ANALYSIS AND SYNTHESIS OF FLOOD CONTROL MEASURES

by

Kon Chin Tai

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ABSTRACT

Adopting scientific methods of analysis and synthesis, flood control planning will become more meaningful and relevant to present and future flood control needs, if the principles and concepts are established from the very beginning.

A methodology incorporating four basic structural elements is presented, involving

(a) a classification scheme for flood control measures,

(b) analyses of the measures classified,

(c) subsequent syntheses of the various mixes of the measures to get the optimal, and

(d) the impact of the proposed measures on the regional economy.

Previous efforts in flood control planning have been carried out piecemeal and often the optimal or *best* strategy is missed by the concern over details rather than the synthesis of all their significant aspects.

The analyses of nonstructural measures, especially land use and insurance, demand a common yardstick to measure costs and benefits comparable to structural measures.

The synthesis of measures is in a state of flux, with no reliable principles and methodology to guide the planning process. A methodology is presented herein which incorporates the difficult problem of hydrologic interdependence of flood control measures.

The methodology of analyses and syntheses of measures is tested for the Arkansas Drainage Basin, above John Martin Dam, in Colorado. The drainage area is about 18,900 square miles, having a thriving economy, but is burdened with recurrent flood problems, both along the main stem of the Arkansas River and its major tributaries.

The economic synthesis is an additional element in this methodology, because the economic model enables the planner to examine the adverse effects, if any, of project proposals, and in addition, to alert him to any significant variables that could undermine the viability of flood control proposals. Sociological, environmental and sediment damages are potential factors in addition to direct flood damage. The Isard-Chenery Regional Input-Output Model is applied to flood planning. It appears to the writer of this paper that this may be the first attempt to apply input-output modeling to flood control planning in a comprehensive but exhaustive manner. The methodology rationalizes the hydrology-economics linkage which is the real synthesis between flood control and regional economic performance.

Chapter 1
INTRODUCTION

1.1 General

The historical perspective on the flood control planning process shows conclusively that a predominant reliance on the one-or-two measure approach of the past is no longer valid. The role of static planning where flood problems were viewed as problems that could be solved *once and for all* may be over. The philosophy, premises, and the inertia of the past are giving way rapidly to innovation.

The absence of a sufficiently thought-out conceptual framework has handicapped attempts so far to formulate guidelines and methodology that would help to search and to identify that flood-control strategy which is both sound and adaptable to present and future flood control needs. Attempts which have been made to formulate guidelines and methodologies have not been very successful.

In the United States, the historical perspective on flood control policy traces out a three phase development:

(a) 1936 to 1966. The thirty year period between the passage of the Flood Control Act of 1936 and the issuance of Executive Order 11296 of 1966 was a time for the supremacy of the technical structural measures, which by themselves alone were conceived to be sufficient in solving the flood problems for some time to come. No account was taken of the effect of project induced growth and the associated land enhancement benefit and it is this very dynamic growth effect that has been largely responsible for increased residual flood damages (Fig. 1-1).

(b) 1966 to 1973. During the seven year period up to 1973, the inadequacy of the past is realized and a greater *reliance* is called for on nonstructural measures in official flood control policy. Experience with the sole use of structural measures has resulted in a steady increase in the total flood damage. To reverse this trend, official policy requires the consideration and integration of nonstructural measures with structural measures.

(c) 1973 to 1975. The two year period marks an accelerated refinement of official flood control policy. Local initiative is to be marshalled, in meeting the problems of flood control and flood damage. A greater degree of self-reliance is called for by the Federal Government, from the state, local and municipal governments and from the occupants of floodplains. This devolvement of federal responsibility to local initiative is marked by the passage of Flood Disaster Protection Act of 1973.

However, despite this progressive evolution and innovation of official flood control policy of the nation, recent efforts to develop a procedural guideline and methodology have not yet been successful. Some of the basic difficulties in this direction arise from one or more of the following major problems:

(1) the lack of a comprehensive conceptual framework not having enough alternatives of flood control measures considered, analyzed and synthesized;

(2) investigators are handicapped by distraction in analysis of details rather than the synthesis of all the significant aspects of flood control measures; and

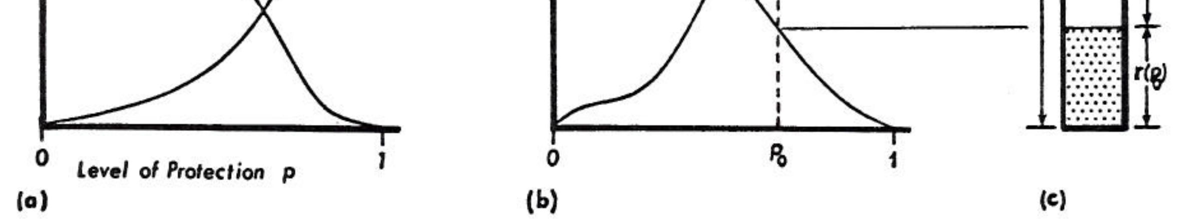


Fig. 1-1 Static and Dynamic Cases of Structural Flood Control Protection. The Static case is shown in (a); the dynamic case in (b); and in (c), $D(p_0)$, the average annual flood damages at protection level p_0; $R(p_0)$, the reduction in flood damages at protection p_0 and $r(p_0)$, the residual flood damages at protection level p_0 (Adapted from Arvanitidis et al., 1970).

(3) a fascination for the enigmas and methodologies of operational research, systems approach and computer programming, so that investigators are more concerned with the defense and acceptability of their techniques rather than with the problem at hand--the search and identification of a flood control strategy, sound and viable, from which the best mix of measures could be established in order to solve the complexities of flood control.

A review of the last ten years' efforts by investigators at academic institutions shows that James (1964) was the first to attempt integration of nonstructural measures with structural measures in flood control planning. However, the number of nonstructural alternatives were limited mainly to flood-proofing and land use. The danger with restricted consideration of a subset of measures is that the optimum from this subset is not necessarily the optimum from the total set of measures. It might be argued that in 1964, James was using only a slide rule and table calculator to analyze the subset of flood control measures, thus limiting the number of alternatives which were analyzed. Even when James developed with Cline and Villines (1968) the University of Kentucky Flood Control Planning Computer Programs II and III, no further nonstructural alternatives were analyzed. Cline reaffirms this position by stating that the programs "are by no means capable of analyzing all potential measures in all possible flood damage situations."

There is also a serious defect in James' methodology. The least-cost approach states that when the sum of the costs of a combination of flood control measures is less than the total of no-measure cost (the average annual flood damage), then the subset of measures is justified. However, the average annual flood damage does not need to remain constant, especially in urbanized areas with growth and land enhancement benefits. His optimization model is static, with this conclusion confirmed subsequently by Arey and Bauman (1971) for the least-cost model. Even in 1972, concerned that economic criteria can and should be used in planning the nonstructural flood control measures, James (1972) presented again the least-cost optimization model. The least-cost optimization procedure is valid as long as circumstances and average annual flood damage remain unchanged.

Day (1973) presented a methodology for planning land use and engineering alternatives for floodplain management. His model is more for particular land-use planning and development activities intended to find the optimum allocation of land for residential, commercial and open spaces. The selection between the nonstructural and structural measures do not appear to be systematic, limited to flood proofing and land fills on the one hand, and channels and dams, on the other. It is not clear to this reviewer what important aspect of flood-mitigation strategy he has considered, analyzed and planned.

Cortes-Rivera (1973) presented what is expected to be a methodology for planning comprehensive flood control projects by mathematical programming. Again, the methodology is applied to an application of land-use zoning to protect two pieces of agricultural land behind a levee system interacting with an upstream flood detention reservoir. The applicability of the methodology proposed appears to be restricted to upland watersheds with predominant agricultural activity. The objective of his study seems to be, to demonstrate the usefulness of his mathematical programming approach using parametric linear programming and dynamic programming for flood control planning. Hence, a fascination with the intricacy of programming methodology and the data needs of a specific planning situation obscures somewhat the necessity for more complex alternatives to be considered. The optimum of the land-use measure interacting with the levee and the upstream dam may not necessarily be the global optimal mix of measures and hence does not reflect the possession of a sound strategic basis in planning for that flood-prone area.

In addition, it appears that there is a disproportionate concern for the future by delving into economic and population projection and their future effects on flood control when the present problems of flood control are not adequately confronted. There are two reasons for this projection into the future. First, most of the watersheds studied by several investigators are upland agricultural watersheds with very little urbanization and development. Secondly, the extent of flood damage is not that extensive along the main stem of the river. Hence, a projection into the future indicates what sequential expansion of the project is necessary.

1.2 Objective and Scope of the Study

The objective of this study is to formulate an integrated investigative framework for the best tactical approach to analysis and synthesis of flood control and flood mitigation. A sound approach should be based on scientifically oriented flood control strategy which will provide solutions to flood, river and sediment problems, for the improvement of the environment, and to enable people to live in harmony with natural extreme events (Fig. 1-2).

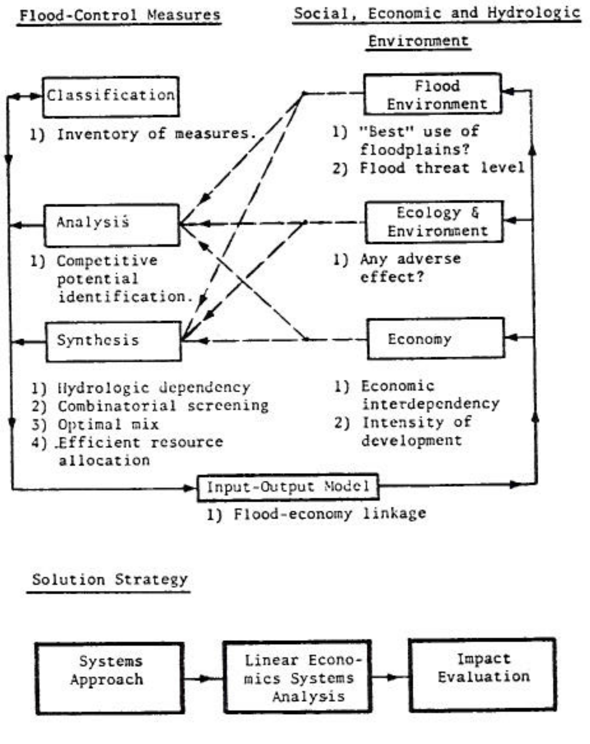


Fig. 1-2 Flow Chart Indicating Plan of Study and Solution Strategy.

The basis of this approach must be relevant to both present flood control needs and to a long range flood control strategy which could account for dynamic changes. A sufficient, built-in flexibility for frequent review of basic premises and principles and allowance for innovation is necessary.

The need for such approaches has already been enunciated by White (1972), who pointed out that, although the sophistication of scientific investigation and engineering analysis and design has advanced in strength and with rapidity, the skill to make integrated investigations of the whole array of flood-control measures has not kept pace. It was, he wrote, the concentration of special aspects of those engineering programs that have obscured the significance of complementary works in the field of flood warnings, land-use regulations, flood proofing and insurance. The result is that the net effect of many of the earlier flood-control works have ended up to be negative rather than positive, in comparison with what had been expected and planned for.

While White (1972) has laid down the philosophical hypothesis for this study's objective, the conceptual framework and basic guidelines have been advanced in a workable procedure by Yevjevich (1973, 1974), with:

(a) the prerequisite for a modern systems approach to planning by the systematization, classification, analysis and synthesis of all known flood-control measures, with the optimization of goals as the result of the synthesis of all the flood-control measures; and

(b) that the procedure would lead to a general strategy of how to treat floods in a modern society of any cultural and economic background.

This researcher has incorporated the philosophy and scientific concepts of White and Yevjevich in the objective of this study.

The phases followed in this study are:

(a) To search and to identify the general flood-control strategy for a given test region,

(b) Out of several areas reviewed in Colorado, the test region selected is the Arkansas Basin in the State of Colorado,

(c) Classification is made of all known flood-control measures applicable,

(d) Analysis is conducted of each measure as though each is independent and its relative potential evaluated in relation to the region's data when available, and extrapolated or assumed when such data were not available.

(e) Synthesis is made of measures with a combinatorial screening of mutually dependent measures where necessary, and allocation of resources by dynamic programming for measures with multi-dimensional, multi-stage approach.

(f) Hydrology-economics linkage is provided for, with the use of the Chenery Input-Output Model (1960), adapted to flood-control needs.

(g) The potential use of the empirical input-output economic model is two fold:

(i) to examine the probable and possible effects of proposed flood-control measures on the economic, environmental, ecological and social sectors of the selected river basin, and

(ii) to provide a basis for relating the presently formulated strategy in flood control with a longer-range strategy in anticipation for the need to constantly revise basic premises and approaches, adapting to changes in technology and economy, and other dynamic changes which are presently unknown and/or unexpected.

1.3 Significance of the Study

The significance of this study is to demonstrate the viability of an integrating methodology in the flood-control planning process. Planning for flood control is defined as a search for those optimal combination of measures that help to accomplish the general goal of flood control.

The integrating methodology which incorporates the scientific framework given by White (1972) and Yevjevich (1974) offers:

(a) a criterion that would shape present flood-control strategy for a given flood-stricken river basin and

(b) concurrently establish standards and criteria against which all current proposed and/or established flood-control projects for that region could be evaluated in their relative order of merits, with the need for improvement and modification thereon shown.

The necessity to analyze all measures, some of which are very dissimilar in their performance and yield of benefits, requires the formulation of common yardsticks in measuring economic net benefits, as the criterion adopted for economic efficiency in this study. Procedures for measuring benefit to cost ratio for structural measures are fairly well established; they are less so for nonstructural measures such as flood insurance.

The study establishes a conceptual framework by which a common measure of effective economic net benefit, stemming from dissimilar measure alternatives, can be evaluated. The study offers a methodology which has been in common use in the field of economics but has not been applied to flood-control problems. The modification of the regional Isard input-output empirical model to the study of flood related economy is attempted. This methodology answers a need expressed by Yevjevich (1972):

> "Total damage is usually separated into direct and indirect damage. An economy is made up of interrelated activities; and the direct damage in one sector affects the production or efficiency of its interconnected economic sectors, even though these sectors may not be in the flood plains. Therefore, not only is a survey of direct damage of importance, but also a methodology is needed which permits assessment of all effects, indirect and direct."

By July 1, 1975 all floodplains in the continental United States would either have to be registered or they would have to forego the future federal aid and assistance and benefits which could go to the aid of flood-plain residents when a severe flood occurs.

Therefore, the results of studies like this may be useful in pursuing the tasks of the continuing flood-control efforts.

Many countries of the world are now in one of the three categories of economic development: (a) depressingly slow, (b) negative growth or (c) stationary growth. The proportion of national product that is affected by fluctuations of natural disasters, such as droughts and floods, amounts in some instances to as much as 2-2.5 percent (White, 1972) or even more. This percentage is the expected annual growth rate for some countries in the immediate forseeable future. To the extent that such an amount could be saved or decreased by a sound flood-control strategy, the integrated flood-control measures and long-range policy may help to minimize the effects of these disasters.

Chapter 2
CLASSIFICATION OF FLOOD-CONTROL MEASURES

2.1 The Criteria and Classification

Classification criteria are given and the classification scheme of flood-control measures presented. These criteria and classification should be broad so as to include all known flood-control measures. A criterion should be included of whether the river is adjusted to man's convenience through engineering flood-control measures or the conceptual opposite, that man's activity is adjusted to the convenience of the river. This criterion is important in the classification of nonstructural measures, as supplemental to structural measures or as mutual alternatives.

Another criterion to consider is whether the classified measures would affect the short-term or long-term readjustments of the streams to flood control. Mackin (1948) proposed a synthesis between the engineers and the geologists ideas, advocating the necessity to give more attention to the latter's point of view.

The engineer is concerned primarily with the short-term reactions and adjusted events of streams to damming, shortening and deepening operations, and other river-training measures. The geologist views erosional and depositional problems in river valleys as the long-term responses of the river to changing conditions which control the flow activity of the river. The emphasis of Mackin is that the very natural changes are in many instances comparable with the changes introduced by man.

Mackin's hypothesis is that the engineering measures which alter the natural equilibrium of rivers by diversions, dammings and channel improvements place a stress on the river system already under natural equilibrium. In terms of Le Chatelier's general law, it is predictable that a reaction must occur by displacing the equilibrium in a direction which tends to absorb the effect of the stress. To quote Mackin, the engineer who laters the natural equilibrium will often find that he has "a bull by the tail and is unable to let go." He has to correct or suppress desirable phases of the chain reaction in the stream to the initial *stress* that is imposed. In the end, he would necessarily place an increasing emphasis on the study of genetic aspects of the equilibrium in order that one may work *with* rivers rather than merely *on* them. It pays to remember the principle, well-recognized but not extensively implemented, that "in dealing with rivers, better results may be achieved with less human effort by working *with* the water, rather than *against* it..." (Mackin, 1948).

2.2 A Review of Classification Schemes

White's Classification Scheme. White (1945) has given a classification scheme based on human adjustment to floods. The objective of the classification was to conduct flood-control policy analysis (Fig. 2-1).

Adjustment to floods is defined as an ordering of occupance to floods and to the flood hazard. The ordering may be systematic or unsystematic, rational or irrational, conscious or unconscious, so long as an observable arrangement of occupance in relation to floods is present.

