. Make comparative studies to describe the dynamics of multiorganizational communication and bargaining strategies during the implementation of flood hazard mitigation policies, with attention to goal displacement.	Political Science

Table 1. Continued

Sociology (Continued)

Research Needed	Interdisciplinary with
55) Managerial Strategies. Identify the types of strategies used by managers responsible for varying aspects of flood hazard mitigation within samples of the diverse range of organizations including federal, state, and local units, and assess the degree to which such strategies are shared and the social processes of diffusion.	Psychology
56) Planning Process Variations. Make comparative studies in urban and rural settings of varying types of planning efforts and the behavioral dynamics involved, with variations reflecting community differences and major barriers.	Geography, Law
57) Hazard Perceptions and Knowledge. Make hypothesis testing studies to delineate the precise interrelations among a large number of social and individual characteristics which seem to structure perceptions and knowledge of the flood hazard, and identify their relative contributions and interaction effects.	Geography, Psychology
58) Adoption of Adjustments. Investigate the social processes whereby families decide to adopt various mitigation measures, including insurance against loss or emergency planning measures such as a family evacuation plan.	Public Health, Economics, Geography
59) Efficacy of Educational Change Efforts. Conduct demonstration experiments wherein social behavioral researchers participate with local and state agencies to design various educational change programs intended to increase public adoption of damage reduction and mitigation adjustments.	
60) Flood Warning System Implementation. Conduct comparative studies of communities confronting similar flood threats to unveil networks of both incentives and constraints to implementation of desired evacuation behavior to assess the social processes which culminated in implementation of effective flood warning systems.	Public Health, Law, Geography, Psychology
61) Flood Warning System Composition. Analyze actual operating warning systems and alternative configurations, in relation to differing social environments, to assess levels of multiagency coordination and the relative effectiveness of the public responses generated.	Meteorology, Hydrology
62) Case Studies for Managerial Training. Document the functioning(day-to-day responsibilitiesof managers) at a series of exemplary warning systems, in communities of varying size, and a parallel series of failures -- and identify key operational problems and the needs for operational training.	
63) Integration of Warning Systems. Examine the adequacy of integrated warning systems (e.g., those that warn of toxic gases as well as floods, tornadoes, etc.) and the procedures for message formulation and diffusion.	Meteorology Hydrology, Public Health

Table 1. Continued

Sociology (Continued)

Research Needed	Interdisciplinary with
64) Adverse Conditions for Evacuation. Conduct demonstration experiments, linking behavioral researchers and local officials, for the design and testing of innovative flood warning systems by which to neutralize adverse conditions for evacuation such as late at night, tourist or other unfamiliar population, and locale with minimum flood experience.	Public Health
65) Evacuating Special Populations. Study for the design of flood warning systems the range of adjustments and the preplanning needed for the evacuation of populations such as the elderly, children, handicapped, and those in institutions (prisoners, mentally ill).	Public Health
66) Evacuation Facilitators/Inhibitors. Study the mechanisms that facilitate and inhibit the effectiveness of public evacuations and the levels of disruption and trauma experienced by evacuees.	Public Health
67) Shelter Requirements. Make comparative studies to estimate the ranges of evacuees seeking public shelter and those taking refuge in homes of relatives and friends in order to predict efficient use of sheltering resources.	Public Health
68) Response of Volunteer Groups. Determine the barriers and incentives altering the degree of integration of volunteer group response with that of core emergency paid professionals, with attention to the uncertainty brought about by "good Samaritan" laws.	
69) Emergent Multiorganizational Networks. Develop mapping techniques to ascertain the relative response effectiveness of emergent multiorganizational networks, including cross-agency communications patterns and network decision-making and control structures.	Political Science
70) Media Relationships during Emergencies. Conduct case studies to explore the effects of unplanned media relationships that adversely affect disaster responses.	Public Health
71) Emergency Operations Center. Carry out comparative research to document the techniques for management of Emergency Operations Centers in differing locales (urban vs rural) and varying flood hazards (riverine vs coastal).	Public Health
72) Emergent Group Processes during Flood Events. Document participant behavior in situational and task processes, in contrast to organizational actions, in such tasks as search and rescue, handling of dead, and security.	
73) Family Recovery Processes. Study of family recovery mechanisms following flood tragedies including social and economic factors such as age, socioeconomic status, and the effect of assistance mechanisms such as financial aid and insurance.	Economics
74) Therapeutic Communities. Conduct comparative field studies to assess the mechanisms affecting the speed, extensiveness, and duration of post-flood therapeutic or altruistic communities (from kin and friendship groups to formal relief agencies).	

Table 1. Continued

Sociology (Continued) Research Needed	Interdisciplinary with
75) Assessments of Agency Interventions. Assess the consequences for recipients, sequential administrative processes, and other aspects of federal disaster assistance after flooding to provide an empirical base for policy review.	Political Science
76) Community Decision Making. Make exploratory case studies in differing types of communities following flood events of varying characteristics to gain improved understanding of the social dynamics by which some communities initiate major alterations in subsequent risk levels (e.g., rezoning or enforcement of previous zoning plans) and the constraints precluding others from taking such actions.	Political Science, Geography, Law
77) Long-Term Primary Group Impacts. Conduct comparative and long-term studies of post-flood alterations in such primary group systems as neighbors, friendship groupings, and voluntary associations whose interactions have important consequences for victims.	
78) Long-Term Family Impacts. Conduct comparative studies on long-term and cross-national family impacts across several flood events, using specific variables now identified in the literature.	
79) Long-Term Individual Impacts. Carry out a program of comparative studies on long-term flood victim impacts including specific measures of individual functioning (physical and mental health) and various interaction effects.	Public Health, Psychology
80) Processes of Community and Organizational Change. Carry out long-term comparative studies of system change and stress responses, especially among emergency organizations.	Political Science
Political Science	
81) Catastrophe and Political Action. Determine for one or a sample of rivers the correlation between major flood events and changes in public policy and levels of implementation with respect to flood mitigation measures.	Sociology, Geography
82) Ideological Involvement. Identify the various ideological positions on flood hazard mitigation within defined publics and determine their relative political importance.	Sociology
83) Flood Mitigation Constituencies--Federal, State and Local. Identify the groups outside government--at federal, state and local levels--that support or oppose particular types of flood mitigation measures and comprehensive planning and action, and specify their activities and effects; and identify groups that might be expected to be such groups but are not actively interested, and determine why not.	Sociology

Table 1. Continued

Political Science (Continued)