Adjustment	Perception by manager of :					
	Theoretical choice	Flood Hazard	Technology	Economic efficiency	Spatial linkage	Practical choice
Loss bearing	I	I	I	I	I	I
Flood protection works	I	I	I	I	I	I
Emergency action	I	I	I	O	O	O
Structural change	I	I	O	O	O	O
Insurance	I	I	O	O	O	O
Public relief	O	O	O	O	O	O
Change in land use	O	O	O	O	O	O

O Not perceived
I Perceived

Fig. 2-1 Diagram of Elements in Decisions as to Adjustments to Floods (Adapted from White, 1964).

Eight major classes of adjustments are presented. It is interesting to note that the meteorological measures of prevention are not listed. Some limitations in White's classification scheme exist. The classification is based on a geographical approach to evaluate the flood problem in the United States with a better method needed to distinguish between physical and nonphysical adjustments. The industrial society's response to floods has generally been physical in nature (Arey and Bauman, 1971). In addition, the classification based on human behavior is difficult to incorporate in adjustments dependent on technology.

Kates' Classification Scheme. Kates (1962) presents a classification scheme designed to reduce the future flood damage. It shows the theoretical range of choices available to federal, state, and municipal authorities and to individuals. Basically, the action to reduce future flood damage is divided between the format for community action of federal, state and local levels and the individual level, with the possible interaction between these two levels. In addition, the classification allows for the interaction of alternatives which are the actual elements of a comprehensive flood-damage reduction program (Table 2-1).

The Kates scheme omits the measure on prevention, meteorological measures and physical control by extensive watershed measure. Its relative advantage is to allow for interdependence of technology and human behavior. Yet, in common with other classification schemes, it cannot serve for evaluating the potential effectiveness of various damage-reduction alternatives. Hence, the program for future flood damage reduction could be substantially altered if the initial expectations and choice of alternatives do not meet the practical realizations of chosen alternatives.

Arey and Bauman's Classification Scheme. Both Arey and Bauman (1971) have come up with a classification scheme to serve the review and revision of federal policies in flood control. The theoretical range of adjustments to floods are broadly classified as direct and indirect adjustments. Adjustments are those actions taken by individuals or groups of individuals in

TABLE 2-1 ELEMENTS IN A FUTURE FLOOD DAMAGE
(Adapted from Kates, 1962)

Theoretical Choice of Actions	Possible Individual Actions	Public Actions to Encourage, Reinforce, or Mandate Individual Actions	
		State-County-Municipal	Federal
Bearing the loss	Bear an unexpected loss** Bear an expected loss* Set aside funds for future loss*	Provide flood hazard information* Provide relief to ease suffering and distress but in such manner as to reduce future flood damages	
Emergency flood fighting, evacuation, and re-scheduling	Maintain stand-by preparations for flood fighting* Prepare advance plans for temporary evacuation of life and property and the re-scheduling of production*	Provide men and materials for emergency flood-fighting** Organize community warning and evacuation assistance plans*	Provide federal warning assistance and expanded radar network** Encourage local disaster plans to provide for flood-damage reduction*
Structural change and land elevation	Use wide variety of structural adjustments presently available for old and new buildings* Land elevation above flood level for new buildings*	Use building codes to make mandatory structural changes and/or land elevation Use channel encroachment laws to prevent increased damage to others as a result of land elevation (fill)*	Provide hazard information on which to design structural changes and land elevation* Require structural changes and or land elevation in flood-prone areas as requirement for HHFA and other loan assistance
Changing land use	Locate structures so as to minimize damage** Change land to open use, such as: parks, playgrounds, parking lots, etc. Abandon high hazard areas*	Mandate patterns of land use by flood plain regulations* Encourage open uses** Prohibit uses subject to high damage or loss of life** Use condemnation power and/or urban renewal to change land use	Provide hazard information for design of regulations* Require flood plain regulations as a provision for flood control, urban renewal, and similar assistance Use HHFA and other federal loan assistance powers to discourage improper flood plain use* Provide federal aid to permanently evacuate flood plain*
Controlling floods	Construct levees or walls, channel improvements, detention reservoirs* Request and promote local, state, and federal flood control projects** Share in costs of local, state, and federal projects*	Construct flood control projects* Request and promote state and federal flood control projects** Share in costs of federal projects*	Provide flood control in the form of levees, walls, channel improvement, land treatment, detention reservoirs**
Flood insurance	Obtain a policy* (Available under one of the following conditions: a) High premium b) Pooled risk with off-flood plain structures in comprehensive policies c) Structural adjustments reduce more frequent flood damage)	Provide standardized flood hazard information on which to base rate structure State supervision of insurance companies to encourage commercial policies that promote minimization of flood damages Subsidize a state-federal insurance program	Subsidize a federal or federal-state insurance program (Administered to promote minimization of flood damages)

*Present application limited

**Present application widespread

order to modify the *impact* of a hazard event. Hazard events work through the environment, and both physically and socially affect the society. The lower portion of Fig. 2-2 shows this influence as the dashed outline of an arrow.

Direct adjustments are classified by Arey and Bauman as:

(i) actions which directly relate to the hazard, (affect the cause, e.g. weather modification);

(ii) actions which directly relate to the environment, (modify the hazard, e.g. channel improvement and flood-control reservoirs), and,

(iii) actions which relate to the impact of the hazard, (modify the loss potential, e.g. by warning and evacuation, flood proofing and land-use changes).

Indirect adjustments which are also shown in Fig. 2-2 are designed to cope with the aftermath of a flood event, e.g. (a) spread of the losses (relief, subsidized insurance; (b) plan for the losses (insurance, reserve funds); and (c) bear the losses (individual loss bearing).

Of significance from the classification methodology is the interdependence of adjustments. The availability of relief (indirect adjustment, spreading the loss) may cause the adoption of land treatment (direct adjustment, affecting the cause of hazard). Likewise, the payment of insurance premiums (indirect adjustment, planning for the losses) may provide the incentive for adoption of land use (direct adjustment, modifying the loss potential).

The authors admit the serious limitations of their own classification scheme. Such a classification of the theoretical range of adjustments does not draw the line between the technological and behavioral factors, although admittedly there is an interaction and interdependence between the two. The authors further suggest that perhaps there is a more useful dichotomy for the purpose of policy analysis, if adjustments are distinguished between those that are physical and those which are not.

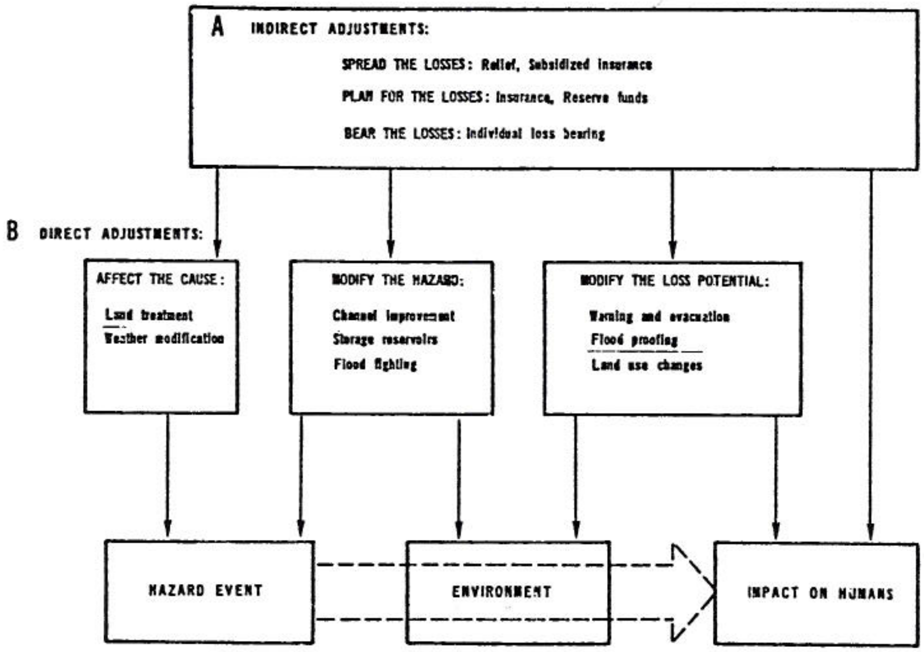


Fig. 2-2 Theoretical Range of Adjustments with Examples from Adjustments to Flood (Adapted from Arey et al., 1971).

Despite these limitations, the significance of the classification is that government is confronted with a choice because the development of flood-control policy over the years will be expected to follow a process of expanding the range of actual selections to fit the theoretical range of alternatives underlined by the authors.

2.3 The Present Context of Flood-Control Problems

The present context should also be presented in the search for a classification. White has expanded on the study of Kates (1970) and has pointed to the relative characteristics of the three historical responses to flood hazard.

The three responses are:

(a) pre-industrial, modifying human behavior to harmonize with nature rather than to control nature;

(b) modern technological or industrial, characterized by a limited range of technological actions, inflexible, difficult to change, and high in capital requirement; and,

(c) comprehensive or post-industrial, which is a response combining features of (a) and (b).

White (1971) has hypothesized that the United States is currently passing the peak of the modern technological type of response to the comprehensive type, as the latter emerges here and elsewhere. This means that a response combining type (a) and (b) will result in a larger range of adjustments, a greater flexibility and a greater variety of capital and organizational requirements. The classification scheme that is now needed should make allowance for this third response.

2.4 The Classification Used in the Study

The Criteria of Classification. The criteria discussed in previous sections on classification schemes are summarized herewith as:

(a) the principles of classification depend on the objectives of the study;

(b) it should be possible to enumerate those measures that allow man to work with the river and those measures that work against the river,

(c) it should be possible to classify flood-control measures on a physical and nonphysical basis, allowing for interdependence and harmonization of technological and human behavioral adjustments,

(d) it should be possible to identify those measures which could impose a stress on the short-term and long-term natural equilibrium of the system of streams, and

(e) it should be possible to identify those which represent direct and those which represent indirect adjustments to flood hazards.

The Classification Used. The classification used in this study is that given by Yevjevich (1973, 1974), since it incorporates a provision for the above criteria. The classification is based on five basic groups of measures: prevention, prediction, proofing, physical control and insurance.

A definitive distinction is made by Yevjevich between flood control and measures. Flood control is defined as all measures, physical or otherwise, that enable the communities living along flood valleys in general and flood plains in particular, to live harmoniously with the natural phenomenon of floods.

Measures are defined as human actions that help accomplish flood control in this broad sense. These include geophysical, engineering, economical, social, administrative and other actions.

Admittedly it is difficult to come out with the same classification scheme, even from two people knowledgeable with all aspects of flood control. Nevertheless, the classification scheme (Fig. 2-3) proposed by Yevjevich is adopted with the following objectives in mind:

(1) The classification permits the analysis of each measure by developing a proper model of its performance, effectiveness, cost, benefit, indirect effects, environmental impacts and various constraints connected with the measure and its model.

(2) The classification allows a check whether all the measures and their combinations have been considered and analyzed in relation to flood-control planning.

(3) The classification can be used in conceiving and analyzing a set of well-integrated flood-control measures.

(4) Such a set of measures may be studied as subsets of all measures feasible in a river basin, with the various constraints of subsystems incorporated.

Complexities of modern flood-control problems cannot be best solved by an all-embracing systems approach, but rather by first breaking the totality of the system down to well defined subsystems, with the relatively either strong or weak links between the identified sybsystems. The classification scheme, therefore, offers an opportunity for development of the topology of flood-control systems, by first helping to conceive a particular system in space and time. The topology means an advanced technique in designing various alternatives to be analyzed and synthesized.

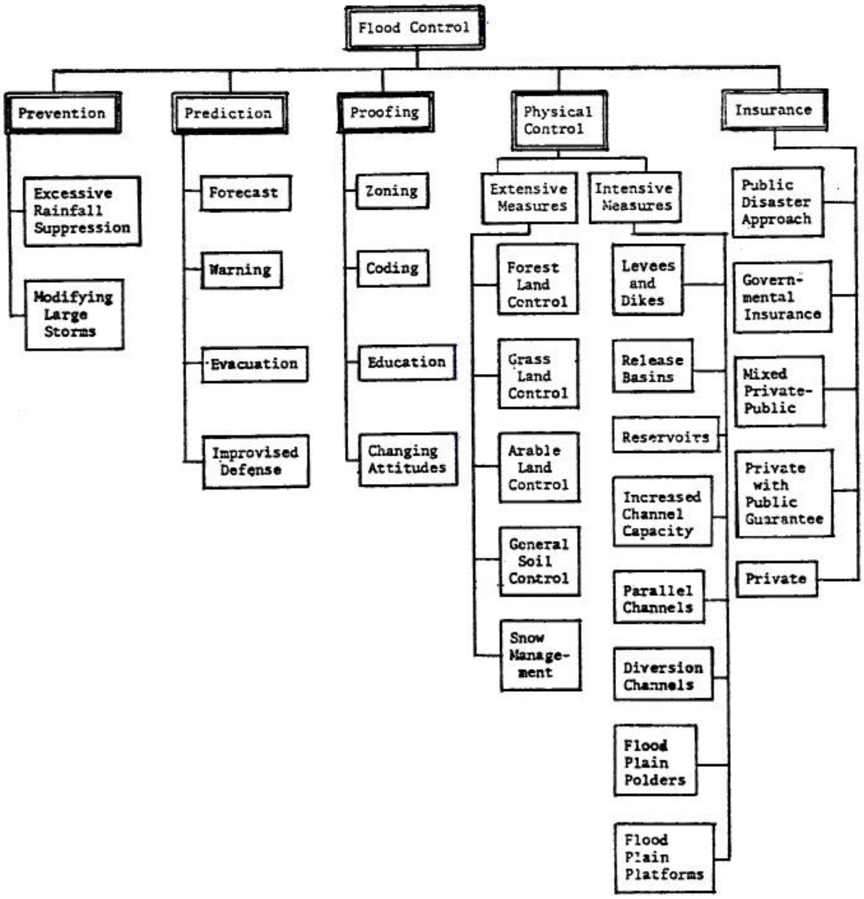


Fig. 2-3 General Classification of Flood Control Categories, and Individual Measures in Each Category. (Adapted from Yevjevich, 1974).

Chapter 3
ANALYSIS OF FLOOD-CONTROL MEASURES

This chapter deals with the analysis of the five basic groups of flood-control measures as classified in Chapter 2: prevention, prediction, proofing, physical control and insurance.

The five basic groups will be analyzed under the following phases:

(1) A general treatment of each basic group under the subheadings:

(a) general description of flood control measures,

(b) statements of objectives, and

(c) the performance models, and

(2) The results of the relevant model's analysis as applied to the particular test basin, the Arkansas Basin.

Of crucial importance to this analysis is the fact that each basic group of measures either alters, modifies or adjusts to the flood hydrograph. These changes and modifications will be discussed in each basic group in its sequence.

The details of the analysis of each basic group will be carried out in relation to the data available from the test region, the Arkansas River Basin and its major tributaries above the John Martin Dam. Reports (1968, 1970) of the District Engineer, U.S. Army Corps of Engineers, Albuquerque, New Mexico, provide these data.

Figures 3-1 and 3-2 indicate the geographical location and the local extent of the proposed projects respectively.

The objective of the analysis of the five basic groups in relation to the test basin is to evaluate the alternative strategy that could have been overlooked by previous project proposals. The U.S. Army Chief of Engineers when testifying in 1973 recognized the need for a broad-range alternative of structural and nonstructural measures, although the Corps District proposals (1968, 1970) have concentrated merely on structural measures with their subsequent environmental objections, and suspension.

3.1 Prevention Measures

(a) General Description. The preventive measure is broadly divided into two: (a) meteorological preventive measures and (b) prevention of breaches of artificial water-impoundment structure such as levees and dams.

The goal of the meteorological preventive measure is to flatten out the resulting flood hydrograph from (a) excessive local rainfall or (b) large storm systems such as hurricanes and typhoons. The goal in prevention of breaches is to reduce the hazard of potential catastrophe such as a landslide or earthquake near a dam, resulting in a sudden release of a flood wave of considerable destructive power.

To flatten the flash flood hydrograph of excessive rainfall, such hydrograph exhibiting the characteristic of small volume but of rapid speed, which leads to its potential destructiveness, the goal is either to decrease the exceptionally high-frequency precipitation intensities or to divert the precipitation away from some initial areas.

To flatten the flood hydrograph of large storms such as hurricane and cyclone, which cause the most damage due to their relatively high wind velocity and subsequent wide-spread areal flooding, the goal in large storm modification is to decrease the exceptionally high precipitation of flood preducing magnitude by retaining a controlled intensity of long duration over larger areas. The goal of this prevention is aimed therefore at the very genesis of causes of storms which lead to subsequent flooding. It is aimed at storm manipulation and success in such an attempt may not be achieved for sometime in the future, because even the most potent forces controlled by man are practically negligible compared to nature.

The prevention of floods caused by snow melt can be done by snow channeling in large depression or by changing the albedo but since the areal snow coverage is so extensive that pure economic considerations alone limit its potential application.

The prevention of floods caused by breaches of impounded water can be improved by periodic inspection and review of all such structures. Early detection of potential danger from landslides and earthquakes causing dams, levees or reservoirs to collapse could lead to timely evacuation, arrangement of public protection, and timely remedial action.

(b) Statements of Objectives.

(1) Excessive local rainfall suppression. It is relatively easy to apply an optimization procedure using economic efficiency criterion in maximization of net benefit to excessive rainfall suppression in a limited geographic area. The net benefit must be positive and exceed all other net returns which can be obtained by alternative measures. (Gutmanis, et al., 1966).

$$\max.\ NB_{RS} = B_{RS} - C_{RS} \qquad (3\text{-}1)$$

where $B_{RS} = X_{DR}$, and

$$C_{RS} = C_{Se.} + C_{Eq.} + C_{Ad.} \qquad (3\text{-}2)$$

NB_{RS} is the expected annual net benefit of excessive rainfall suppression.