Research Needed	Interdisciplinary with
84) Authority and Funds--State and Local. Identify instances of successes and failures of state and local governments to obtain authority and funds for planning and action related to flood mitigation and determine the reasons for success and failure via correlation with public opinion, interest group activity, organizational arrangements of the flood mitigation unit, application of federal leverage, etc.	Sociology, Economics, Law
85) Strategies for Management and Resolution of Conflict. Identify successes and failures in management and resolution of conflict over flood mitigation measures and the methods that were utilized; determine the specific economic, social and political factors involved and their relative importance; and suggest strategies for management and resolution of conflict that have a likelihood of success.	Sociology, Law
86) Regulation of Private Land and Public Land Acquisition. Study public attitudes involved in these conflicting public interests as they relate to flood hazard mitigation, with a view to discovery of means to resolve conflict.	Sociology, Geography
87) Private Institutional Impacts on Flood Mitigation. Identify the interests of each of private institutions such as insurance, real estate, land developers, and lending institutions with respect to their positive and negative impacts on public flood mitigation efforts, and evaluate means by which their impacts might become more supportive.	Law
88) Pre-Flood Planning of Post-Flood Measures. Identify alternative public policies and programs for handling pre-flood planning, on the basis of case studies or hypothetical conditions, and evaluate these alternatives in terms of their political and administrative advantages and disadvantages.	Sociology, Public Health Geography, Law
89) Alternatives to Direct Land Regulation. Identify alternatives to direct governmental regulation discovered or considered in other areas of public policy; evaluate their applicability to flood mitigation; fomulate technically feasible policy proposals; and determine their political feasibility.	Economics, Geography
90) Implementation of Local Flood Plain Regulation. Determine the quality of local flood plain regulation in comparison to a standard (e.g., the minimum standards of the Federal Emergency Management Agency) and comparatively among localities; and determine effectiveness of enforcement in terms of administrative action, local political support, use of variances and judicial actions.	Law, Geography

Table 1. Continued

Political Science (Continued)

Research Needed	Interdisciplinary with
91) Enforcemnt Role of Lending Institutions. Determine the policy and administrative response, with respect to the enforcement role by lending institutions, of federal instrumentalities (e.g., Federal Reserve Board, Federal Home Loan Bank Board, Comptroller General, etc.) that control the activities of lending institutions; and determine the policy and administrative responses of lending institutions to this public responsibility and private opportunity by type of hazard zone (i.e., riverine, coastal, and landslide) and degree of hazard.	Economics, Law
92) River Basin vs Localized Flood Mitigation Efforts. Determine the utility of federal-state compact commissions, in cooperation with local governments, in planning and implementing flood mitigation measures; studies comparing commission vs non-commission basins could be made.	Geography, Law
93) Interagency Task Force. Determine what the task force has done or not done, factors involved in successes and failures, and evaluate this FEMA-led task force in relation to the strengths and weaknesses of alternatives.	
94) Implementation of Presidential Executive Order 11988. Review the literature on Presidential executive orders with respect to their substantive, as distinguished from their symbolic, utility as a basis for examining the probable utility of a particular executive order; and determine and evaluate federal agency responses to Executive Order 11988 regarding riverine and coastal flood hazard mitigation.	Law
95) Local Community Responsibility. Formulate hypotheses concerning, and undertake case studies of, development of local assumption of responsibility (i.e., political, regulatory, and financial) for flood mitigation measures in the context of state and/or federal pressures; and make case studies involving apparent successful and unsuccessful assumption of responsibility.	Sociology, Geography
96) Implmentation of WRC's Unified Program. Review the literature on the substantive utility of presidential messages and policy statements, executive orders, policy commission reports, and other high level official educational documents, and determine the nature of the reception and degree of response of governmental actors to the Water Resources Council's Unified Program and compare these results with expectations derived from the literature review.	
97) Implementation of Land Acquisition Policies. Formulate hypotheses and determine through intensive studies the political and other factors responsible for successes and failures of land acquisition as a mitigating measure, and evaluate the case studies comparatively.	Law

Table 1. Continued

Political Science (Continued)

Research Needed	Interdisciplinary with
98) Policy Analysis Research: Impact. Design a plan study of policy impact for the Water Resources Council, its successor or FEMA and test the design in limited geographical areas; and conduct independent impact analysis of particular policy elements in the total mix of mitigation measures or of all elements as they impact a particular river basin or river segment.	All Disciplines
99) State Organizational Arrangements. Develop hypotheses and evaluate states comparatively, assessing strengths and weaknesses of their organizational arrangements, based upon comparable state data.	Sociology
100) Local Organizational Arrangements. Develop hypotheses and evaluate local governments comparatively, assessing strengths and weaknesses of their organizational arrangements, based upon comparable local data.	Sociology
101) New Federalism and Flood Mitigation. Identify the presumptions of fact and value that underline the existing allocation of responsibility for flood hazard mitigation; identify alternative allocations of responsibility and their presumptions of fact and value; and evaluate these alternatives among themselves and as compared to the status quo.	Law
102) Flood Mitigation Management and Scarce Resources. Develop alternative strategies, responsive to different normative criteria, to cope with increasing scarcity of resources to implement flood mitigation policies.	Economics
103) Urban and Rural Regional Districts. Compare one or more urban regional districts with regional areas that have no such district and evaluate the strengths and weaknesses of each organizational arrangement.	Geography
104) Flood Insurance Rates. Study the implementation of flood insurance law in FEMA and its predecessors to ascertain how rate issues have been handled and decisions made; and perform political feasibility analyses of one or more rate policies, that could include sample opinion surveys of insurance policy holders, agents, insurance companies and the financial institution enforcing the purchase of flood insurance.	Economics
105) Performance Standards for Local Governments. Design alternative standards for possible use by FEMA in judging adequacy of the performance of local governments, indicating their pros and cons; and field test these alternative standards as regards "fairness," etc.	
106) Flood Mitigation and Social Goals. Examine flood hazard mitigation strategies to determine the extent to which social goals conflict with other goals, from the perspective of several disciplines including political science, which could contribute normative analysis, political and administrative feasibility analyses, means of conflict management and resolution, etc.	Sociology