B_{RS}, C_{RS} is the expected annual benefit and cost of the rainfall suppression.

X_{DR} is the expected annual flood damage reduction, and

$C_{Se.}, C_{Eq.}$, and $C_{Ad.}$ are the expected annual costs of seeding; of equipment and of administering the program respectively.

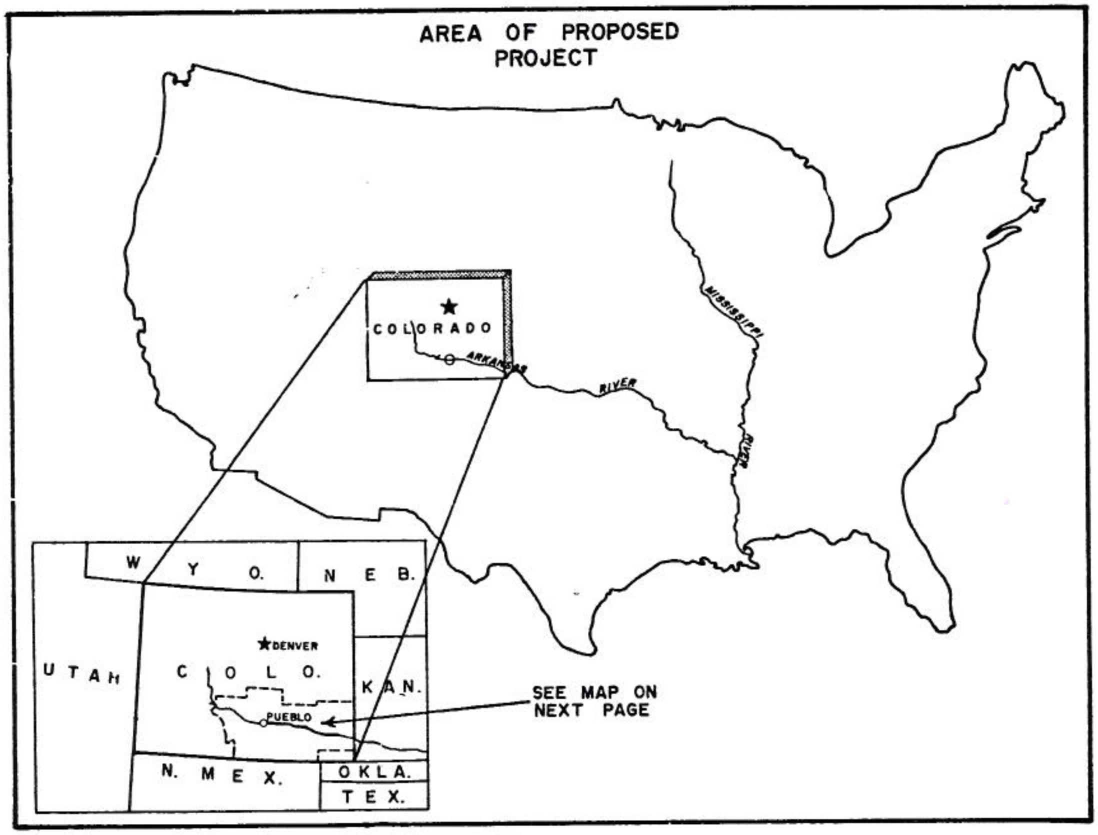


Fig. 3-1 Area of Proposed Project.

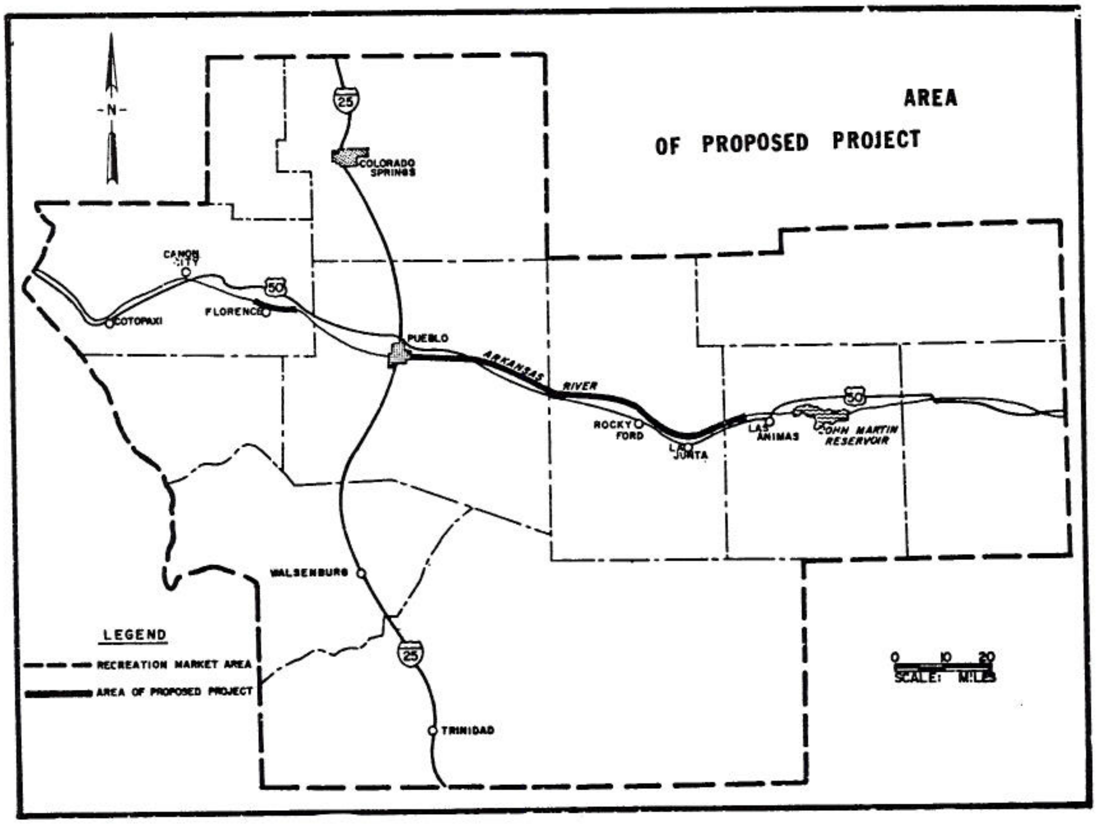


Fig. 3-2 Area of Proposed Project.

(2) Excessive storm modification. Storm modification is expected to create external diseconomies causing huge social costs. By decreasing the rainfall intensities over a larger area, an area in which tourism predominates and which favors no precipitation may be affected more than an agricultural area which requires the rainfall.

The objective is to maximize the expected annual net benefit of storm modification, NB_{SM}, i.e.,

$$\max. \quad NB_{SM} = B_{SM} - C_{SM} \tag{3-3}$$

where B_{SM}, C_{SM} are the expected annual benefit and cost respectively of the storm modification program.

$$B_{SM} = X_{DR} + X_{W} - X_{ED} \quad \text{and} \tag{3-4}$$

$$C_{SM} = C_{SMT} + C_{Eq.} + C_{Ad.} + C_{con.} \tag{3-5}$$

where

X_{DR}, X_{W}, and X_{ED} are respectively the expected annual benefits from flood damage reduction; potential uses of excess water from the storms, and the resulting social cost in local external diseconomy and,

C_{SMT}, $C_{Eq.}$ and $C_{Ad.}$ are respectively the expected annual costs of storm modification technology; of equipment and of administering the storm modification program. Vital to this program is the cost of control $C_{con.}$ in order to discriminate with and without storm modification results.

(3) Breaches of artifical impoundment of water. If the life of the structure such as a levee or a dam is a relatively long one, the expected value approach is again valid to estimate risks and uncertainties associated with breaches.

The objective is to maximize the expected annual net benefit of preventing breaches of artificial impoundment of water, NB_{BI} i.e.,

$$\max. \quad NB_{BI} = B_{BI} - C_{BI} \tag{3-6}$$

where,

B_{BI}, C_{BI} are the expected annual benefit and cost respectively of the prevention program.

$$B_{BI} = X_{DR} + X_{LL} + X_{ED} + X_{EA} + X_{com.}, \quad \text{and} \tag{3-7}$$

$$C_{BI} = C_{RA} + C_{Ev.} + C_{Re.} + C_{Sec.}, \tag{3-8}$$

where

X_{Dr}, X_{LL}, X_{ED}, X_{EA} and $X_{com.}$ are respectively the expected annual benefits of preventing flood damage, subsequent loss of life, external diseconomy, emergency aid, and compensation.

C_{RA}, $C_{Ev.}$, $C_{Re.}$, $C_{Sec.}$ are respectively the expected annual costs of remedial action, emergency evacuation, subsequent rehabilitation and public security protection.

(c) The Performance Models. The performance model is usually an economic optimization model as previously outlined in the section on statement of objective. Incorporated or imbedded in this overall economic model is the technological submodel which deals with the particular problem at hand, e.g., excessive local rainfall suppression, large storm modification, regional snow melt or artificial breaches. Even in one subclassification, excessive rainfall suppression, the technological submodels vary in complexities in accordance to the varieties of local weather processes. Cold cloud seeding by iodide or dry ice is different, for example, from warm cloud seeding by sodium chloride. The natural cloud processes also vary according to geographical location, temperate or tropical regions.

There are technological submodels available which are related to potential breaches of levees. (Bogardi I, 1968, 1971, 1972). Four modes of levee failures have been studied; overtopping of the crest by flooding; boils and hydraulic soil failure in the substratum; loss of slope-stability and sliding due to seepage and erosion caused by wave action.

The Submodel for the Test Area. The submodel chosen for the Arkansas Basin is related to the airmass thunderstorms due to convective heating and orographic lifting. The latter type is responsible for precipitation in the form of intense storms, which cause flash floods of short duration and small volume but of damaging intensities. Colorado Springs and Pueblo, for instance, have peak thunderstorm activity in July, with an average between 13 and 17 thunderstorm days, respectively. The attention here is an evaluation of whether a potential economic benefit exists in seeding warm clouds of the convective type (isolated cumulus clouds) in order to diffuse them or to divert such potential rainfall away from the land producing floods along the most important urbanized and agricultural floodplains.

Durham (1973) has investigated rainfall augmentation from warm cumulus clouds by sodium chloride seeding. This study was interested, however, in evaluating the potential benefit of the Durham's model in relation to flash flood suppression. The choice of Durham's climatological model is based on the fact that the study area covers Denver, which is the next largest basin closest to the Arkansas River Basin.

The Durham (1973) performance submodel is a one-dimensional steady state cumulus cloud model. It considers the lateral entrainment process, droplet growth by condensation and coalescence and the development and fallout of precipitation. It covers the standard thermodynamic and dynamic processes in isolated warm cumuli.

The performance parameters are divided broadly into two groups:

(i) the initial conditions at the cloud base at the time of seeding such as updraft velocity, updraft radius and cloud droplet spectra, and

(ii) a vertical profile of pressure, temperature, relative humidity and horizontal wind speed.

(d) The Results of the Model's Analysis as Applied to the Particular Test Basin, The Arkansas River Basin. The results of the writer's analysis show that although precipitation could be induced through seeding of isolated warm cumulus clouds, the efficiency of the precipitation mechanism is very low. Efficiency in this case is defined as the ratio of precipitated water to condensed water available in the cloud.

Durham's analysis is optimistic because his results show precipitation induced in the range of 7.4 to 137.0 acre-ft of rainfall over an area of 2.72 to 8.17 square miles respectively, with a corresponding efficiency range for Denver from 1.29 to 2.00 percent. These ranges correspond to a rainfall intensity of 0.05 to 0.3 inches per acre. The writer believes that Durham's results do not reflect the average climatological conditions for seeding, but rather the optimal climatological situation. Nevertheless, the efficiency of the precipitation mechanism induced by seeding is still extremely low, even under those optimal conditions.

The writer has tested the above hypothesis with average radiosonde soundings available for both Denver, Colorado and Fort Worth, Texas. Sensitivity analysis is carried out with a systematic variation of initial updraft velocity at the cloud base at the time of seeding. The results confirm the hypothesis that seeding of warm cumulus clouds over the Arkansas River Basin will not be of economic benefit in flash flood suppression. The Fort Worth vertical radiosonde profile is included to cover the range of average climatological conditions expected to prevail over the Arkansas River Basin (Tables 3-1 and 3-2).

TABLE 3-1 AVERAGE DAILY MODEL.
ASSESSED SEEDING RESULTS

Cloud Radius (km)	Initial Updraft Velocity (cm/sec)	Rainfall (acre-ft)	Efficiency (percent)
	Denver and the adjacent Arkansas River		
0.5	200	0.139×10^{-8}	0.329×10^{-9}
	400	0.145×10^{-8}	0.201×10^{-9}
	600	0.149×10^{-8}	0.146×10^{-9}
	800	0.149×10^{-8}	0.113×10^{-9}
1.0	200	0.676×10^{-8}	0.348×10^{-9}
	400	0.697×10^{-8}	0.212×10^{-9}
	600	0.748×10^{-8}	0.159×10^{-9}
	800	0.723×10^{-8}	0.122×10^{-9}
2.0	200	0.305×10^{-7}	0.406×10^{-9}
	400	0.319×10^{-7}	0.248×10^{-9}
	600	0.341×10^{-7}	0.189×10^{-9}
	800	0.439×10^{-7}	0.188×10^{-9}

3.2 Prediction Measures

(a) General Description. The prediction measures include flood forecasting, flood warning, flood fighting defense and evacuation of people, livestock and goods.

The goal of the prediction measure is to reduce the flood hazard in the river basin by accurately predicting the expected *magnitude* and *time* of arrival of floods, since floods represent a rapidly evolving disaster. Hence there is no alteration or adjustment made of the flood hydrograph, only its genesis; its peak and stage and its expected time of arrival is made in the forecast and warning.

TABLE 3-2 AVERAGE DAILY MODEL.
ASSESSED SEEDING RESULTS

Cloud Radius (km)	Initial Updraft Velocity (cm/sec)	Rainfall (acre-ft)	Efficiency (percent)
	Fort Worth Radiosonde Vertical Profile with Denver's Droplet Spectra		
0.5	200	0.099×10^{-8}	0.705×10^{-9}
	400	0.102×10^{-8}	0.264×10^{-9}
	600	0.107×10^{-8}	0.238×10^{-9}
	800	0.113×10^{-8}	0.173×10^{-9}
1.0	200	0.726×10^{-8}	0.498×10^{-9}
	400	0.737×10^{-8}	0.281×10^{-9}
	600	0.748×10^{-8}	0.196×10^{-9}
	800	0.763×10^{-8}	0.150×10^{-9}
2.0	200	0.303×10^{-7}	0.464×10^{-9}
	400	0.326×10^{-7}	0.269×10^{-9}
	600	0.346×10^{-7}	0.195×10^{-9}
	800	0.367×10^{-7}	0.156×10^{-9}

Without prediction, there are basic risks associated with the state and occupancy of the river floodplains. With prediction these basic risks are modified by altering the conditions, state and occupancy of the floodplains before the flood. The adjustment is made by evacuation or temporary abandoning of the floodplain areas, with people moving to higher ground, and doing whatever is possible to minimize damage to the properties which cannot be moved. Flood fighting operations may become necessary at some sections of the river system, when the degree of natural protection is lower than the actual flood level.

Two basic questions have been raised related to flood protection: (Yevjevich, 1964):

(1) How feasible are the forecasts and how far in advance can they be made?

(2) What is the economic worth of these forecasts?

The *feasibility* of the forecasts is limited to short-range and medium-range hydrologic forecasts (Lambor, 1967), which are characterized quantitatively, based on the physical course of phenomena and on precipitation and runoff measurements.

On major tributaries, flood warnings can be issued hours to days in advance of the flood wave traveling down the major tributaries. Main stem river forecasts can be issued as far as several days or even weeks in advance. In general, the time lapse between rainfall or snowmelt and the rise in river height increases with the size of the river.

Besides the forecast time, the *flood warning time* t_w, is one of the most important parameters in floodplain operation (if the floodplain is regarded as an elastic reservoir), and as such the flood warning time should be extended as far as possible to secure the various potential benefits such as evacuating low lying areas; moving personal property, mobile equipment and livestock to higher ground; alerting emergency and relief organizations to care for refugees; to prepare for the inevitable subsequent health hazards caused by floods and even harvesting valuable crops in advance of the destructive flood.

The weakest link is not in either the *speed* of collection and analysis of meteorological and hydrological data or the *speed* of transmission of the ensuing forecast or the *time* of travel of the flood wave but the *speed* of disseminating the forecast and warning to all the economic activities endangered in the floodplains (Bugliarello, et al., 1963).

The *economic worth* of flood forecasts is related to the level of economic development in the river basin, for which flood forecasts are needed. The requirements and economy of the area dictate the relative economic worth of flood forecasts (Kohler, M.A. 1967). Since economic losses in the United States due to flooding have shown a more persistent upward trend than lives lost, (White, 1973), the economic worth of flood forecasts is found to be equivalent to about 5 percent of the total expected annual economic losses sustained by flood damages. Day, (1970), Grayman and Eagleson (1973) and White (1973) have reportedly quoted the range between 2 to 5 percent of total economic losses that can be prevented through prediction and warning systems.