Table 1. Continued

Political Science (Continued) Research Needed	Interdisciplinary with
107) Risk-Benefit Analysis. Undertake risk assessments relating to the flood hazard including residual risks after mitigation; and compare risks from floods with other forms of risk as an aid in public policy judgment.	Economics, Hydrology
Law	
108) Tax Policy. Explore how federal and state tax policies can be used best to mitigate flood damages and to promote sound nonstructural measures for this purpose, such as land-use planning and flood warning systems.	Political Science, Economics, Land-Use Planning
109) Enforcement of Flood Plain Laws. Conduct an empirical study of the mechanisms and success rates of different enforcement proceedings to allow more effective procedures under future laws and regulations, including an analysis of how criminal sanctions could be used to strengthen the law.	Political Science, Sociology
110) Limitations on Reconstruction. Study the possible violation of constitutional prohibitions on interference with private property rights when governments delay reconstruction on flood plains after flooding to allow time to implement new regulations.	
111) Warnings. Conduct research on whether liability exists for issuing incorrect predictions of flooding, with respect to private individuals, partnerships and corporations, and state and local governments.	
112) Flood Plain Mapping. Assess the extent to which possible conflict between federal mapping for the National Flood Insurance Program and mapping for local land-use planning might frustrate the federal program.	Hydrology, Geography, Land-Use Planning
Interdisciplinary Research	
113) Evaluation of Major Policies and Programs. Establish a team of experienced scientists to make a short-term (4 to 6 months) appraisal of the implementation and effects of major federal policies and programs to provide a base for continuing or shifting present policies.	All Disciplines
114) Design for a Basic Data System. Establish a scientific team to design a simple, unified system for collection of data on property losses; injuries and loss of life; expenditures for flood control, flood relief and reconstruction, and mitigation of losses (including insurance); and status of local and state land use regulations and plans.	All Disciplines
115) The Barrier Islands. Make a comprehensive investigation of the special conditions and problems that exist for barrier islands along the East and Gulf Coasts that are at risk from tropical storms and where rapid growth and development prevail, evacuation is difficult, and populations include many elderly and handicapped.	All Disciplines

Table 2. Frequency of Research Tasks by Priorities and Disciplines

	High Priority	Interdisciplinary	Critical Priority
Meteorology	6	4	2
Hydrology	17	9	9
Ecology	5	2	5
Health	8	5	8
Economics	12	7	4
Sociology	32	22	17
Political Science	27	24	5
Legal	5	3	0
Interdisciplinary	3	3	3
Totals	115	79	53

The classification of criticality for a research task was defined generally by the strong need for immediate attention. The 53 critical research recommendations are listed in Table 3.

As shown in Table 2, 53 of the 115 high priority tasks were identified as critical. The four physical science areas identified 24 critical priority research tasks, and the social sciences identified 29, including the three within the interdisciplinary classification.

Recommendations Addressing Major National Issues and Trends in Policy

The high priority and critical research recommendations identified in Tables 1 and 3 were further classified according to whether they addressed major national issues and trends in policy. This was performed to allow funding agencies and the scientific community to discern those research tasks which more specifically address, and potentially answer, the problems within broader issues.

The research recommendations were classified according to five important issues. These included 1) the National Flood Insurance Program, 2) emergency assistance efforts, 3) the trend from structural to nonstructural approaches for flood mitigation, 4) the new federalism with the shift from federal to state-local responsibilities, and 5) the efficient use of flood-prone lands. Although the general approach to the selection of the research needs was within the context of the efficient use of flood-prone lands, as opposed to reduction in loss, certain of the research tasks more specifically address the issue of efficiency and these were so identified. Other research tasks relate, for example, to how to cope more effectively when flooding occurs. The listings of the research recommendations sorted according to these five categories appear in Tables 4 through 8.

Table 4 lists the 33 research tasks that address, in one form or another, the National Flood Insurance Program. These involve widely varying research including studies of flood plain boundaries (#12); the collection of data on public health (#29) and economic losses (#41); the study of adoption processes (#53); investigations of the implementation of flood plain regulations (#54); and legal studies of enforcement of flood plain laws (#109).

Table 5 identifies those research recommendations related to emergency assistance. In all, 29 high priority tasks are identified and 18 of these are classed as critical, or those needing immediate attention. Many of the research tasks relate to public health and sociology.

The interest and emphasis on use of nonstructural approaches to flood hazard mitigation led us to identify those research recommendations that generally addressed these approaches. Table 6 presents 39 such high priority research recommendations. They span a wide range of research tasks including land use effects (#9); land use management to reduce pollution (#31); strategies of those dealing with varying flood mitigation approaches (#55); evacuation of special populations (#65); land acquisition policies (#97); and effects of

Table 3. Critical Research for Flood Mitigation

Research Needed	Interdisciplinary with
Meteorology	
* 2) Predictions - Large Amounts	Hydrology
3) Predictions - Tropical Storms	Public Health
Hydrology and Hydraulics	
7) Flood Probability - Ungaged Areas	
8) Uncertainty - Flood Probability	Meteorology
9) Methods for Predicting Effect of Land Use on Floods	Ecology, Public Health
10) Mitigation Performance with Probable Maximum Flood	
11) Improve Flood Flow Estimates	
12) Defining Flood Plain Boundaries	Ecology, Law, Land-Use Planning, Geography
13) Methods to Improve Precipitation Estimates	Meteorology,
14) Reliable Flash Flood Warnings	Sociology, Public Health, Geography
15) Hydrometeorologic Network Design	Meteorology
Eaology	
24) Floods as Natural Phenomena	
25) Organic Decomposition Processes	
26) Effects of Flood Mitigation on Natural Stream Benefits	Hydrology
27) Effect of Land Use Management on Storm Flows	Hydrology
28) Flood Plain Classification	
Public Health	
29) Public Health Data for Floods	All Disciplines
30) Epidemiological Studies	
31) Land Use Management to Reduce Pollution	Hydrology, Law
32) Methods of Wastewater Treatment during Floods	
33) Effect of Evacuation Procedures	
34) Master Plan for Flood Mitigation	All Disciplines
35) Successes and Failures of Flood Plans	Sociology
36) Effect of Flooding on Groundwater Quality	Groundwater Hydrology
Economics	
37) Redefinition of Objective of Flood Mitigation	All Disciplines

* Numbers are those assigned in Table 1.

Table 3. Continued

Research Needed	Interdisciplinary with
Economics (Continued)	
40) Proper Measures of Flood Damage	Sociology
41) Collection of Economic Data	
43) Economic Evaluation of National Flood Insurance Program	Law
Sociology	
49) Process of Policy Formation	Political Science
52) Research Utilization	
57) Hazard Perceptions and Knowledge	Geography, Psychology
58) Adoption of Adjustments	Public Health, Economics, Geography
59) Efficacy of Educational Change Efforts	
63) Integration of Warning Systems	Meteorology, Hydrology, Public Health
66) Evacuation Facilitators/Inhibitors	Public Health
68) Response of Volunteer Groups	
69) Emergent Multiorganizational Networks	Political Science
70) Media Relationships during Emergencies	Public Health
71) Emergency Operations Center	Public Health
73) Family Recovery Processes .	Economics
74) Therapeutic Communities	
75) Assessments of Agency Interventions	Political Science
77) Long-Term Primary Group Impacts	
78) Long-Term Family Impacts	
79) Long-Term Individual Impacts	Public Health, Psychology
Political Science	
81) Catastrophe and Political Action	Sociology, Geography
88) Pre-Flood Planning of Post-Flood Measures	Sociology, Public Health, Geography
95) Local Community Responsibility	Sociology, Geography
101) New Federalism and Flood Mitigation	Law
102) Flood Mitigation Management and Scarce Resources	Economics
Law	
(None Critical)	
Interdisciplinary Research	
113) Evaluation of Major Policies and Programs	All Disciplines
114) Design for A Basic Data System	All Disciplines
115) The Barrier Islands	All Disciplines

Table 4. Research Addressing the National Flood Insurance Program

	Research Needs	Disciplines
5)	Statistical Procedures	Meteorlogy, Hydrology
*12)	Defining Flood Plain Boundaries	Hydrology, Ecology
22)	Predicting High Tides and Coastal Floods	Hydrology
23)	Flow Hydraulics on Alluvial Fans	Hydrology, Geology
*28)	Flood Plain Classification	Ecology
*29)	Public Health Data for Floods	All Disciplines
38)	Economic Rationale for Public Action	Economics, Sociology
*41)	Collection of Economic Data	Economics
*43)	Economic Evaluation of National Flood Insurance Program	Economics
44)	Benefits and Costs of Land Use Controls	Economics
45)	Economic Evaluation of Construction in Flood Plains	Economics
50)	Collective Behavior Analyses	Sociology
*52)	Research Utilization	Sociology
53)	Adoption Processes	Sociology, Political Science
54)	Implementation Processes	Sociology, Political Science
*57)	Hazard Perceptions and Knowledge	Sociology,Geography, Psychology
*58)	Adoption of Adjustments	Sociology, Public Health, Economics, Geography
*59)	Efficacy of Educational Change Efforts	Sociology
*73)	Family Recovery Processes	Sociology, Economics
76)	Community Decision Making	Sociology, Political Science, Geography
87)	Private Institutional Impacts on Flood Mitigation	Political Science
*88)	Pre-Flood Planning of Post-Flood Measures	Political Science, Sociology, Public Health, Geography
89)	Alternatives to Direct Land Regulation	Political Science, Economics, Geography
90)	Implementation of Local Flood Plain Regulation	Political Science, Law, Geography
91)	Enforcement Role of Lending Institutions	Political Science, Economics
96)	Implementation of WRC's Unified Program	Political Science
98)	Policy Analysis Research: Impact	All Disciplines
104)	Flood Insurance Rates	Political Science, Economics
109)	Enforcement of Flood Plain Laws	Law, Sociology, Political Science
110)	Limitations of Reconstruction	Law
112)	Flood Plain Mapping	Law, Hydrology, Geography
*113)	Evaluation of Major Policies and Programs	All Disciplines
*114)	Design for a Basic Data System	All Disciplines

* = Critical

Table 5. Research Related to Emergency Assistance

	Research Needs	Disciplines
*3)	Predictions-Tropical Storms	Meteorology, Public Health
10)	Mitigation Performance with PMF	Hydrology
*29)	Public Health Data for Floods	All Disciplines
*30)	Epidemiological Studies	Public Health
*32)	Methods of Wastewater Treatment during Floods	Public Health
*33)	Effect of Evacuation Procedures	Public Health
44)	Benefits and Costs of Land Use Controls	Economics
47)	Economic Evaluation of Relief and Recovery Assistance	Economics
61)	Flood Warning System Composition	Sociology, Meteorology, Hydrology
62)	Case Studies for Managerial Training	Sociology
*63)	Integration of Warning Systems	Sociology, Meteorology, Hydrology, Public Health
64)	Adverse Conditions for Evacuation	Sociology, Public Health
65)	Evacuating Special Populations	Sociology, Public Health
*66)	Evacuation Facilitators/Inhibitors	Sociology, Public Health
67)	Shelter Requirements	Sociology, Public Health
*68)	Response of Volunteer Groups	Sociology
*69)	Emergent Multiorganizational Networks	Sociology, Political Science
*70)	Media Relationships during Emergencies	Sociology, Public Health
*71)	Emergency Operations Center	Sociology, Public Health
72)	Emergent Group Processes during Flood Events	Sociology
*73)	Family Recovery Processes	Sociology, Economics
*74)	Therapeutic Communities	Sociology
*75)	Assessments of Agency Interventions	Sociology, Political Science
*88)	Pre-Flood Planning of Post-Flood Measures	Political Science, Sociology, Public Health, Geography
99)	State Organizational Arrangements	Political Science, Sociology
100)	Local Organizational Arrangements	Political Science, Sociology
*113)	Evaluation of Major Policies and Program	All Disciplines
*114)	Design for a Basic Data System	All Disciplines
*115)	The Barrier Islands	All Disciplines

* = Critical

Table 6. Research Related to Nonstructural Approaches to Flood Mitigation

Research Needs	Disciplines
*9) Methods for Predicting Effect of Land Use on Floods	Hydrology, Ecology, Public Health
*14) Reliable Flash Flood Warnings	Hydrology, Sociology, Public Health
18) Tsunamis Prediction	Hydrology, Seismology
21) Prediction of Landslides	Hydrology
*29) Public Health Data for Floods	All Disciplines
*31) Land Use Management to Reduce Pollution	Public Health, Hydrology
*33) Effect of Evacuation Procedures	Public Health
*34) Master Plan for Flood Mitigation	All Disciplines
42) Evaluation of Existing Public Policies	Economics, Political Science
44) Benefits and Costs of Land Use Controls	Economics
53) Adoption Processes	Sociology, Political Science
54) Implementation Processes	Sociology, Political Science
55) Managerial Strategies	Sociology
56) Planning Process Variations	Sociology, Geography
*58) Adoption of Adjustments	Sociology, Public Health, Economics, Geography
*59) Efficacy of Educational Change Efforts	Sociology
64) Adverse Conditions for Evacuation	Sociology, Public Health
65) Evacuating Special Populations	Sociology, Public Health
*66) Evacuation Facilitators/Inhibitors	Sociology, Public Health
*73) Family Recovery Processes	Sociology, Economics
76) Community Decision Making	Sociology, Political Science, Geography
*77) Long-Term Primary Group Impacts	Sociology
*78) Long-Term Family Impacts	Sociology
*79) Long-Term Individual Impacts	Sociology, Public Health, Psychology
80) Processes of Community and Organizational Change	Sociology, Political Science
85) Strategies for Management and Resolution of Conflict	Political Science, Sociology
86) Regulation of Private Land and Public Land Acquisition	Political Science, Sociology, Geography
87) Private Institutional Impacts on Flood Mitigation	Political Science
89) Alternatives to Direct Land Regulation	Political Science, Economics, Geography
90) Implementation of Local Flood Plain Regulation	Political Science, Law, Geography

* = Critical

Table 6. Continued

Research Needs	Disciplines
91) Enforcement Role of Lending Institutions	Political Science, Economics
92) River Basin vs Localized Flood Mitigation Efforts	Political Science, Geography
93) Interagency Task Force	Political Science
97) Implementation of Land Acquisition Policies	Political Science, Law
*102) Flood Mitigation Management and Scarce Resources	Political Science, Economics
106) Flood Mitigation and Social Goals	Political Science, Sociology
108) Tax Policy	Law, Political Science, Ecomomics, Land-Use Planning
114) Design for a Basic System	All Disciplines
115) The Barrier Islands	All Disciplines

* = Critical

tax policies (#108). It should be noted that the 39 recommendations presented in Table 6 do not address flood insurance, one of the nonstructural approaches, because these are presented in Table 4.