(b) Statements of Objectives. The objectives of the analysis depend upon the selection of the appropriate kind of flood forecast which depends upon the particular flood type. Four principal flood types have been identified and classified for temperate region, (Lambor, Warsaw and Australia, 1967),

(1) Rainfall floods, (type 0);

(2) Snowmelt floods, (type R);

(3) Storm floods on the sea coast (type S_z); and

(4) Winter floods (type z).

The most violent floods are identified as type 0, the rainfall floods, in temperate countries. Type 0 is further subdivided into:

(1) Short thermal storm flood, (type 0_n);

(2) Frontal rainfall flood, (type 0_f); and

(3) Frontal rainfall flood, intensified by ground orography, (type 0_r).

Flood types appeared hitherto not to have been classified and identified for the tropical regions (Chin, 1967).

Of all the rainfall floods, flash floods of type 0_n are the most difficult to predict because of their localized nature and speed of travel. Both hydrologic forecasts of the short and medium-range give too short a notice of the flash flood. Though radar could be used to predict the specific areas where excessive rains will fall, radar interference is present where there are mountains in the area, Philip, et al., 1972).

However, prediction prospects for the other two types of rainfall floods, 0_f and 0_r of the frontal character are much more favorable. In fact both meteorological medium-range forecasting F_m, and hydrologic short and medium-range forecasting, P_h and F_h can be used conjunctively, (Lambor, J., 1967).

The objective is to maximize the annual expected net benefit of flood prediction NB_p, i.e.,

$$\max NB_p = B_p - C_p \tag{3-9}$$

where B_p, C_p are respectively the expected annual benefit and cost of the prediction measure.

(c) The Performance Models. The performance model is the overall economic model of maximizing net benefit, in which is embedded the climatic-hydrologic submodels. Once the particular submodel is chosen for the particular flood type, such a submodel is incorporated into computer simulation models to simulate the impact of the areal and time distribution of rainfall, runoff and subsequent level of flooding at the given time and place and its estimated effects on the resources situated at the various locations identified. The flood warning information is the expected flood stage, its flood peak and its expected time of arrival of the flood. Hydrologic conceptual models for basin runoff and flood prediction are available such as the Stanford Watershed Model, SSARR model of the Corps of Engineers and the National Weather Service, the Hydrologic Engineering Center 1 model, and others.

The Submodel of the Test Area. The climatic-hydrologic submodel chosen for the test area is the M.I.T. meso-scale weather submodel for the frontal type floods (type 0_f). The prediction is for slow floods of the frontal weather type, caused by convergence of cold artic air from the north with the warm moist Gulf air from the south. Prediction for this type of flood has been found to be promising.

The M.I.T. submodel is due to Grayman and Eagleson (1973) and in applying to the test region, the assumption is made that the parameters of the meso-scale weather system of the New England region is applicable to the Arkansas Basin in Colorado.

The economic model involves maximizing the expected annual net benefit of the prediction measure, i.e., max. $NB_p = B_p - C_p$, where the symbols B_p, C_p have been defined previously.

$$B_m = r_e \sum_{j=1}^{N_r} \sum_{i=1}^{N_j} F_{(i,j)} \sum_{k=1}^{N_j} P_{(i,j,k,m)} \left[B_{(i,j,k)} - C_{(i,j,k)}\right] \tag{3-10}$$

where B_m = the net benefits to floodplain occupants; r_e = the fraction of occupants that respond to a flood warning; N_r = the number of river reaches; N_j = the number of discrete levels in reach j; $F_{(i,j)}$ = the probability of a flood of level i occurring in reach j in any year; $P_{(i,j,k,m)}$ = the probability of an actual flood of level i, for reach j, resulting in a predicted flood level k, using measuring network m; $B_{(i,j,k)}$ and $C_{(i,j,k)}$ = the gross benefits and private costs accruing to floodplain occupants in reach j resulting from a flood of level i whose predicted level was k. Evacuation and rehabilitation costs are usually entered into $C_{(i,j,k)}$, but where flood fighting is involved, such an additional cost may be added here, since there is at present such a paucity of data available. (Day, 1970).

The network costs in the prediction measure is,

$$C_m = C_a + (C_c \times C_r), \tag{3-11}$$

where C_m = the network costs for network m, in the form of expected annual costs, is determined by amortizing the capital cost C_c over a lifetime L = 50 years, at a discount rate of R percent; with a capital recovery factor C_r; and C_a = the annual operation and maintenance cost for network m (Appendix A).

Hence the expected annual net benefits of the prediction measure covering capital cost of equipment and forecast, type of measuring network; and evacuation, rehabilitation and flood-fighting is:

$$NB_m = B_m - C_m . \tag{3-12}$$

The technological submodel for the raingage network is, (Appendix B);

$$\log \sigma_x = -a \log\alpha - b, \tag{3-13}$$

where σ_x = the raingage flood peak prediction error; a and b are fitting parameters and $\alpha = 2G/\lambda\beta$ is the independent variable for the cyclonic storm over a relatively large size of catchment (Grayman and Eagleson, 1973).

The technological submodel for the radar-raingage network is

$$\sigma_y = C_s \sigma_t \left[1 - \frac{1}{\kappa}(1-e^{-\kappa})\right] \tag{3-14}$$

where $\kappa = 2.3\sqrt{A}/R_c \sqrt{\pi}$; σ_t = the accuracy parameter of the radar system in a particular climatic situation; A = the spacing of calibrating raingages, in square miles per raingage and C_s = a coefficient that is a function of catchment area and storm duration; and σ_y = the radar-raingage flood peak-prediction error.

(d) The Results of the Model's Analysis as Applied to the Particular Test Basin, the Arkansas River Basin. The worth of the flood forecast and flood warning is limited to about 5 to 10 percent of the annual expected economic losses due to flood hazard, without loss of life being taken into account. The expected annual net benefit of the prediction measure using the optimal telemetering raingage subsystem for the Arkansas Basin is $66,517 per year with a benefit to cost ratio of 2.54.

Sufficient warning time of at least 6 to 12 hours is ensured, since all the Arkansas River subwatersheds have time of concentration exceeding the minimum requirement of the M.I.T. model, viz. 6 to 12 hours.

The feasibility of the prediction measure is limited to frontal rainfall flood, the slow flood. The flash flood (the quick flood) is at present difficult to predict, for the Arkansas River Basin.

Sensitivity analysis of two performance parameters, raingage performance parameter, b, and sociological response factor, r_e, shows that the latter is critical.

Optimality of the precipitation measuring network is telemetering raingage over radar and raingage. The optimal density is one raingage per 528 square miles, along the main stem of the Arkansas River and its major tributaries (Fig. 3-3 and Appendix B).

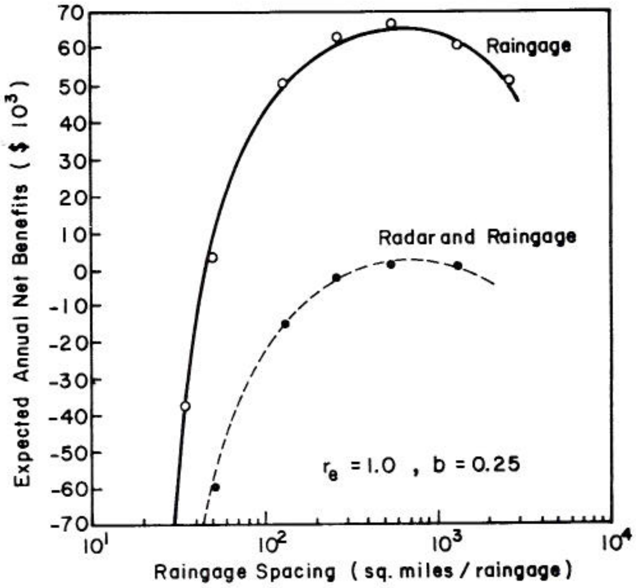


Fig. 3-3 Optimality of Raingage Precipitation Measuring System.

Sensitivity Analysis

Effect of Raingage Performance, b

Test Series	r_e	b	Net benefit/ year	B/C
A	1.0	0.25	$66,517	2.54
B	1.0	-0.15	$48,667	1.95

Effect of Sociological Response to Flood Warning, r_e

Test Series	r_e	b	Net benefit/ year	B/C
A	1.0	0.25	$66,517	2.54
C	0.5	0.25	$11,712	1.27

Computer results are shown for tests A and C in Table 3-3 and Figs. 3-4 and 3-5 show them as the graphical relationships.

TABLE 3-3 EXPECTED VALUE MODEL.

Average Annual Net Benefits based on 50 year life	Test Series A (Dollars)	Test Series C (Dollars)
Maximum possible benefits	122,683	122,683
Radar without raingages	- 9,611	-51,769
Radar + 1 gage per 1320.0 sq. mi.	1,254	-47,981
Radar + 1 gage per 528.0 sq. mi.	1,869*	-50,141
Radar + 1 gage per 264.0 sq. mi.	- 2,154	-56,265
Radar + 1 gage for 132.0 sq. mi.	- 14,764	-70,794
Radar + 1 gage per 52.8 sq. mi.	- 59,912	-118,043
Radar + 1 gage per 35.2 sq. mi.	- 99,570	-158,433
Radar + 1 gage per 26.4 sq. mi.	-139,815	-199,117
Radar + 1 gage per 13.2 sq. mi.	-302,715	-362,813
Radar + 1 gage per 8.8 sq. mi.	-466,561	-526,982
Radar + 1 gage per 5.3 sq. mi.	-794,953	-855,670
1 gage per 2640.0 sq. mi.	51,185	7,335
1 gage per 1320.0 sq. mi.	60,784	11,312
1 gage per 528.0 sq. mi.	66,517*	11,712*
1 gage per 264.0 sq. mi.	63,623	6,152
1 gage per 132.0 sq. mi.	50,647	-8,560
1 gage per 52.8 sq. mi.	3,674	-56,721
1 gage per 35.2 sq. mi.	- 36,877	-97,558
1 gage per 26.4 sq. mi.	- 77,701	-138,531
1 gage per 13.2 sq. mi.	-241,765	-302,809
1 gage per 8.8 sq. mi.	-406,133	-467,239
1 gage per 5.3 sq. mi.	-735,009	-796,169

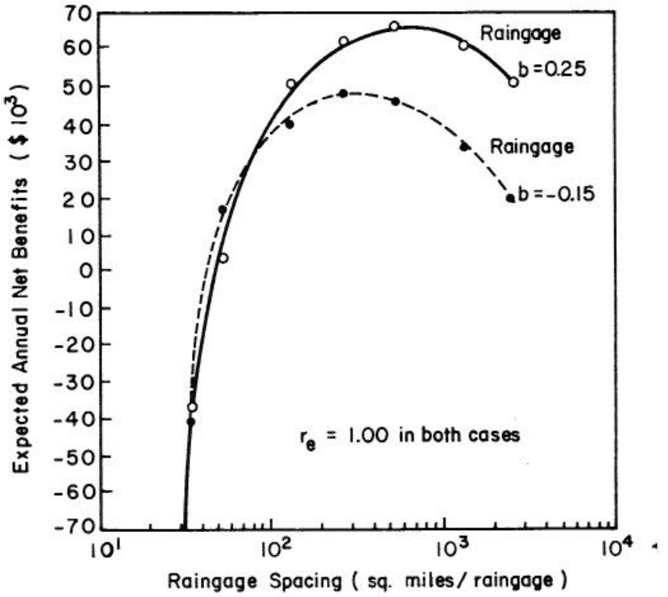


Fig. 3-4 Sensitivity Analysis of Raingage Accuracy Parameter, b.

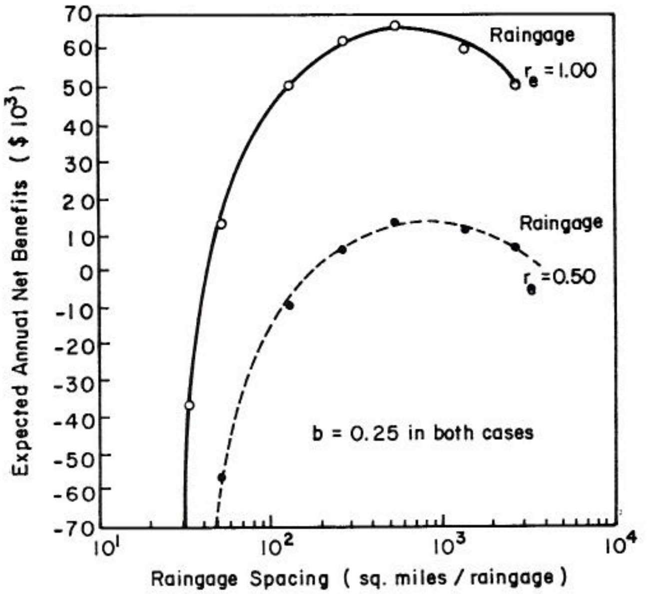


Fig. 3-5 Sensitivity Analysis of Sociological Response Factor, r_e.

3.3 Floodplain Proofing and Floodplain Zoning Measures

(a) General Description of Flood Control Measures. Floodplain zoning and floodplain proofing are measures of significant social and economic importance in the overall strategy of flood control.

Nature has originally developed its own requirements for the natural passage of floods with the limits and characteristics of all natural floodways discernible. However, man's activities on the floodplains have modified the natural conditions of the floodways and often the net result of such human intervention is felt not only in the channel itself but also throughout the drainage basin. Too often, the net effect of such changes has been to increase stages and to extend the original limits of the overflow area.

Floodplain zoning is therefore aimed at restoring the floodway to the river. It is an adjustment concept of learning to live with floods. Zoning is therefore aimed at reserving the designated floodway or establishing the encroachment lines which should be adequate for the passage of major floods without unduly raising upstream water surface elevations. Flood hydrographs of major floods up to the zoning level are allowed free unhindered passage within the encroachment lines.

An important and effective adjunct to floodplain zoning protection is *flood proofing measure*, taken to render existing or proposed structures, property and grounds less vulnerable to flood losses. Flood proofing is defined as the combination of *structural* changes and *adjustment* to properties subject to flooding, primarily for the reduction of flood damages.

Outside the designated floodway, *controls* are necessary over development in restrictive zones to permit the most effective use of land without undue risk of damage from flooding. Controls may be accomplished by limiting the type of land use, filling the land, elevating structures, or other measures. The important criteria for use of the areas along both sides of the designated floodways (the restrictive zones) are (1) minimum elevations for floors, fills and other improvements and (2) provision for local drainage. Hence the *structural code* could establish minimum elevations below which floors of structures in these restricted areas would not be permitted. The minimum elevations should be related to a *selected* flood profile in order that the risk at all points along the river will be uniform and have the same probability. This water surface profile should be determined by consideration of the local flooding probabilities. Building codes and floodplain regulations must be related to flood velocities which are often an important consideration.

The role of *educating public opinion* and changing public attitudes is of crucial importance. Since most communities want economic growth and will not long support programs which retard it, they would rather prefer structural flood control measures to other nonstructural measures which includes flood proofing, zoning, coding and other floodplain regulations. But floodplain regulations covering zoning ordinance, subdivision regulations, building code, flood proofing, or other regulations adopted by the respective government body are to assure the orderly development of the community for the greatest *benefit of all*.

Of crucial importance to the zoning measure in determining designated floodways is the zoning flood standard. There has been a dilemma facing the legislative decision-making process whether to adopt the 100 year flood frequency as the minimum standard in the United States. But the kind of zoning restriction and standard criteria must be in keeping with the *changes* in vulnerable property located in the floodplain. White (1973) has identified, for example, the Gulf and the Atlantic coasts of the United States as the most rapidly growing site for catastrophic events in the United States. The rates of growth in those areas in the 50 and 100 year flood frequency zone are 4, 5 or 10 times as great as in adjoining higher elevation areas. Depending on the random occurrences of floods, the first areas will be the sites for enlarged catastrophes. Some political pressure has been used to question the *reasonableness* of a 100-year flood level, which is being used as a basis for floodplain regulation and rates assessment for flood insurance.

There is an optimum national tradeoff between the protection standard and the changes in vulnerable property being located more and more in floodplains. The national tradeoff is between (1) and (2):

(1) a lowering of flood protection level increases the probability of a damaging flood: a) damages to property will be greater because of increased flood depths and velocities of flood waters, coupled with a longer flood duration; b) increased damages to public facilities, since they would have to be placed at a lower elevation and increased threat to life and health. Rescue and relief measures may become increasingly difficult. (Wright, 1973)

(2) raising the flood protection level involves a greater sacrifice of the economic value of land and a greater loss of existing beneficial commercial, industrial and transportation activities.

Questioning the proper flood level for regulatory purposes, confronts the philosophy revolving around two central issues:

(1) What should be the desired allocation of costs when flood damages occur?

(2) What is a reasonable protection level for life and health?

The first question involves a greater subsidy to floodplain occupants if flood protection level is lowered. The second question is related to whether assistance should be given in the event of catastrophic losses from rare flood events or for cases of regular flood losses which occur on a more predictable basis, and against which such losses could have been avoided through proper prior action. However, the national optimum has not yet been established, and a 100 year minimum zoning standard is being adopted on an ad hoc basis for regulatory purposes.

(b) Statements of Objectives. The objective is to maximize the expected annual net benefit resulting from the adoption of flood zoning, flood proofing and land-use measure, i.e.

$$\max.\ [NB^Z]_{ijt\lambda} = [B_a^Z]_{ijt\lambda} - [C_a^Z]_{ijt\lambda} \qquad (3\text{-}15)$$

where $[NB]^Z$ = the expected annual net benefit from flood-zoning, etc.; Z = the adoption of zoning etc.; i = an index denoting a specific land use; j = an index denoting a specific location and t = an index denoting a specific time period, during which development for land use i may begin to occur at a site at location j. B_a^Z and C_a^Z are the expected annual benefit and cost resulting from adoption of the zoning and flood-proofing measure, for a given regulatory flood hazard standard λ.