The new federalism with its shift of responsibilities on many flood issues to state and local agencies led us to identify the recommendations of research tasks that were directly related to state and/or local interests, problems, and responsibilities. We identified 48 (of the 115) tasks which related to state-local concerns and these are listed in Table 7. These span the disciplines of hydrology (5 tasks), ecology (1 task), public health (2), economics (3), sociology (16 tasks), political science (17), law (2 tasks), and two of three major interdisciplinary efforts recommended. Thus, the local and state governments have a major stake in a national research agenda, a situation that will likely necessitate at least state involvement in the research.

As noted earlier, one of the key themes identified in this comprehensive research assessment was a view of efficient use of flood-prone lands as a goal of research, not just loss reduction. To this end, several of the research tasks identified either directly or indirectly support this view, or are rooted in this philosophy. The 31 high priority research recommendations in this category are listed in Table 8. Notably, 17 of the 31 are identified as critical. The research is largely concentrated in ecology (4 tasks), public health (3 tasks), economics (7), sociology (8), and political science (7). Many are also interdisciplinary in nature.

Performers of the Research

By and large, in this assessment of research, we did not choose to specify particular groups or persons who should, or should not, perform the specific 115 high priority research tasks. There was concern expressed that some past agency approaches for obtaining researchers in the social sciences had resulted in poor quality research, presumably from a "hired gun" approach without involving quality scientists over long periods of time. There is also concern that for objectivity, the social, economic, ecological, and policy related research should be performed by those not employed by the federal or state governments, and rather within the university community or foundations. The public health, hydrology, and meteorologic research should be heavily governmental in nature. The legal research assessment did note that various groups such as bar associations, law research institutes, and law schools should be involved in specific tasks. These are identified in the chapter on legal research.

Funding the Research

Most flood-related research has been funded by federal agencies concerned with water and its management. This orientation has emphasized physical and engineering solutions to the control and mitigation of flood losses.

This research assessment did not attempt to identify specifically which agencies, federal or state, or private enterprise, should fund the 115 high

Table 7. Research Related to State and Local Responsibilities

	Research Needs	Disciplines
*11)	Improve Flood Flow Estimates	Hydrology
*12)	Defining Flood Plain Boundaries	Hydrology, Ecology
*14)	Reliable Flash Flood Warnings	Hydrology, Sociology Public Health
18)	Tsunamis Prediction	Hydrology, Seismology
21)	Prediction of Landslides	Hydrology
*27)	Effect of Land Use Management on Storm Flows	Ecology, Hydrology
*30)	Epidemiological Studies	Public Health
*32)	Methods of Wastewater Treatment during Floods	Public Health
38)	Economic Rationale for Public Action	Economics, Sociology
39)	Economic Case for Various Levels of Public Intervention	Economics, Political Science
48)	Economic Evaluation of Alternative Financing Policies	Economics
50)	Collective Behavior Analyses	Sociology
53)	Adoption Processes	Sociology, Political Science
54)	Implementation Processes	Sociology, Political Science
55)	Managerial Strategies	Sociology
*59)	Efficacy of Educational Change Efforts	Sociology
60)	Flood Warning System Implementation	Sociology, Public Health
61)	Flood Warning System Composition	Sociology, Meteorology, Hydrology
62)	Case Studies for Managerial Training	Sociology
*63)	Integration of Warning Systems	Sociology, Meteorology, Hydrology, Public Health
64)	Adverse Conditions for Evacuation	Sociology, Public Health
67)	Shelter Requirements	Sociology, Public Health
*69)	Emergent Multiorganizational Networks	Sociology, Political Science
*71)	Emergency Operations Center	Sociology, Public Health
*75)	Assessments of Agency Interventions	Sociology, Political Science
76)	Community Decision Making	Sociology, Political Science, Geography
80)	Processes of Community and Organizational Change	Sociology, Political Science
*81)	Catastrophe and Political Action	Political Science, Sociology, Geography
83)	Flood Mitigation Constituencies—Federal, State and Local	Political Science, Sociology
84)	Authority and Funds--State and Local	Political Science, Sociology, Economics

* = Critical

Table 7. Continued

Research Needs	Disciplines
85) Strategies for Management and Resolution of Conflict	Political Science, Sociology
86) Regulation of Private Land and Public Land Acquisition	Political Science, Sociology, Geography
*88) Pre-Flood Planning of Post-Flood Measures	Political Science, Sociology, Public Health, Geography
90) Implementation of Local FLood Plain Regulation	Political Science, Law, Geography
91) Enforcement Role of Lending Institutions	Political Science, Economics
92) River Basin vs Localized Flood Mitigation Efforts	Political Science, Geography
*95) Local Community Responsibility	Political Science
96) Implementation of WRC's Unified Program	Political Science, Sociology, Geography
97) Implementation of Land Acquisition Policies	Political Science, Law
99) State Organizational Arrangements	Political Science, Sociology
100) Local Organizational Arrangements	Political Science, Sociology
*101) New Federalism and Flood Mitigation	Political Science
103) Urban and Rural Regional Districts	Political Science, Geography
105) Performance Standards for Local Governments	Political Science
108) Tax Policy	Law, Political Science, Economics, Land-Use Planning
112) Flood Plain Mapping	Law, Hydrology, Geography
*113) Evaluation of Major Policies and Programs	All Disciplines
*115) The Barrier Islands	All Disciplines

* = Critical

Table 8. Research Specifically Addressing the Efficient Use of Flood-Prone Lands

	Research Needs	Disciplines
17)	Storm Surge Protection	Hydrology
*24)	Floods as Natural Phenomena	Ecology
*26)	Effects of Flood Mitigation on Natural Stream Benefits	Ecology, Hydrology
*27)	Effect of Land Use Management on Storm Flows	Ecology, Hydrology
*28)	Flood Plain Classification	Ecology
*29)	Public Health Data for Floods	All Disciplines
*35)	Successes and Failures of Flood Plans	Public Health, Sociology
*36)	Effect of Flooding on Groundwater Quality	Public Health, Ground-water Hydrology
*37)	Redefinition of Objective of Flood Mitigation	All Disciplines
38)	Economic Rationale for Public Action	Economics, Sociology
*40)	Proper Measures of Flood Damage	Economics, Sociology
*41)	Collection of Economic Data	Economics
42)	Evaluation of Existing Public Policies	Economics, Political Science
44)	Benefits and Costs of Land Use Controls	Economics
45)	Economic Evaluation of Construction in Flood Plains	Economics
*49)	Process of Policy Formation	Sociology, Political Science
50)	Collective Behavior Analyses	Sociology
51)	Media Responses	Sociology
*52)	Research Utilization	Sociology
*77)	Long-Term Primary Group Impacts	Sociology
*78)	Long-Term Family Impacts	Sociology
*79)	Long-Term Individual Impacts	Sociology, Public Health, Psychology
80)	Processes of Community and Organizational Change	Sociology, Political Science
*83)	Flood Mitigation Constituencies--Federal, State and Local	Political Science Sociology
85)	Strategies for Management and Resolution of Conflict	Political Science, Sociology
97)	Implementation of Land Acquisition Policies	Political Science, Law
101)	New Federalism and Flood Mitigation	Political Science
*102)	Flood Mitigation Management and Scarce Resources	Political Science, Economics
106)	Flood Mitigation and Social Goals	Political Science Sociology
107)	Risk-Benefit Analysis	Political Science, Economics, Hydrology
109)	Enforcement of Flood Plain Laws	Law, Sociology, Political Science

* = Critical

priority or critical research tasks. Certainly, the missions of various water-interest agencies will relate to the research recommended, particularly those tasks identified under the five major national issues and trends identified in Tables 4 through 8. The strong call for basic research and for addressing the non-mission oriented socioeconomic and political research recommended suggests that the National Science Foundation should play a major national role in support of these types of research.

The continuing new federalism trend with a greater shift of responsibilities to state and local entities, will bring an increasing need for state-supported research of flood mitigation activities (Table 7), as opposed to almost total federal support. Most state support in the past has been through the Water Resources Centers in each state, a program matching state university funds and federal funds.

General Recommendations and Conclusions

In the direction, performance, and review of this research assessment, five central themes have emerged, along with a concern for the future of flood research. These are found as repeated expressions of needs in several of the discipline assessments; in the recognition of current and future national issues and emerging policies related to floods and their mitigation; and with the recognition that the nation's flood problems are major and there is a great need to reduce the ever-mounting loss to floods in the United States.

Inadequate Knowledge and General Priority Setting. The first major finding relates to the amount of existing knowledge about floods and their mitigation. The knowledge base is very uneven. Much more is known in the physical sciences and hence about the structural approaches to flood mitigation than is known in the social sciences. Within the social sciences, such as sociology, more knowledge exists in some topical areas than in others, where major gaps of data and information exist. *Hence, one major conclusion of this study is that, in general, much more research attention, both by the scientific communities and by the funding agencies, should be given to the economic, geographic, sociological, and political scientific research than to the physically oriented research*. This greater need in the social sciences exists because they have been largely over-looked in prior years, and knowledge gains per dollar spent will be high because social research is less expensive than that in the physical/engineering areas. Hence, the payoff seems to be much greater for finding solutions with emphasis on the social-oriented interdisciplinary research. The National Science Foundation should encourage and support this type of research. This general theme of emphasis on the social scientific research also is consistent with the current national shift to nonstructural approaches to flood mitigation.

A Research Program Based on Efficient Use of Flood Lands. This assessment has shown that national expertise in flood research strongly supports a philosophy that research, where possible, should have as a national goal the efficient use or enhancement of flood-prone lands, not a view of loss reduction. As stated in the chapter on economic research, "there is a great need for a reformulation of the goal of hazard reduction *per se* to be one of efficient use of flood-prone lands and the determination of socially acceptable levels of residual risk." This concept is also integral to the ecological research needs where it is stated in Chapter 4, "there is a need to evaluate flood mitigation in terms of natural benefits in the streams and rivers, and the flood plains, and in the wetlands that are an integral part of these systems." If this view is to be accommodated nationally, a general order of research is needed.

Basically the efficiency view addresses two broad parts of the flood hazard mitigation activities: 1) the prepardness/mitigation aspects, and 2) the recovery/restoration aspects. The research relating to warnings and emergency responses (what happens during the flood) is largely separate from the efficiency concept. Of necessity, a broad plan involving a philosophical shift to address these two concepts, or courses of research action, necessitates a long-term developmental approach. First, we must take the time necessary to develop nationally the concept of efficiency through research in certain fields (primarily in economics, ecology, sociology and political science, but also in law), while simultaneously pursuing the priority research yet needed in the warning and emergency response areas. A temporal ranking of the critical research needs would find two at the top: Evaluation of major policies and programs (recommendation #113) and exploration of economic rationales for public and private intervention in flood hazard mitigation (recommendations #38 and #39). These efforts should be performed *now*.

One view of looking at the priority and the sequencing of future research that can be gleaned from this comprehensive assessment is presented in Figure 1. In a general context, it attempts to evaluate the major themes interwoven in all the recommended research. In this research scenario, three major avenues would be followed:

1) Research largely relating to the aforementioned concept of efficient use of flood lands, with its nonstructural theme and largely focused on mitigation, prepardness, recovery and restoration;
2) Research aimed at warning and emergency responses, comprising disciplinary and interdisciplinary tasks; and
3) Development of a better flood data and information base, a major problem in all disciplines.

If this proposed sequence were followed in setting top priority research, certain other critical research tasks should follow after the evaluation of major policies and programs (#113), the development of economic rationale for public action (#38), and development of the economic case for various levels of public intervention (#39). In the mitigation-recovery sequence (Figure 1 and Table 9), the research to be addressed first would be in the economic and ecological areas. These should include initially the redefining of the objectives of flood mitigation (#37 and #40), and developing better understanding of the ecological benefits of flooding (#26).

These studies should be followed closely by high priority research in sociology and political science. It will be very important to have early study of flood mitigation management alternatives in light of scarce governmental resources (#102) and to support this with evaluations of successful and unsuccessful flood plans (#35). Research on the reasons for use of findings of