(c) The Performance Models. The economic productivity of an individual parcel of land subject to land use regulation in the floodplain can be assessed by an approach, '*with and without zoning measure*'. The expected annual flood damage with no zoning measure (NZ), is $\varepsilon[D]_{ijt}^{NZ}$, where i,j and t have been defined previously. With the adoption of the zoning, landfill and floodproofing measure (WZ), however, the expected annual residual flood damage is $\varepsilon[D]_{ijt}^{WZ}$.

The expected annual benefit of the measure is therefore $B_{ijt}^Z = \varepsilon[D]_{ijt}^{NZ} - \varepsilon[D]_{ijt\lambda}^{WZ} = [X^{DR}]_{ijt\lambda}$ which is the benefit of flood damage reduction (DR) for land use i, location j and time period t.

The expected annual cost of the zoning measure is

$$[C_a^Z]_{ijt\lambda} = [C_\ell^Z]_{ijt\lambda} + [C_p^Z]_{ijt\lambda} + [C_f^Z]_{ijt\lambda} \qquad (3\text{-}16)$$

where C_a^Z = the expected annual cost of the zoning measure for land use i, location j and time t, with a flood hazard λ; C_ℓ^Z = the expected annual cost of land value sacrificed under zoning regulation; C_p^Z and C_f^Z are respectively the expected annual cost of flood proofing and filling.

Therefore the expected annual net benefit of the zoning measure is:

$$[NB^Z]_{ijt\lambda} = [B_a^Z]_{ijt\lambda} - [C_a^Z]_{ijt\lambda}$$

$$[NB^Z]_{ijt\lambda} = [X^{DR}]_{ijt\lambda} - [C_\ell^Z]_{ijt\lambda} - [C_f^Z]_{ijt\lambda} - [C_p^Z]_{ijt\lambda} \qquad (3\text{-}17)$$

Mathematical Submodels. A mathematical submodel of an *urban floodplain* has been developed (Bhavnagri, and Bugliarello, 1965) for: (a) formulating computations of flood damages to an urban area and (b) studying the effects of both economic characteristics of the floodplain and flood probability on the damages.

The urban floodplain is divided up into contour intervals and in each of these contour intervals are various types of residential and commercial structures subject to flooding. It is hypothesized that direct damage to the contents of structures and sometimes to the sturctures themselves form the most significant fraction of total damages, and that among the factors governing direct damage, *depth* of flooding is the most significant.

A mathematical submodel of an *agricultural rural floodplain* for formalizing computations of agricultural flood damages has also been developed (Kinori, 1973). It is hypothesized that direct damage is influenced by two factors: 1) the area A inundated by flood waters and 2) the duration of flooding t, where t is the time of flooded condition (flooding + stagnation + recession).

Using the analogy of the unit damage function of the urban floodplain submodel, the flood damage to a given agricultural crop is:

$$d(A,t) = K_{crop}\,\delta(A,t), \qquad (3\text{-}18)$$

where $\delta(A,t)$ is the unit damage function denoting the manner in which flood inundation causes damage to any given agricultural crop, and K_{crop} is the individual characteristic damage in dollars, and is constant for any given crop but unlike δ, varies from crop to crop.

The hypothesis given above, that the depth of water on the floodplain having only a secondary effect on the loss of agricultural yield seems justified.

After the crop has been totally covered by flood water, it is rather the time t of flooded condition and the overflooded area A than the additional flood water depth that determines the primary cause of total or partial destruction of the crop.

The Submodel for the Test Area. The economic model for the test area, the Arkansas River Basin, is modified from the general economic model outlined earlier. The model performance is based on Fig. 3-6 which shows that for a given zoning standard λ, the altered damage-state curve results in a modified damage-frequency curve.

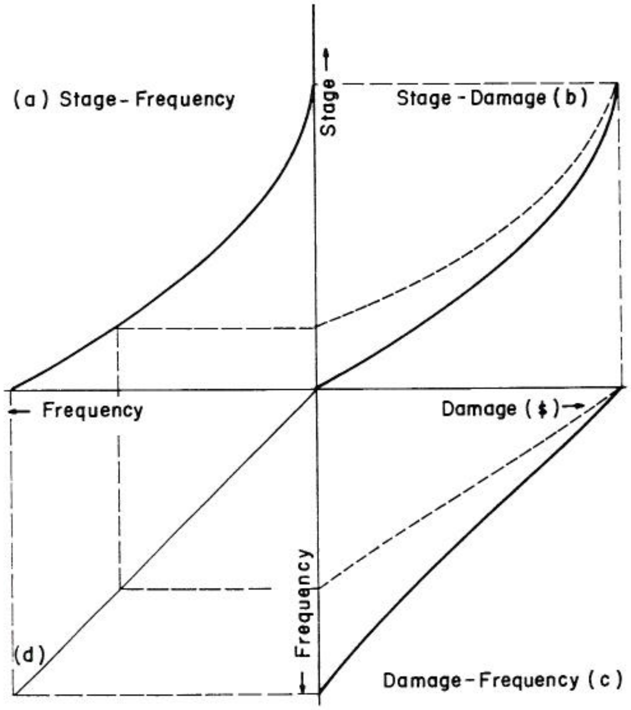


Fig. 3-6 Prohibitory Zoning and Flood Insurance

The expected annual net benefit of the zoning measures is

$$[X^{DR}]_{ijt\lambda} = \varepsilon[D]^{NZ}_{ijt} - \varepsilon[D]^{Z}_{ijt\lambda}, \qquad (3\text{-}19)$$

and λ is the flood frequency standard used in defining the floodplain encroachment levels. λ is varied at twelve flood frequencies 5, 10, 25, 50,..., 225 and 250 years in order to establish the optimum zoning criteria and to compare this local optimum with the 100 year regulatory standard.

The expected annual cost of zoning is obtained by amortizing the capital cost of urban land that comes under zoning restriction for a 100 year period at a discount rate of 7 percent.

The cost of the zoning measure is therefore:

$$[C^{Z}_{\ell}]_{ijt\lambda} = \{([C^{Z}_{TNLC}]_{ijt\lambda} \cdot C_{CRF}) + [C^{Z}_{TANL}]_{ijt\lambda}\} \quad (3\text{-}20)$$

where C^{Z}_{ℓ} = the net annual loss of capital, income and production; C^{Z}_{TNLC} = the total net loss of capital as a result of changes by zoning, and C^{Z}_{TANL} = the net annual loss of income and production due to zoning: C_{CRF} = the capital recovery factor.

It is assumed that C^{Z}_{TANL} is zero in the cost model, because the loss of income and production could presumably be balanced by locating activities above the restriction level of zoning code.

Two criteria are used for evaluating the net loss of land capital, C^{Z}_{TNLC}: 1) for the central business district of Pueblo, the average price of land is estimated to be $42,110 per acre (value established in 1967 by the Corps of Engineers), and 2) for all other suburban areas, excluding Colorado Springs, the land value assessed is $8,422 per acre. The cost model for land is taken to be $1.0[V_L]_\lambda$ and $0.2[V_L]_\lambda$, for items (1) and (2) respectively, where V_L is the present worth of land so sacrificed under zoning standard λ.

(d) The Results of the Model's Analysis as Applied to the Particular Test Basin, the Arkansas River Basin. The results of the analysis on land use and zoning indicate:

(1) The problem area is the central business district of Pueblo, situated right on the low-level floodplain at the confluence of the Arkansas River and the Fountain Creek.

(2) Only communities of Cotopaxi, La Junta and Rocky Ford could sustain the 100-year flood standard, given the assumptions of this analysis.

(3) Heavy encroachments of floodplains are apparent at: Chandler and Oak Creek, Coal Creek, Portland in Fremont County, central business district of Pueblo, Day Creek at Pueblo County; King's and Andersen Arroyo in Otero County.

(4) The tabulated results are shown in Tables 3-4 and 3-5.

3.4 Physical Control Measures

The physical flood control comprises two major subclassifications: 1) extensive and 2) intensive measures.

Extensive Flood Control Measures.

(a) General Description. The extensive measures are related to land treatment with the objectives to attenuate flood peaks by longer water retention on the surface, to reduce sediment load and to maintain other desirable streamflow conditions. Extensive control may also be defined under the following categories: 1) vegetative-biological cover control, 2) general soil control, and 3) snow management.

(1) Vegetative-biological cover control through jungles, forests, grasslands and arable lands. The beneficial effect of vegetal cover is in retarding or hindering runoff for minimizing overland flow, runoff and erosion. The jungles and forests humus covers are the best and the order of flood peak attenuation decreases as one goes from jungles and forests to grasslands and arable lands. In fact there is no overland

TABLE 3-4 OPTIMUM ZONING LEVEL

FREEMONT COUNTY

Location	Annual Net Loss of Capital ($)	Benefit of Zoning $	Net Benefit $	B/C	Zoning Level (Years)
Florence	7,554	16,631	9,077	2.20	75*
	8,057	17,108	8,601	2.12	100
	9,568	18,171	8,603	1.90	200
Cotopaxi	5,576	6,463	887	1.16	125*
	5,147	5,689	542	1.11	100
	6,862	7,219	357	1.05	200
Chandler & Oak Creek	49,875	146,909	97,034	2.95	50*
	61,385	156,050	94,665	2.54	100
	72,895	161,608	88,713	2.22	200
Coal Creek	10,321	10,073	-248	0.98	50
	13,568	12,188	-1,380	0.90	100
	15,086	13,708	-1,378	0.91	200
Portland	16,098	23,744	7,646	1.47	25*
	29,777	31,046	1,269	1.04	100
	35,410	33,128	-2,282	0.94	200
PUEBLO COUNTY					
Fountain Creek (below 8th bridge)	77,065	137,816	60,751	1.79	25*
	161,837	179,946	18,109	1.11	100
	200,369	189,517	-10,852	0.95	200
		Central Business District, Pueblo			
Fountain Creek (above 8th bridge)	166,498	0	-166,498	0	5 no zoning
	1,248,699	57,275	-1,191,424	0.05	100
	1,581,653	82,645	-1,499,008	0.05	200
Dry Creek	938	0	-938	0	5 no zoning
	17,823	565	-17,258	0.03	100
	20,637	1,049	-19,588	0.05	200

*Asterisk indicates optimum

TABLE 3-5 OPTIMUM ZONING LEVEL

OTERO COUNTY

Location	Annual Net Loss of Capital ($)	Benefit of Zoning $	Net Benefit $	B/C	Zoning Level (Years)
King's Arroyo	6,393	6,535	142	1.02	25*
	10,656	8,768	-1,888	0.82	100
	12,432	9,961	-2,471	0.80	200
Anderson Arroyo	1,942	12,371	10,429	6.37	10*
	5,827	14,171	8,344	2.43	100
	6,937	14,596	7,659	2.10	200
La Junta & N.Y. Junta (reach 2 urban)	94,882	214,328	119,446	2.26	100*
	114,857	231,816	116,959	2.02	200
Rocky Ford	11,759	25,301	13,542	2.15	100*
	13,897	26,761	12,864	1.93	200

*Asterisk indicates optimum.

flow for jungle and forest covers since the undergrowth and biological humus cover only allow interstitial or interlayer flow. Overland flow is of hydrologic importance for two reasons: a) it moves quickly to stream channels, thereby creating the flashiest flood peak and b) by virtue of its velocity, it has the capacity to detach soil particles and is therefore an important agent in eroding soil and impairing water quality by increasing turbidity. Hence the velocity of overland flow largely determines its flood and erosion potential. Therefore flood and sediment runoff from grasslands and arable lands generally exceeds that from jungles or forest lands, all other things including location being equal. Land use effects vary immensely when jungle or forested areas are compared to arable croplands (Tai, Prediction of Floods from Small Watersheds with Limited Hydrologic Data, 1973).

(2) General soil control. The general measures on soil erosion and sedimentation control are aimed at restoring the biological-vegetative cover and putting the arable land into proper erosion-resistant topology. Two categories of soil control measures are classified by Thronson (1973): a) vegetative measures and b) structural measures. In actual practice a combination of the two categories are employed to suit the requirements of the particular site. Vegetative measures include planting perennial grasses; annual cover; trees, shrubs and vines; and mulches (organic and inorganic) to support vegetation and protect soil. Structural measures include: small flood control dams, dikes and levees; stream channel improvements and bank stabilization works; sediment basins and outfall structures; terraces, diversion structures and channels; grassed waterways and outlets. Such structural measures are usually required for effective control of channel erosion, while vegetative land measures generally are adequate to control sheet erosion and wind erosion. (Moore et al., 1968)

(3) Snow management is another approach that should be considered when economically feasible. Snowmelt floods could be reduced in severity by delaying snowmelt and by increasing forest cover since forest cover also delays snowmelt by shading. (Lull, 1972)

Although land treatment measures have only a partial effect in reducing downstream floodwater, erosion and sediment damages, nevertheless, such work does have a significant local effect on the less intense but more frequent storms which cause the bulk of the average annual damages. Two general results are discernible: 1) land treatment measures have their greatest influence on the shorter duration storms which occur more frequently on the smaller watersheds and 2) as the duration of storms increases, the amount of reduction in runoff by land treatment measures becomes less than the original total direct runoff. (Moore et al., 1968)

Land treatment and overall structural measures installed on upland watersheds and therefore the first line of *defense* against uncontrolled runoff and sediment production. The principle of watershed land treatment is therefore to productively use the greatest amount of rainfall, conserve much of the surplus, and to dispose of unretardable excess water to prevent flood damage, erosion and maintain waterways free of silt. This is almost restoring the environment as close as possible to its natural undisturbed state.

(b) Statements of Objectives. Since extensive physical flood control measures are aimed at reducing the flood and erosion potential, not only are there more benefits arising out of reduction in flood damages, erosion and sedimentation damages but also the more positive factors, conservation of water surplus and maintenance of stream purity and environmental quality.

The objective is therefore to maximize the expected annual net benefit of the watershed land management program i.e.

$$\max.\ NB_a^{(LM)} = B_a^{(LM)} - C_a^{(LM)} \tag{3-21}$$

where $NB_a^{(LM)}$ = the expected annual net benefit of the watershed program; $B_a^{(LM)}$ and $C_a^{(LM)}$ are the expected annual benefit and cost of the watershed measure respectively; LM = an index denoting land management.

(c) The Performance Models. The performance models will be discussed under the *hierarchical-multilevel* approach which allows for large scale and complex systems of large watersheds to be decomposed into subsystems where each is separately and independently optimized. The first level of solution is joined by coupling variables manipulated by second level controls (Haimes, 1972).

The multilevel optimization technique first optimizes the performance of each decomposed subsystem and the maximization of the total system's performance is coordinated at a higher level to obtain the overall optimal policy. Decomposition and multilevel techniques are promising with room for flexibility and consideration for primary and secondary benefits of watershed extensive control.

The performance submodels are based on the principles of Buras (1962) integrated with the outlines of the second-level model given by Yacov (1972). The allocation model is solved via dynamic programming technique. (Fig. 3-7)

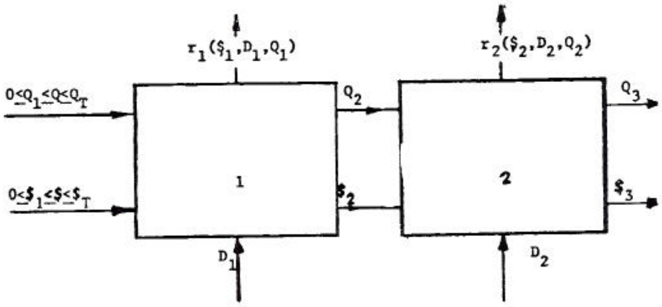


Fig. 3-7 Two Dimensional State Variables Dynamic Programming.

The function $f_1^{j_1}(Q,\$)$ is the maximum net benefit return function from allocating fund \$ for flood peak Q in the subsystem 1. The net benefit return comprises two components: a) the primary benefits of reducing flood and erosion damages and b) the secondary benefits of preserving or promoting stream water quality and environmental quality. Therefore

$$f_1^{j_1}(Q,\$) = \max_{\substack{0\le Q_1\le Q\le Q_T\\ 0\le \$_1\le \$\le \$_T\\ \ell_1 \in J}} [g_1(Q_1,\$_1,D_1,\ell_1;\lambda) + \phi(T(Q_1,\$_1,D_1,\ell_1;\lambda)] \qquad (3\text{-}22)$$

in which $g_1[Q_1,\$_1,D_1,\ell_1;\lambda]$ is merely the primary net benefit return function, where Q_1 = the flood peak reduction or attenuation due to the extensive measure of the subsystem; $\$_1$ = the amount of fund allocated to the subsystem ℓ_1 and λ = the pricing level. $\phi[T(Q_1,\$_1,D_1,\ell_1;\lambda]$ is the secondary net benefit return function, where $Q_1,\$_1,D_1,\ell_1$ and λ are symbols previously defined, but it denotes the return from preserving or transforming stream water and environmental qualities. Hence the expected net return expressed on an annual basis is:

$$r_1^{j_1}(\$_1,D_1,Q_1) = g_1(Q_1,\$_1,D_1,\ell_1;\lambda) + \phi_1(T(Q_1,\$_1,D_1,\ell_1;\lambda)) \qquad (3\text{-}23)$$

for the subsystem 1, where ℓ_1 = the extensive measure; j_1 = a vector of sample choice in the selection of elements of the extensive measure and J is the set space of feasible extensive measures.

Similarly for subsystem 2, the net benefit return function can be expressed as

$$f_2^{j_2}(Q,\$) = \max_{\substack{0\le Q_2\le Q\le Q_T\\ 0\le \$_2\le \$\le \$_T\\ \ell_2 \in J}} [g_2(Q_2,\$_2,D_2,\ell_2;\lambda) + \phi\,(T(Q_2,\$_2,D_2,\ell_2;\lambda)) + f_1^{j_1}(Q_1,\$_1,D_1,\ell_1;\lambda)] \qquad (3\text{-}24)$$

The *general* recursive relationship for the serial subsystem 1 to N is therefore:

$$f_1^{j_1}(Q,\$) = \max_{\substack{0\le Q_1\le Q\le Q_T\\ 0\le \$_1\le \$\le \$_T\\ \ell_1 \in J}} [g_1(Q_1,\$_1,D_1,\ell_1;\lambda) + \phi(T(Q_1,\$_1,D_1,\ell_1;\lambda))]$$

$$\vdots$$

to

$$\vdots$$

$$f_N^{j_N}(Q,\$) = \max_{\substack{0\le Q_N\le Q\le Q_T\\ 0\le \$_N\le \$\le \$_T\\ \ell_N \in J}} [g_N(Q_N,\$_N,D_N,\ell_N;\lambda) + \phi(T(Q_N,\$_N,D_N,\ell_N;\lambda)) + f_{N-1}^{j_{N-1}}(Q_{N-1},\$_{N-1},D_{N-1},\ell_{N-1};\lambda)] \qquad (3\text{-}25)$$

Coordination of the Submodels. Coordination of the subsystems' performances is necessary with the total system covering the entire extensive subbasins. A balance coordination method is necessary for achieving an overall system optimum. The balancing is done at the second level with the total expected annual net benefit $B^{(LM)}_{(\$,Q)}$ for the entire watersheds system summed, i.e.,

$$B^{(LM)}_{(Q,\$)} = \sum_{k=1}^{K} f_{I,k}^{j_I}(Q_k,\$_k) \qquad (3\text{-}26)$$

where $f_{I,k}^{j_I}(Q_k,\$_k)$ = the total annual maximum benefits from the subsystems, with flood peak reduction parameter Q_k, and investment fund $\$_k$; I = the number of subsystems in the basin; j_I = the choice of measure in each subsystem and LM = an index denoting extensive land measure control.

The total system cost is $C^{(LM)}_{(Q,\$)}$, where

$$C^{(LM)}_{(Q,\$)} = \sum_{k=1}^{K} C_{I,k}(Q_k,\$_k)\ . \qquad (3\text{-}27)$$

The goal of the third level is to adjust demands of flood and erosion damages and environmental and water quality requirements with the available supplies in funds, and hence the objective is to maximize the annual net benefit of the total system to enhance regional development, i.e.

$$\max.\ NB^{(LM)} = B^{(LM)}_{(Q,\$)} - C^{(LM)}_{(Q,\$)}\ . \qquad (3\text{-}28)$$

subject to fund availability $0 \le \$ \le \$_{Total}$.

The Submodels for the Test Area. The submodels chosen for the test area are limited to erosion and sedimentation because data on flood peak attenuation were not available to the writer. The Soil Conservation Service maintains a few scattered upland watershed projects but the relatively large ones are situated outside of the relevant countries of this study.

Since water and wind erosion in the Arkansas River basin is the second most serious of all river basins in the State of Colorado and since erosion and sedimentation affect the main stem of the Arkansas and all adjoining tributaries, the submodel selected is the mathematical linear programming model to assess annual sediment damages sustained in the relevant countries. The effect of downstream flood peak attenuation due to upstream extensive physical control of upland watersheds is expected to be relatively small in comparison to erosion and sediment damages along the main stem of the Arkansas River and the adjoining irrigated floodplains.

The objective function is to *minimize* the annual sediment yield, given the present constraints of different rates of sediment yield for different watersheds:

$$\begin{aligned} &\text{Minimize } \underline{C}\ \underline{X}\\ &\text{subject to } \underline{A}\ \underline{X} = \underline{b}\\ &\text{and } \underline{X} \ge 0 \end{aligned} \qquad (3\text{-}29)$$

where $\underline{X}$ = the column vector of watershed areas; $\underline{A}$ = the matrix of coefficients expressed in terms of sediment yield rate; $\underline{b}$ = the column vector of average annual sediment yield, for the constraint relationship, and $\underline{C}$ = the row vector of sediment yield rate in the objective function.

$\underline{C}$ values are assumed to be: a) 0.37 acre-ft per square mile and per year for mountainous and foothills areas and b) 1.00 acre-ft per square mile and per year for the plains. These are Corps of Engineers assumed values.

(d) The Results of the Model's Analysis as Applied to the Particular Test Basin, the Arkansas River Basin. The results of the analyses on annual sediment damage is relatively significant in relation to flood damage. The linear programming assessment model assumes a unit damage rate of $115/60¢ per acre-ft: this is the rate recommended by the Corps of Engineers for their sediment detention storage for the Fountain Creek Dam (Corps of Engineers, 1968 and 1969). If sediment damage rate is assessed at 10¢ per cubic yard, an acre-foot is $161/33¢, which is therefore a higher damage rate than the Corps of Engineers' figure. Nevertheless the Corps' figure is used in keeping with design values for the test area, and estimating the effects of sediment damage in the following categories: 1) the loss of reservoir capacity in relation to already established sediment control structures, the Pueblo and John Martin dams and the proposed Fountain Dam; 2) the loss of river capacity at high and low flows; 3) the increased annual costs of cleaning the irrigation canals and 4) the cost of repeated releveling of irrigated fields. The attached Table 3-6 shows the summary of sediment damage.

The agricultural sector sustains nearly twice as much damage from sediment as the urban sector (46 percent to 25 percent), due to heavy use of irrigation water loaded with sediments. The annual average removal of suspended sediment from the Arkansas River between Pueblo and Los Animas is 3,800 acre-ft for the river length of about 80 miles.

The sediment problem is treated in this analysis since no data is available basin-wide to estimate the effect of upland extensive control on flood peak attenuation. Since the effects of upland extensive measures are felt only on the shorter duration storms over localized watersheds, and their effects diminish as storm durations increase, effects of land-use changes on peak discharges are not as large.

The effects are greater only when deforestation of a natural watershed to agricultural cover crop takes place. These vegetative-biological cover changes of the forest appear to cause a larger increase in the flood peak of the unit hydrograph than is the case of changing agricultural practices for a given size of watershed (Tai, 1973).

Intensive Flood Control Measures.

(a) General Description. Intensive measures on flood control are all those engineering works which are related to intensive physical control of confining, retaining, and channeling of flood waters.

Failure to recognize the nature of the flood threat and the limitation of engineering works has downgraded the proper role of structural flood control works. All physical flood control works are effective in protection of life and property from floods as long as their performance capacities are not exceeded. [Leopold and Maddock, 1953; Hoyt and Langbein, 1965; Kuiper, 1965].

The precise advantages of structural elements in flood control are not sufficiently emphasized. The direct advantage of *levees* is the protection of the area where the greatest protection is required. However, if the levees are overtopped, the damage from flooding becomes as great, or even greater, when no dikes had existed at all. In contrast to dikes or levees, *channel diversions* increase their beneficial effect when the design flood is exceeded. The higher the flood stage, the larger the capacity of the diversion. Diversions, like dikes, will perform their

TABLE 3-6 TOTAL AVERAGE ANNUAL SEDIMENT DAMAGES ESTIMATED WITH AND WITHOUT THE THREE DAMS

Sediment Damage (by spectra)	Fremont ($)	El Paso ($)	Pueblo ($)	Crowley ($)	Otero ($)	Bent ($)	Total ($)
		With Dams (Pueblo, Hueferno, and John Martin Dams)					
Agricultural Sector	119,877	87,624	164,730	101,381	219,640	54,910	748,162 (46%)
Urban Sector	69,243	38,840	118,490	12,946	135,714	24,854 293,277*	400,087 (25%)
Total	189,122	126,466	283,220	114,328	355,354	373,041	1,441,531
			Without The Dams				
Pueblo Dam	--	--	40,261	24,778	53,681		118,720 (7%)
Hueferno Dam	--	--	20,032	12,329	26,710		59,071 (4%)
John Martin Dam	--	--	--	--	--		293,277* (18%)
					Total Sediment Damage		1,619,318

Note: The starred value of $293,277* is due to loss of sediment storage in John Martin Dam. The value is included in Bent County, as the location of damage is situated there, though the benefit of sediment storage is felt downstream of the John Martin Dam. The starred value is to caution against double accounting.

function regardless of the duration of the flood. The effect of *channel improvements* is much the same as that of diversions. When the design flow is exceeded, the channel improvement remains effective. The type of channel improvement and the channel characteristics influence the extent of stage reduction. The effectiveness of a flood control *reservoir* depends on two factors: 1) *duration* of the flood, and 2) the *magnitude* of the flood. Design capacity of the flood control reservoir may be exceeded in duration or in magnitude, e.g. a reservoir designed with the same peak flow may not be able to accommodate a flood with a much larger duration base, and the reservoir may be full by the time the peak arrives, with the result that minimal storage capacity is left to reduce the peak. The converse argument is true for a flood that has the same duration but exceeds the design peak capacity. Hence, flood control reservoirs perform their function well, as long as floods do not exceed the reservoir design flood in peak flow or in duration. When the design flood is exceeded, the beneficial effect of reservoir is gradually reduced, until it may become practically nil for extremely large floods. One more additional factor affects the effectiveness of a flood control reservoir, and that is the relative distance between the reservoir and the area to be protected. Two reasons are given why distance reduces effectiveness: 1) the probability that floods will originate in parts of the drainage basin that are not controlled by the reservoir and 2) the flood peak may be attenuated by natural channel storage (Kuiper, 1965). Without the reservoir, for example, let it be assumed that under natural conditions, a flood peak of 100,000 cfs passes the prospective reservoir site and is reduced to 60,000 cfs by natural channel storage by the time the flood hydrograph reaches the area to be protected. With the reservoir, the flood peak of 100,000 cfs is reduced to a safe bankfull discharge of say 20,000 cfs which is not further reduced by natural channel storage. As far as the area to be protected is concerned, the effectiveness of the reservoir is a peak flow reduction of 40,000 cfs and not 80,000 cfs.

The intensive measures are now *defined* in their order of capacities and costs.

Levees and dikes are the oldest structural measures of flood control because of their low initial cost and simple technology. Levees or earth dikes are usually made of random earth fill and are used to confine streamflow within a specified area along the stream. However there may be higher maintenance cost, especially where floods occur annually. The 10-year-flood frequency is a common protection level for agricultural land.

Channel improvements are taken to include intensive measures such as: 1) increased channel capacity; 2) parallel channels and 3) diversion channels. The common objective is to increase the capacity of an existing channel. The general criteria for all channel improvement is to avoid significant increases in downstream peaks or downstream stages and to avoid degradation of the upstream or downstream channel systems.

Increasing channel capacity is one of the ways to control floods by: 1) widening or deepening channels to increase the flow area; 2) shortening the meandering channels to increase the slope; and 3) shaping them to decrease the relative roughness. Hence all channel capacity improvements are related to four hydraulic factors: flow area, hydraulic radius, slope and relative roughness. In addition, improving channel capacity is very much connected with the control of bank erosion and maintaining an equilibrium sediment-carrying capacity.

Parallel channels have been successfully used when an increase of the capacity of the main channel is not practicable. The flood water is divided into two or more branches and the flood levels are thus decreased.

Diversion channels are new channels diverting the flood waters either into inland lakes or directly into the sea or even into off-channel reservoirs. The diverted water is not usually returned into the channel from which it is diverted.

Floodplain polders are flood-prone areas encircled by dikes with sufficient pumping stations to pump all infiltrated water and rainfall out of that area during the passage of a flood wave; or if the polders are relatively large in number, each of them is regarded as a separate unit since each has approximately the same elevation within its own boundaries. Each polder will therefore have its own drainage system, with its own ditches and canals and its own drainage outlet upon exterior watercourses (Kuiper, 1965).

Floodplain earth platforms are earth platforms inside floodplains so that the critical and most damage-prone activities within the floodplains are located above the highest estimated water levels during rare floods of a given probability of occurrence.

Reservoirs for flood control are supplemental means of providing flood protection when the natural reservoir storage potential of a watershed may not provide as much storage as is needed (Rutter, et al. 1964).

The amount of storage required depends upon the degree of protection needed and the nondamaging capacity of the stream channel. Hitherto the desired degree of protection determines the magnitude of the flood adopted as a basis for reservoir design. It appears to the writer that a protection syndrome has existed where "complete" protection is accepted as the maximum probable flood to prevent loss of life or disastrous property damages.

Two types of reservoirs are classified: 1) surface reservoirs conceived as spaces procured in valleys or other areas with new spaces predominantly above but not excluding the floodplains and 2) underground reservoirs in some karst areas where underground storage may be used for flood control.

The effect of storage is to decrease the flood peak without actually eliminating any of the volume of flood water. The advantages of surface reservoirs are: 1) a longer and larger volume of water can be held behind a dam for each successive increment of height, hence it might be cheaper to build a multi-purpose reservoir than a single-purpose flood-control reservoir, and 2) it is effective in reducing flood peaks in the reach of streams immediately below the dam. The disadvantages are requirements for sediment storage, excessive cost of spillways, and relatively large land areas needed for water storage. A controversy has existed earlier between upstream reservoir flood-control and downstream main stem flood control. Leopold and Maddock (1954) have pointed out that a system of upstream reservoirs cannot replace protective works downstream, nor is the reverse true.

Release basins are parts of the floodplains utilized to accept the flood peaks with a minimum of damage, thus decreasing the flood peaks downstream. Provisions are required in providing the intake structures for filling the release basins and the outlet structures to empty them when downstream conditions allow for such releases. Some natural or artificial inland lakes could be used as release basins provided the flood damage to adjoining areas of the lakes is negligible.

(b) Statements of Objectives. The objective is to maximize the annual net benefit of the intensive measures such that

$$NB_a^{(IM)} = B_a^{(IM)} - C_a^{(IM)} \tag{3-30}$$

where $NB_a^{(IM)}$ = the expected annual net benefit of the structural measures; $B_a^{(IM)}$ and $C_a^{(IM)}$ are the expected annual benefits and costs of the measures, and IM = an index denoting intensive measures are used.

Dynamic programming of the resource allocation type appears eminently suitable for the evaluation of the stagewise optimum. This systems approach combines the analysis of performance characteristics at each individual stage with the synthesis of their final performance in the set of selected flood control measures. Its potential lies in the analysis-synthesis aspect of mathematical programming, as a technique-oriented solution rather than a specific optimization.

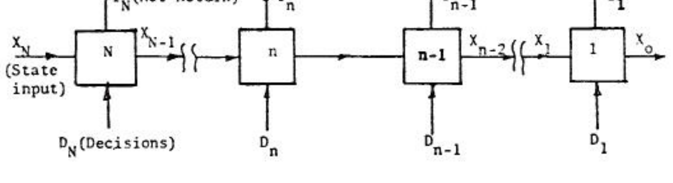
(c) The Performance Models. The performance models of intensive measures modeled in accordance with the resource allocation type are divided into two broad categories:

(1) those affected by hydrologic independence and

(2) those that are not.

The performance model will be established in accordance to first basic principles of dynamic programming for the simpler case first, case (2) above, for the subsystems of intensive measures that allow free passage of the flood peaks without creating hydrologic dependence between their subsystems. Levees and dikes, and increased channel capacity are typical examples.

(1) Basic modeling without hydrologic dependence in the serial subsystems. The one-dimensional state dynamic programming is:



The maximum N-stage return $f_N(X_N)$ is

$$\text{I: } f_N(X_N) = g[r_N(X_N^*,D_N^*), r_{N-1}(X_{N-1}^*,D_{N-1}^*),\dots,r_1(X_1^*,D_1^*)]$$

$$= \max_{D_N,\dots,D_1} g[r_N(X_N,D_N),\ r_{N-1}(X_{N-1},D_{N-1}),\dots,r_1(X_1,D_1)] \tag{3-31}$$

subject to $X_{n-1} = t_n(X_n,D_n)$, $n=1,\dots,N$.

The objective is to decompose formulation I with N decision variables, N state variables and N constraints into N equivalent subproblems, each containing only one decision variable and one state variable.

Each of the subproblems is roughly equivalent to a one-state optimization problem. Hence, instead of solving one big optimization problem, in which all of the decisions are interdependent, the optimal decisions are found almost one at a time.

To quote Nemhauser (1966), the analysis-synthesis principle is apparent:

> "Our approach is the familiar one of using multistage analysis *first* to decompose the original problem into N subproblems. *Then* the solutions from the subproblems are combined to obtain the solution to the original problem."

The decomposition problem with additive returns has a highly restrictive constraint: the return from any activity is independent of the allocations to the other activities. (Bellman et al., 1962).

(i) If function g is decomposed then

$$g[r_N(X_N,D_N),\ r_{N-1}(X_{N-1},D_{N-1}) + \dots + r_1(X_1,D_1)]$$

$$= r_N(X_N,D_N) + r_{N-1}(X_{N-1},D_{N-1}) + \dots, + r_1(X_1,D_1), \tag{3-32}$$

then the maximum N stage-return is

$$f_N(X_N) = \max_{D_N,\dots,D_1} [r_N(X_N,D_N) + r_{N-1}(X_{N-1},D_{n-1}) + \dots + r_1(X_1,D_1)] \tag{3-33}$$

subject to $X_{n-1} = t_n(X_n,D_n)$, $n = 1,\dots,N$.