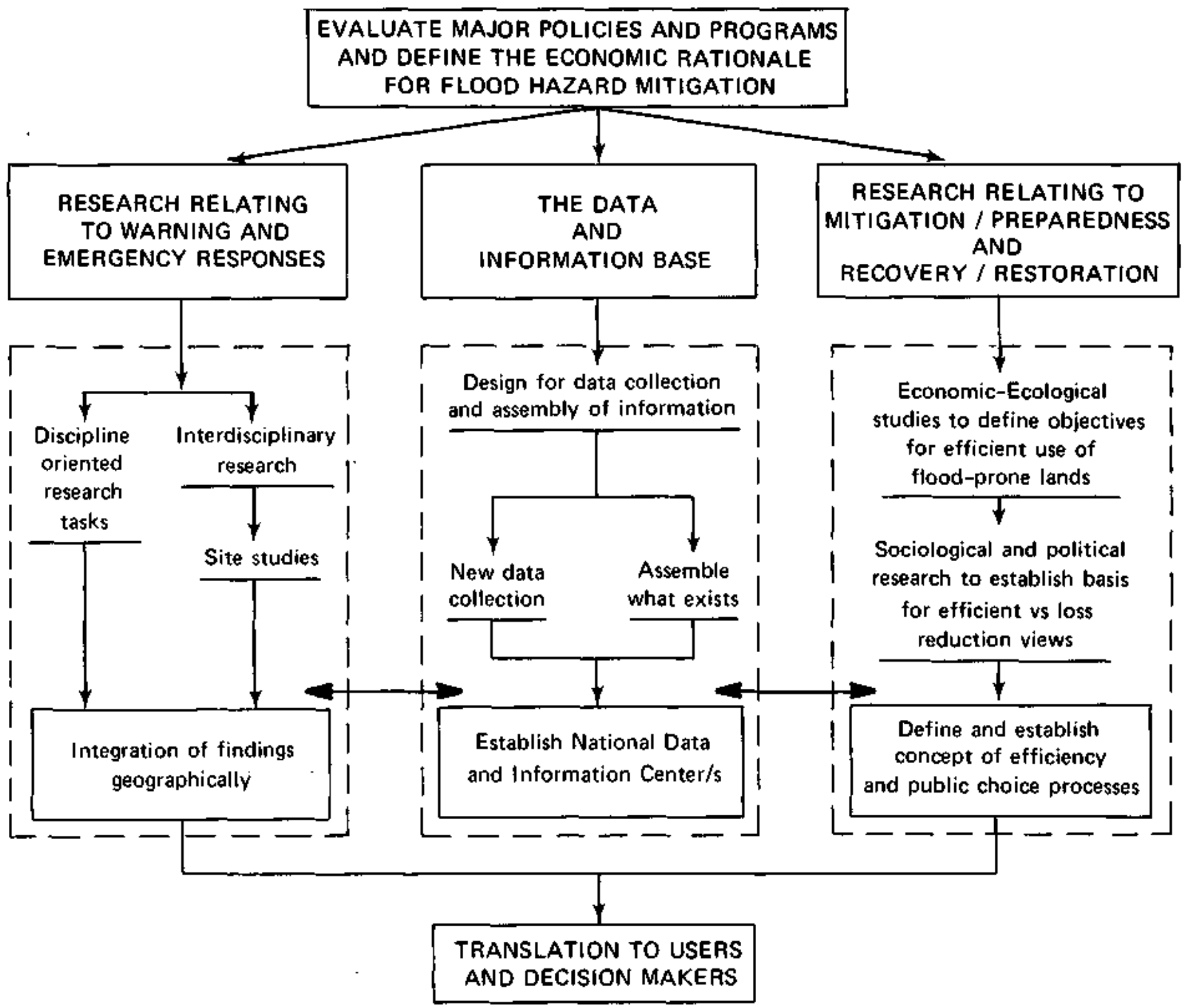

Figure 1. The major research components and one approach for sequencing of research in flood hazard mitigation

Table 9. Proposed Top Priority Research in Flood Mitigation Based on a Time-Ordered Sequence

A) First Steps

1) Evaluation of Major Policies and Programs (#113)

2) Economic Rationale for Public Action (#38)

3) Economic Case for Various Levels of Public Intervention (#39)

B) Parallel Second Steps

Mitigation-Recovery Sequence

1) Redefinition of Objectives of Flood Mitigation (#37)
Effects of Flood Mitigation on Natural Stream Benefits (#26)
Proper Measure of Flood Damage (#40)

2) Flood Mitigation Management and Scarce Resources (#102)
Successes and Failures of Flood Plans (#35)

3) Research Utilization (#52)
Process of Policy Formation (#49)

4) Long-Term Impacts to Primary Groups, Families, and Individuals (#s 77, 78, 79)

Warning-Emergency Response Sequence

1) Predictions - Large Amounts (#2)
Predictions - Tropical Storms (#3)
Predictions - Landslides (#21)

2) Reliable Flash Flood Warnings (#14)
Integration of Warning Systems (#63)

3) Case studies of the Barrier Islands (#115)

4) Evacuation Facilitators/Inhibitors (#66)
Effect of Evacuation Procedures (#33)
Emergency Operation Centers (#71)

5) Pre-Flood Planning of Post-Flood Measures (#88)
Local Community Responsibility (#95)

Data and Information Base

1) Design for a Basic Data System (#114)

2) Collection of Economic Data (#41)

3) Public Health Data for Floods (#29)

behavioral scientists (#52) is needed along with a study of policy formulation relating to flood mitigation (#49). Other top priority research in this chain of research relates to the long-term impacts of primary groups (#77), to families (#78), and to individuals (#79).

In the other basic research areas, the warning and emergency response areas (Figure 1 and Table 9), there are certain equally critical tasks to be done first and in parallel with those identified above. These include work to improve predictions of large rainfall amounts (#2) and of tropical storms (#3). In light of growing concern and the many uncertainties about landslides, the prediction of landslides (#21) has been included in this top priority group of research needs. Research into improvements in reliable flash flood warnings (#14) is needed along with the integration of flood warning systems with other warning systems (#63). Of particular importance is to perform case studies of the warning and emergency responses in barrier islands (#115).

Attention to evacuation is of great importance, including studies of ways to facilitate evacuation (#66), effects of evacuation on morbidity and mortality (#33), and the management of emergencies (#71). Research attention is needed relating to pre-flood planning of post-flood measures (#88) including local community responsibilities in flood mitigation (#95).

Coupled with these top priority research areas, are three highly recommended and equally critical tasks relating to the data and information base thrust (Figure 1 and Table 9) seen as parallel to the two major research avenues. The first of these efforts is to design a basic data system for flood data (#114), and to follow this with the procurement of economic data (#41), and of public health data (#29).

This proposed research avenue for the mitigation and recovery areas places the benefit oriented research in economics and ecology first, closely followed and linked to the critical sociological research and the integral political sciences research. This general sequence will get the efficient use concept defined, as well as identify the individual and institutional incentives to adopt the most appropriate mitigation solutions.

It is important to appreciate also, that certain research disciplines — economics, sociology, geography, and ecology — have research tasks with a similar over-riding theme. That is, all require considerable development of theoretical concepts in certain crucial scientific topics.

<u>Essentiality of Interdisciplinary Research</u>. The above stated theme of research oriented toward the efficient use of flood-prone lands and the scientific disciplines that it embraces, illustrates the third major conclusion: the extreme need to integrate the research and findings across disciplines. There is a clarion call for interdisciplinary research in the field of flood hazard mitigation with 79 of 115 recommended research tasks being interdisciplinary in nature. All of the discipline-oriented research assessments called for interdisciplinary teams to work in both data collection and research.