(ii) With the constraint outlined above, that the N-th stage return does not depend on $D_{N-1},\dots,D_1$, and with the further assumption that for any arbitrary real-valued function $h_1(U_1)$ and $h_2(U_1,U_2)$,

$$\max_{U_1,U_2}[h_1(U_1) + h_2(U_1,U_2)] = \max_{U_1}[h_1(U_1) + \max_{U_2} h_2(U_1,U_2)] \tag{3-34}$$

then the maximum N stage return is *further* decomposed thus:

$$f_N(X_N) = \max_{D_N}[r_N(X_N,D_N) + \max_{D_{N-1},\ldots,D_1} (r_{N-1}(X_{N-1},D_{N-1}) + \ldots + r_1\ (X_1,D_1))] \qquad (3\text{-}35)$$

subject to $X_{n-1} = t_n(X_n,D_n)$, $n = 1,\ldots, N$.

(iii) From the definition of $f_N(X_N)$, it follows that

$$f_{N-1}(X_{N-1}) = \max_{D_{N-1},\ldots,D_1} [r_{N-1}(X_{N-1},D_{N-1}) + \ldots + r_1(X_1,D_1)], \qquad (3\text{-}36)$$

then $f_N(X_N) = \max_{D_N}[r_N(X_N,D_N) + f_{N-1}(X_{N-1})]$

subject to $X_{N-1} = t_N(X_N,D_N)$

or

$$f_N(X_N) = \max_{D_N}[r_N(X_N,D_N) + f_{N-1}(t_N(X_N,D_N))]. \qquad (3\text{-}37)$$

Defining:

$$Q_N(X_N,D_N) = [r_N(X_N,D_N) + f_{N-1}(t_N(X_N,D_N))]$$

$$f_N(X_N) = \max_{D_N} Q_N(X_N,D_N)$$

$$= \max_{D_N}[r_N(X_N,D_N) + f_{N-1}(t_N(X_N,D_N))] \qquad (3\text{-}38)$$

is a one-stage initial state optimization problem, considering the backward numbering of stages.

(iv) Hence the original N-stage problem is simplified into two smaller optimization problems:

$$(1)\quad f_{N-1}(X_{N-1}) = \max_{D_{N-1},\ldots,D_1} [r_{N-1}(X_{N-1},D_{N-1}) + \ldots + r_1(X_1,D_1)] \qquad (3\text{-}39)$$

subject to $X_{n-1} = t_n(X_n,D_n)$, $n = 1,\ldots, N-1$,

as an (N-1) - stage optimization, and

$$(2)\quad f_N(X_N) = \max_{D_N} Q_N(X_N,D_N) = \max_{D_N}[r_N(X_N,D_N) + f_{N-1}(t_N(X_N,D_N))] \qquad (3\text{-}40)$$

as a one-stage optimization.

(v) Stating the N problems more compactly:

$$f_n(X_n) = \max_{D_n} Q_n(X_n,D_n),\ n = 1,\ldots,N. \qquad (3\text{-}41)$$

$$f_n(X_n) = \max_{D_n} Q_n(X_n,D_n) = \max_{D_n} r_n(X_n,D_n),\ n=1$$

and

$$f_n(X_n) = \max_{D_n} Q_n(X_n,D_n) = \max_{D_n}[r_n(X_n,D_n) + f_{n-1}(t_n(X_n,D_n))],\ n = 2,\ldots,N \qquad (3\text{-}42)$$

Note the backward numbering of stages as against the forward multi-stage solution starting from $n = 1,2,\ldots,N$.

(2) Basic modeling with hydrologic dependence in the subsystems. The *one-dimensional state dynamic* programming model needs to be adapted when the subsystems of intensive measures behave with hydrologic dependence. Such typical examples are: 1) the combination of subsystems of a dam with levees, dikes or channels downstream, 2) parallel channels or diversion channels, 3) release basins as an off-stream adjunct to levees, dikes and channels and 4) floodplain polders and floodplain earth platforms which could alter or modify the passage of rare flood hydrographs. Such combinations of subsystems of intensive structural measures therefore call for *two-dimensional state* dynamic programming model with the additional state variable being expressed in terms of the flood peak or flood stage.

Nemhauser (1966) has given extensive coverage to various geometries of basic nonserial subsystems and any reader interested in the specific geometric requirement of his modeling problem could refer to his text. Four basic elementary nonserial systems are outlined: 1) a diverging branch, 2) a converging branch, 3) a feedforward loop and 4) a feedback loop.

However the objective of the modeling here is to build a general basic model exhibiting serial stagewise hydrologic dependence and the need for linking up variation of the subsystem nonserial structure is left to the particular requirement of each problem, in accordance to the selection of such types and sequence of structural measures and geometry. Note the order of numbering of stages and the order of solution are the same. (Fig. 3-8)

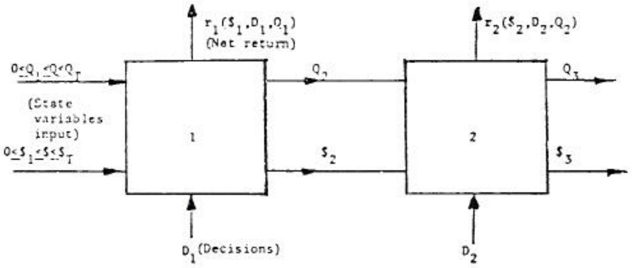


Fig. 3-8 Two Dimensional State Variables Dynamic Programming

The function $f_1^{j_1}(Q,\$)$ is the maximum expected annual net benefit from allocating fund \$ for flood peak Q, in the subsystem 1, beginning with the subsystem furthest at the upstream end.

$$f_1^{j_1}(Q,\$) = \max_{\substack{0\le Q_1\le Q\le Q_T \\ 0\le\$_1\le\$\le\$_T \\ \ell_1 \in J}} [g_1(Q_1,\$_1,D_1,\ell_1;\lambda)] \qquad (3\text{-}43)$$

where $g_1(Q_1,\$_1,D_1,\ell_1;\lambda)$ is the expected annual net benefit function and is equal to the subsystem return, $r_1(\$_1,D_1,Q_1)$ in the diagram just shown. Q_1 = the flood peak reduction or attenuation due to the subsystem interaction; $\$_1$ = the amount of fund allocated to the subsystem ℓ_1; D_1 = a decision variable (expressed in dollars) that controls the subsystem performance at 1; and λ = the pricing level. ℓ_1 = the intensive measure; j_1 = a vector of sample choice in the selection of structural elements of the intensive measure and J is the set space of feasible intensive measures.

The hydrologic flood peak variable Q could be interchanged with the hydrologic flood stage variable S, in case the system considers the flood stage rather than the flood peak variable to be more important. The basic performance of the two-dimensional state dynamic programming model does not change because of this replacement.

Now for subsystem 2 downstream of subsystem 1, the return function of expected annual net benefit is given by

$$f_2^{j_2}(Q,\$) = \max_{\substack{0\le Q_2\le Q\le Q_T \\ 0\le \$_2\le \$\le \$_T \\ \ell_2\ \varepsilon\ J}} [g_2(Q_2,\$_2,D_2,\ell_2;\lambda) + f_1^{j_1}(Q_1,\$_1,D_1,\ell_1;\lambda)] \tag{3-44}$$

where the symbols have their common significance as are previously defined for subsystem 1.

The *general* recursive relationship for the subsystems 1 to N interlinked in serial sequence is therefore

$$f_1^{j_1}(Q,\$) = \max_{\substack{0\le Q_1\le Q\le Q_T \\ 0\le \$_1\le \$\le \$_T \\ \ell_1\ \varepsilon\ J}} [g_1(Q_1,\$_1,D_1,\ell_1;\lambda)]$$

$$\vdots$$

to

$$\vdots$$

$$f_N^{j_N}(Q,\$) = \max_{\substack{0\le Q_N\le Q\le Q_T \\ 0\le \$_N\le \$\le \$_T \\ \ell_N\ \varepsilon\ J}} [g_N(Q_N,\$_N,D_N,\ell_N;\lambda) + f_{N-1}^{j_{N-1}}(Q_{N-1},\$_{N-1},D_{N-1},\ell_{N-1};\lambda)] \tag{3-45}$$

(d) The Results of the Model's Analysis as Applied to the Particular Test Basin, the Arkansas River Basin. In order for the writer to gain an insight into the process of dynamic programming, the one-dimensional state performance model is used to test the Corps of Engineers proposals (1968, 1969). With the confidence gained by this process, the writer applies the dependence model in the next chapter on syntheses of measures, with further refinements of procedure and intricacies of mixes of measures.

To apply the one-dimensional state dynamic programming model, the economic device of the Corps of Engineers in "*routing*" back downstream benefits due to the Fountain Dam to the dam itself was adopted. The results of decoupling the accrued benefits removes the dependence element in economic optimization of expected annual net returns based on resource allocation and hence the results of the performance model's analysis are:

1) Using the dynamic programming of the resource allocation type, the global optimum is always obtained. Unlike linear programming model, linearity requirements are present in the objective function and constraints equations, and the global optimum may not be always found (Gottfried et al., 1973).

2) The performance characteristics in the form of net annual benefit and annual cost of stagewise structure could be linear, nonlinear or discontinuous. Digitization is used in the dynamic programming.

3) The allocation of resources confirms the accuracy of the Corps of Engineers' results which were obtained by not using the systems approach. The differences, if any, are mainly due to the relative coarse digitization intervals used in dynamic programming, (see Figs. 3-9 and 3-10).

4) The reader is cautioned against the exclusion of \$585,000 of unemployed resources benefits due to expanded agriculture thus enabling the Corps of Engineers to show an overall B/C ratio of 1.1 instead of 1.3 as shown in the results of Table 3-8.

5) It is relevant to note that allocation is carried out in dynamic programming in less than 4 seconds with CDC 6400 for each of the Corps of Engineers projects of capital cost \$66,770,000 for channelization and an additional \$32,401,000 for the Fountain Dam (see Tables 3-7 and 3-8 and Figs. 3-9 and 3-10).

3.5 Flood Insurance Measure

(a) General Description. Flood insurance as a fiscal flood control measure does not reduce the flood risk. It can however be used to achieve two goals: 1) use of the insurance premiums to eliminate economically unwarranted uses of floodplain lands and 2) indemnification for the residual damage protection, say after structural flood protection and land-use regulation has been adopted and against this residual damage potential, it is not economic to seek protection; hence the indemnification.

Yevjevich (1974) has given five categories of fiscal measure: 1) public disaster approach, 2) governmental insurance, 3) mixed private-public insurance, 4) private with public guarantee and 5) private insurance. The five measures are defined and discussed:

(1) The public disaster approach has undergone a change in the United States recently. In the past, the practice has been to let the Federal Government bear the increasing burden of public disasters such as earthquakes, floods and droughts and pest epidemics. In recent years, however, public relief in natural disasters have increased and the socialization of the disaster burden has advanced to a remarkable extent. For the flood-prone areas, the result is the passage of the Flood Insurance Act of 1973 and the complementary Flood Disaster Protection Act of 1973, which signal the federal effort to reverse the tide of federal involvement. Two sobering factors were largely responsible for this action. They are the recognition

TABLE 3-7 1968 CORPS OF ENGINEER'S CHANNELIZATION PROJECT FOR THE ARKANSAS RIVER AND ADJOINING FOUNTAIN CREEK

Location of Stagewise Subsystems	Total Annual Benefits ($)	Annual Charges ($)	Annual Net Benefits ($)	Optimal Design Standard (R.P in Years)	Annual Net Benefits ($)	Optimal Design Standard (R.P. in years)
Upstream (Top)		CORPS OF ENGINEER'S ANALYSES			RESOURCE ALLOCATION MODEL (Dyn. Program)	
1) Brewster to Florence	36,020	31,000	5,020	100	2,000	100
2) Portland	43,230	19,400	23,830	100	22,000	100
Upstream (Bottom)						
1) Pueblo (F'tn Creek)	149,000	133,900	15,100	100*	43,000	50*
Downstream (Plains)						
1) Reach 7	220,740	180,390	40,350	100	56,930	100
2) Reach 6	300,240	136,180	164,060	100	178,740	100
3) Reach 5	332,650	212,960	119,690	100	119,690	100
4) Reach 4	590,770	473,670	117,100	100	117,100	100
3) Reach 3	1,217,820	578,200	639,620	100	639,620	100
2) Reach 2 (Urban)	522,230	437,510	86,720	225 SPF	84,720	225 SPF
1) Reach 2 (Rural)	768,550	411,090	357,460	100	357,460	100
Total	4,142,910	2,614,300	1,528,610		1,621,260	

Corps of Engineers Overall B/C = 4,142,910/2,614,300 = 1.59 ≑ 1.6
Resource Allocation Overall B/C = 4,271,260/2650,000 = 1.61 ≑ 1.6
Note: 3 1/4% interest:June 1967 prices.

TABLE 3-8 1969 CORPS OF ENGINEER'S CHANNELIZATION PROJECT FOR THE ARKANSAS RIVER AND FOUNTAIN DAM

Location of Stagewise Subsystems	Total Annual Benefits ($)	Annual Charges ($)	Annual Net Benefits ($)	Optimal Design Standard (R.P. in years)	Annual Net Benefits ($)	Optimal Design Standard (R.P. in years)
Upstream (Top)						
1) Brewster to Florence	47,380	34,000	13,380	100	13,380	100
2) Portland	41,600	27,250	14,350	100	14,350	100
Upstream (Bottom)						
3) Pueblo (Ft'n Creek) Fountain Dam (1st added)	2,299,450	1,882,000	417,450	350 SPF	430,000	350 SPF
Downstream (Plains)						
1) Reach 7	285,200	210,000	75,200	100	55,000	175
2) Reach 6	305,000	150,000	155,000	125	175,000	150
3) Reach 5	365,000	235,000	130,000	125	120,250	50
4) Reach 4	582,885	582,885	0	100	0	100
3) Reach 3	1,075,800	809,950	265,850	100	255,000	100
2) Reach 2 (urban)	444,160	258,700	185,460	225 SPF	184,000	225
2) Reach 2 (rural)	758,000	562,000	196,000	125	187,500	175
Total	6,204,475	4,751,785	1,452,690		1,434,480	

Corps of Engineers Overall B/C = 6,204,475/4,751,785 = 1.31 ≑ 1.3
Resource Allocation Overall B/C = 6,634,480/5,200,000 = 1.28 ≑ 1.3
Note: 4 7/8% interest: January 1969 prices

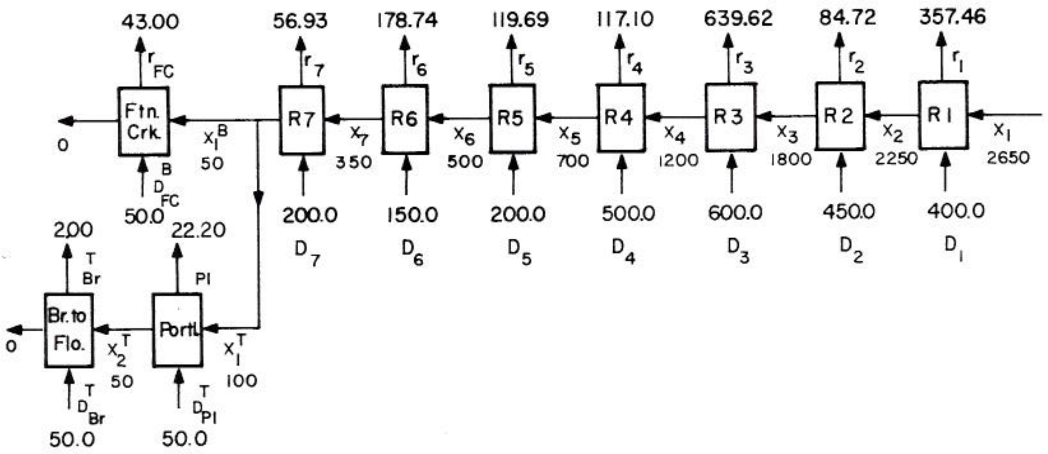


Fig. 3-9 Resource Allocation by Dynamic Programming for the Arkansas River System. Corps of Engineers 1967 Channelization Project. Figures are in $1,000 units. Small adjustment of capital ($50,000) to harmonize 100 year return period for channelization. Total annual charge is $2,650,000.