Certain orientations were noted that offer the possibility of merging research efforts of several disciplines. One is the body of organizational theory encompassing contributions from political science and sociology. A number of the research tasks are concerned with how individuals and organizations respond to and prepare for crisis situations. Another construct is the aggregation of studies that incorporate economics, decision making and policy analysis. Much of the proposed research inherently calls for systematic examination of the geographic, economic, social, and political aspects of how public choices are made with respect to floods, and of the effects of particular public policies (see Figure 1).

The interdisciplinary assessment (Chapter 10)- called for three studies requiring very early attention. These should be directed at 1) an evaluation of the implementation and effects of major federal policies, 2) the design of a minimal system for data collection (which is described in the next section), and 3) an analysis of the special problems raised by barrier islands along the hurricane coasts.

Data and Information Needs. The fourth major conclusion relates to flood data and information. It is evident in all nine chapters that the nation lacks a comprehensive base of information about many parameters of floods, flood plain use, and the consequences of floods. For example, in the economic chapter (Chapter 7) one finds the following statement, "because of poor data quality, we do not know the precise magnitude of the flood hazard problem or its relation to other problems in society." In the public health chapter we find these statements. "At present there is a lack of an integrated, routine, systematic collection of data before, during and after floods . . . it appears that little consideration has been given to integrating existing data in the various disciplines to determine a collective impact on each other, and particularly, on public health."

Thus, the nation and the research community are faced with a key need for data within disciplines and across disciplines, and the possibility of the formation of a multidisciplinary flood data bank (Figure 1). The public health and interdisciplinary chapters recommend, for example, the formation of a multidisciplinary team to assess current data and design the components of the desired data base.

As a result, the development of appropriate data banks of flood information for research is a singular theme reflected in Figure 1. In addition to the intense data needs for research, such information is vital to the efficient management of riverine and coastal areas subject to flooding. If broad recognition of the data/information problem were to materialize and be under serious consideration, an effort comparable to the present development of a comprehensive plan for research would likely be required. Groups of researchers, practitioners, and agency representatives could develop and design the dimensions of an adequate flood data bank. A key final step would be to establish and institutionalize a series of flood centers, operated on a continuing basis. In some cases, as with National Weather Service and U.S. Geological Survey, expansions of present efforts would probably be most logical. In other instances, it will probably require new programs and agencies such as the Federal Emergency Management Agency or the Bureau of the Census. The proposed design effort for a basic data system is more fully addressed in the interdisciplinary research chapter (Chapter 10).

Transfer of Research Results. The fifth major conclusion of this assessment has been that research, where possible, needs to be oriented to user needs. Where possible, research should consider the transfer of information. Clearly, more is known now than is being implemented, particularly in the sociological and ecological areas. In the ecological chapter (Chapter 4) a major recommendation states, "there is a need to develop public understanding of the river and its flood plain as a single natural unit, that is, to redefine the public's perception of the river so that the flood plain is included."

The recommended emphasis on socioeconomic research, as opposed to physical-engineering research, reflects the needs for a cost effective approach to future research to aid in the flood mitigation issues. This, coupled with a conscious effort to focus on a view of efficient use of flood-prone lands (vs a goal of loss reduction), creates a theme of "research for applications." The research results cannot be left on the pages of scientific or legal journals; they must be aimed at application and use. Research proposals where appropriate, should identify the users and show how results will be transferred.

Ensuring Future Attention to Flood Research. A final major recommendation, based on this assessment and the changing world in which it took place, is that a review of the research needs and priorities stated herein should be made at least every 3 years under the direction of the National Science Foundation. From this review, a brief report assessing progress and focusing on revised priorities of the research tasks needed should be prepared and distributed to much the same audience as this report — the government agencies involved in flood research and the scientific community. Only through such continuing assessment of progress and review of priorities can realistic progress toward flood mitigation be made.

APPENDIX

Flood-Related Research Priorities

based on

Report on "Federal Water Resources Research:
A Review of the Proposed Five-Year Program Plan"

1. Flood frequency determination
2. Climate variability and trends
3. Weather and hydrologic forecasting
4. Control of pollution from nonpoint sources
5. Management of resources under flood and drought hazards
6. Flood and drought hazard mitigation
7. Institutional arrangements for water resources research

Recommended Flood-Related Research

based on

"Report on Flood Hazard Mitigation"

5A. Research on the causes, extent, and effects of weather and climate changes caused by cities should be supported.

6A. A high priority should be applied to data gathering and to research on flood frequency.

6B. The current flood frequency prediction methodology should be revised in terras of current hydrologic knowledge.

11B. Research should be conducted to determine ways of making individuals aware of the limitations of flood control projects.

15B. There should be increased support for various mechanisms, including workshops and conferences, so that basic research findings, especially those from the social and behavioral sciences, can be transferred better to practitioners.

16B. ---Hydrological and meteorological research and refinement of models appropriate for flood forecasting should be carried out so that these models can be adopted for operational use.

17A. FEMA should undertake research to better analyze the nature, size, and trend of federal subsidy to the National Flood Insurance Program. This should include ----

22A. Research should be authorized and funds to develop analytical methods for calculating the benefits and costs of proposed economic and community development measures----and given due consideration in justification----

24D. Research should be initiated on policies which would permit flood victim relocation----

24E. Research should be encouraged on the legal liabilities confronting those responsible for flood hazard decisions in the pre- and post-event phases.

25A.. Methods should be developed through field studies and research to increase attention to and improve adoption of flood mitigation decision.

25B. Research should be encouraged on assessing alternative modes of implementing decision support systems.

25C. Studies should be made which link the decision process of individuals, groups, and communities with flood mitigation policy formulation and evaluation.

26A. Interidsciplinary studies should be conducted on the incentives and constraints on local governments related to the adoption----

26D. The dynamics of post-disaster community decision making and flood policy formulation requires future research----

26E. Research studies should be initiated which seek to determine how information presented in different forms----

26F. ---studies are needed to determine how many families actually renew their flood insurance policies.

27A. Research should be initiated on mental and physical health impacts of flooding----

28A. Research should be conducted to determine present and potential roles:
(1) How the insurance industry and its agents can stimulate----
(2) How real estate agents can be required----
(3) How lending institutions can encourage----

29A. ---should study the potentials for major coastal erosion, landslides, and mudslides----

30C. ---research should be undertaken to identify ways----to strengthen the role of local governments----

31A. Research should be conducted to identify the sources and failures of various institutional arrangements----

31B. Research should document damage prevented by proper administration of regulations in cities----

31C. Case studies should verify the effectiveness of state and local innovative actions----

32A. The Water Resources Council should undertake a comprehensive study of policies covering levees and channel modifications----

33A. The distribution of costs and benefits should be studied and policies designed to insure the elimination of any gross inequities.

34A. Research should be supported to determine the general beneficial aspects of flooding----

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