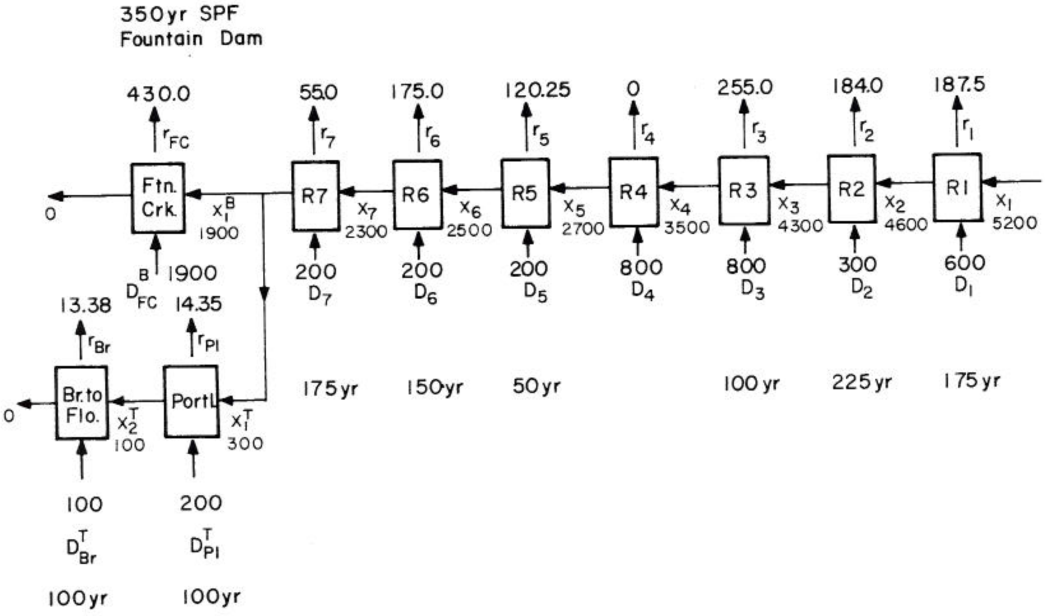


Fig. 3-10 Resource Allocation by Dynamic Programming for the Arkansas River System. Corps of Engineers Channelization and Fountain Dam Project. Figures are in $1,000 units. Total annual charge is $5,200,000.

that mean annual flood losses is increasing over the last forty years in the United States, and the vulnerability to catastrophic losses has increased, i.e. a larger proportion of losses have been coming from extreme events.

Under the new disaster approach, the following five efforts are adopted to *reduce* the future burden of disaster relief: 1) disaster loans (not outright grants) are given to minimize public dislocation in employment following the wake of a disaster, 2) such disaster loans to replace, restore, repair or construct a property must be underwritten by such types and extent of insurance to protect against future loss to the property, 3) certain minimum standards are to be followed and such compliance to minimum standards may be required by regulation, with the submission of appropriate evidence, 4) state and local government are required to evaluate the hazards in those areas where the grants or loans are to be used, and to take appropriate action to mitigate such hazards, including safe land use and construction practices; evidence of compliance may be required by regulation, and 5) flood insurance is mandatory and this means that all federally insured or regulated loan institutions (banks, savings and loan associations) could not take a mortgage on any *new* construction in flood prone areas, unless that mortgage is secured by flood insurance.

(2) Governmental insurance or an all Federal program of flood insurance is the next fiscal measure which requires an extensive and expensive administrative organization from the federal to the local level. The organization and effort required is tremendous, in dealing with local officials, to sell and service flood insurance policies and the adjustment or settlement of claims. Hence it is not a prospective candidate measure to select.

(3) Mixed private public insurance, with the private insurance industry operating a federal flood insurance program, is perhaps the best of all the four major alternatives in administering a nation-wide flood insurance coverage. The advantages are more than any of the other alternatives analyzed. It utilizes the expertise and the extensive organization of the private insurance industry and gains the support of the greater financial strength of the Federal Government. The role of the Federal Government in flood insurance is not diminished in this mixed private-public insurance program. With the burden partially shared by the private insurance sector, the federal sector could in fact proceed to discharge its proper executive functions. The Federal Government would work with states and local government to devise and to apply suitable legislation; and to plan the management of flood-prone areas. In addition, the Federal Government would encourage fiduciary lending institutions not to loan in such areas without flood insurance, establish the flood insurance premium rates, and pay subsidies to those premiums for existing properties where the costs are more than the occupants could resonably pay and finally provide excess insurance coverage against flood losses of catastrophic proportions, beyond some defined level: the "excess loss point."

(4) Private insurance program with public guarantee, an alternative approach, would result in the private insurance industry serving as fiscal agent for the Federal Government, the former writing flood insurance policies, collecting premiums and settling claims for flood damages, while the Federal Government would provide a supportive role and would provide all or most of the initial capital required. However, in the interest of the private insurance sector, they are not so willing to undertake this mixed private-public insurance program because the prospect for profit is not encouraging in spite of Federal assistance and it would upset the fluid equilibrium already established amongst the various interests and competitive strengths of insurance companies and agents.

(5) Private insurance program is not an attractive commercial adventure for profit-making purposes. The American Insurance Association presented two reports (1952-1955; 1962) indicating that it is impossible to make private insurance against flood damage coverage because of the certainty of loss and its associated catastrophic variability: it is difficult to make private insurance self-supporting without charging high rates to pay annual losses.

Private insurance companies are only interested in marketing policies for which diversification of risks is assured. If the entire portfolio of a particular insurance firm covers individuals in the same general location against the same disaster, then financial solvency in case of a disaster is questionable. Historically there has been financial failures both in 1897 and the late 1920's (Dacy and Kunreuther, 1969). Even though reinsurance could help, it could still be difficult for small regional firms to charge competitive rates and still diversify enough to protect themselves against unusually catastrophic losses.

To summarize, the present situation in the United States is that, whole new patterns of losses due to natural disasters have been developed over the past forty years and that the patterns of losses reflect a higher property loss rather than loss of lives. The types of losses are due more to catastrophic floods rather than to small floods and the destruction caused, is due more to hurricanes than inland river flooding.

Current practice in USA: The Flood Insurance Act, 1973, accepts the approach of the mixed private-public insurance program, with the complementary Flood Disaster Protection Act of 1973, which closes all the loopholes of the previous 1968 flood insurance measure; it makes flood insurance mandatory instead of voluntary, in floodplains.

The premiums paid by individual homeowners and businesses would constitute the "chargeable premium" which is only 10 to 15 percent of the estimated actual cost of providing coverage. The remaining 85 to 90 percent could be federally subsidized contribution. But there will be no federal subsidy on *new* development, otherwise it would promote uneconomic floodplain occupancy, by removing the incentives for nonfederal groups to seek other measures, designed to reduce damage potential. After July 1, 1975, no federal financial assistance or federal-related assistance would be available for any acquisition or construction project in any flood-prone area, if any identified community is not participating in the Public Flood Insurance Program. Though it may be regarded as a mandate, that land use and insurance should be conjunctively implemented, for the purpose of analysis, in this paper, the insurance measure is treated independently.

The viability of an insurance program depends upon correct flood risk evaluation and the cost of the administrative program.

The objective of the flood insurance measure is based upon the economy of scale, with all risks spread over as large an area as possible, to minimize the insurance premium rates.

There is not much that can be done with respect to a correct flood risk evaluation. Normally, several federal agencies in USA are involved with this evaluation. However, much can be done with the administrative overhead costs. If one were to accept the guidelines of the Corps of Engineers on flood insurance (1970), then the average weightage in actual cost of administering the policies is $c_w = 0.76$ by arithmetic averaging and $c_w = 0.73$ by compounded flood rate damage averaging. This appears to be too high a factor. The weightage is the average factor used to compute expense loading, which includes the transaction cost, reinsurance and underinsurance, and processing of claims.

The national flood insurance program is expected to top an insurance coverage of $20 billion in USA after July 1, 1975, a sum far greater than the $7 billion thus far expended on structural works. Assuming an annual urban flood damage of $1.4 billion and if c_w factor is 0.73, then at least $1 billion goes under expense loading, administrative cost, coinsurance and underinsurance ($20 billion x 7/100 x 0.73 = $1 billion).

In Guidelines for Flood Insurance Studies, the Corps of Engineers have established the loss portion of the rate, the average annual damage rates in dollars for $100 value for each class of structure and each class of contents. Two percent is deducted from each value of rate damage and the weightage factors indicated below at the right hand side of the listing are used to determine actuarial rates.

If rate for flood damage less deductible is:	Use this factor to compute the actuarial rate
up to $4.50	1.84
$4.51 to $5.40	1.80
$5.41 to $6.30	1.77
$6.31 to $8.10	1.75
$8.11 to $10.00	1.72
$10.01 and above	1.69

The actuarial rates are computed by multiplying damage less deductible rates by the appropriate adjustment factor. These factors make adjustments for expense load and coinsurance or underinsurance.

However, the main issue is whether the administrative cost is too high, since the potential viability and relative competitiveness of the national flood insurance program may be undermined.

(b) Statement of Objectives. The objective of the analysis on the mixed private-public insurance measure is to evaluate its potential competitiveness with the other flood-control measures. In this objective it is assumed that property losses affected by flooding are fully covered in order to unravel its relative effectiveness with the other measures.

The public objectives of flood insurance are a prompt restoration of the flooded areas to economic health, and minimization of future flood damage hazard (Insurance and Other Programs for Financial Assistance to Flood Victims, 1966).

The first objective to minimize the extent of economic dislocation subsequent to flooding, will be studied in the insurance model. The second objective is a joint objective for synthesized measure of zoning and insurance, and this will be dealt within the chapter on synthesis of flood-control measures.

(c) The Insurance Performance Model. Monetary loss due to floods is indemnified by annual payment of insurance premiums. Therefore, this is merely a transfer of funds. The minimization of economic dislocation, whether it is to residential, commercial or industrial activity, is the direct measure of benefits obtained by analyzing with and without insurance.

The performance model assumes the lag time in economic recovery is one year with flood insurance. The flood damage is fully indemnified and the property restored on a linear time basis.

Without insurance, the lag time is three years. If one were to obtain a loan, the loan can come from a bank that is not federally assisted; therefore, the interest rate is higher. The lag time of three years in economic recovery plus higher interest rate (10 percent assumed) results in a less efficient restoration or making good the flood damages.

The benefit evaluation from direct reduction of economic dislocation is

$$B_a^{(I)} = \varepsilon[D]^{(\cancel{I})} - \varepsilon[D]^{(I)} \qquad (3\text{-}46)$$

where $B_a^{(I)}$ = the direct benefit in minimizing economic dislocation, and $\varepsilon[D]^{(\cancel{I})}$ and $\varepsilon[D]^{(I)}$ = the expected annual flood damage *without* and *with* flood insurance, respectively.

Hence,

$$\begin{aligned} B^{(I)} &= (1 + R)^n \cdot \varepsilon[D] - \frac{1}{2} \cdot (1) \cdot \varepsilon[D] \\ &= (1 \cdot 10)^3 \cdot \varepsilon[D] - 0.5 \cdot \varepsilon[D] \\ &= 0.83\ \varepsilon[D]. \qquad (3\text{-}47) \end{aligned}$$

The annual cost model of administering the flood insurance program is assumed to be

$$C_a^{(I)} = c_w \cdot \varepsilon[D] \qquad (3\text{-}48)$$

where c_w is the weightage cost factor, assumed to be 0.5 in this performance model instead of 0.73 as recommended by the Corps of Engineers (1970). The writer realizes the heavy administrative overhead cost that is applied to the national flood insurance program, but nevertheless, in anticipation that mandatory flood insurance and the national economy of scale will lower this value in the future, the writer has used a more conservative weightage cost factor in the insurance measure.

The net benefit of the flood insurance program is thereforre

$$NB_a^{(I)} = B_a^{(I)} - C_a^{(I)} = 0.33 \cdot \varepsilon[D] \qquad (3\text{-}49)$$

where $NB_a^{(I)}$ = the expected annual net benefit of flood insurance, and $B_a^{(I)}$, $C_a^{(I)}$ are the expected annual benefit and annual cost respectively of the insurance measure.

The benefit to cost ratio is $B_a^{(I)}/C_a^{(I)} = 0.83/0.50 = 1.66$. This is better when compared with the Corps of Engineers guideline $B/C = 0.83/0.73 = 1.14$.

(d) The Results of the Model's Analysis as Applied to the Particular Test Basin, the Arkansas River Basin. The results of the performance analysis indicate that the economic viability of a public flood insurance program rests not only on the correct hydrologic and economic analysis of flood damages, but also, more significantly on the weightage that is applied to the program's administration costs.

The public flood insurance program has been conceived as a major new approach to bearing the loss. As a fiscal strategy in conjunction with land use, it demonstrates potential signs of economic viability and competitiveness with the other flood control measures. But the level of this viability could be undermined by too high an overhead cost.

Chapter 4
SYNTHESIS OF FLOOD-CONTROL MEASURES

Chapter 3 on the analysis of flood-control measures has dealt separately with the five basic categories of measures as though each category is independent of the other. The five basic categories are: prevention; prediction; proofing and zoning; physical control and insurance. The synthesis of flood-control measures, however, removes this artificial assumed measure's independence and calls for combinatorial as well as adjustment in mixes of measures, structural and nonstructural, which allows for interdependence and interaction with each other, to take advantage of their complimentarity.

The synthesis of the five basic categories of flood-control measures will be dealt with under the basic headings:

(1) a general treatment of each basic category under the subheadings:

(i) general description of synthesis of each basic group of measures with the other groups, with the basic group regarded as the primary measure upon which the other basic measures are dependent or interactive with it,

(ii) statements of objectives, and

(iii) the performance models of the synthesized measures.

(2) The results of the relevant synthesized model's analysis as applied to the particular test basin, the Arkansas River Basin.

The synthesis of flood-control measures is an important phase in developing strategy for cutting down flood losses. Certain difficulties have to be overcome. They are: 1) bureaucratic inertia, 2) urgency of the local government and the needs of floodplain occupants and 3) a greater need in refining strategy with technological varieties of the flood control systems.

The National Water Commission in their 1972 Report (Draft Report, Vol. 1., 1972) have noted that in *principle* most planners have accepted the premise that all the feasible alternatives in flood control should be given full and equitable consideration. The objective should be to find the *best* combination of measures. In *practice*, however, the Commission noted, the implementation stage is still in a state of flux, and that federal agencies have not been particularly successful in putting this concept into *effect*.

Nevertheless, the *imperative need* still remains. Gilbert White in one of his assessments (1973) states: "Unless there is a marked change in the mix of adjustments applied to the nation's floodplains, there will be no overall decrease in flood losses."

In the meantime, however, floodplain zoning and interrelated flood-insurance program is scheduled to become operational on July 1, 1975. Local governments and citizen groups are in urgent need of guidelines and recommendations that would help them to react responsibly towards federal policy and planning. The integrated measures of land-use zoning and federal flood insurance signal a radical change in federal policy and reflects and overall strategical initiative to cut the nation's flood losses. Under this new policy, contribution to the reduction of future flood losses will be based on a tri-lateral structure, with the Federal Government emphasizing the overall strategical framework, the State and local governments enforcing the policies at the local level, and the floodplain occupants bearing the cost of floodplain occupancy.

The study on syntheses of flood-control measures answers a third need, namely a refinement in the synthesis will enable the development of a sound flood-control strategy that is both currently relevant, long-range and flexible. The final selection of a particular strategy will come out of technological varieties of multi-directional measures and requirements of a sound strategy. Short-term, mid-term or long-term strategies are likely to reveal that "rarely one measure alone or a small number of measures, either structural or nonstructural, represent the most feasible long-range strategy" (Yevjevich, 1974).

4.1 Synthesis of Prevention Measures with the Other Measures

(a) General Description. Prevention measures have been subdivided into two broad sub-categories: 1) meteorological prevention measures such as excessive rainfall suppression and large storm modification, and 2) snowmelt prevention and prevention of breaches in artificial water-impoundment structures.

The synthesis of the meteorological prevention measures with the other categories of measures is at present handicapped by a lack of either adequate workable technology or prohibitory costs. The prevention of snowmelt, because of its large areal coverage, is limited purely by economic consideration. The prevention of breaches in artificial water-impoundment structures depends upon future technology in predicting earthquakes and landslides.

(b) Statements of Objectives. Synthesis of the prevention measures with the other categories of measures appear at present to be infeasible. Therefore the writer proposes to go to the next synthesis, synthesis of prediction measures using the other basic groups.

4.2 Synthesis of Prediction Measures with the Other Basic Groups

(a) General Description. Flood forecasting and flood warning have been found to be limited to short-range and medium-range hydrologic forecasts. Of all the flood types identified for the temperate countries, the rainfall floods of the frontal type, the *"slow"* flood appears to be the most promising for prediction. Both medium-range meteorological and hydrologic forecasting could be used conjunctively to establish the prediction under the weather system of the meso-scale range.

The prediction measure could be synthesized with any or all the other basic categories: flood proofing and zoning; physical control and insurance. If physical control is further divided into intensive and extensive physical control, there will be at the most, four basic groups to synthesize with the prediction measure. The combinatorial arrangement, given that the prediction measure is the sole primary measure, upon which the other basic categories could depend, indicates fifteen possible combinations of basic categories, where order is not important:

$$\sum_{x=2}^{n=5} \binom{n-1}{x-1} = \sum_{y=1}^{4} \binom{4}{y} = 15 \text{ possible combinations,} \qquad (4\text{-}1)$$

where n = the total number of basic groups: 1) prediction, 2) zoning and proofing, 3) extensive measure 4) intensive measure and 5) flood insurance. The prediction measure is the independent primary measure in the synthesis, and is present in all the possible combinations, starting with pairwise combination to all mutually inclusive combination of the total. Therefore out of (n-1) supplementary choices, there are (x-1) ways to combine the basic measures, with x=2, 3, 4, 5. Where order is important, the permutation within each combination is $y!\binom{4}{y}$. The physical constraints of the terrain usually could help to eliminate some of the permutation in each combination.

The question of the levels of sizes of each measure in each basic group does not arise, since such component sizes are independent of the prediction measure. The operation of the basic dependent categories upon the prediction measure rests on three performance parameters. They are the forecast period, τ; the forecast accuracy, e; and the level of the human response to flood forecast, r_e. The role of each of these performance parameters will be indicated in the performance models to be synthesized.

(b) Statement of Objectives. Given the prediction measure of flood forecast and flood warning the objective is to indicate how the prediction measure could be integrated with the other basic category and how a total composite integration could be established with the prediction measure taken to be the primary independent measure, on which the other basic dependent measures are to operate. For purposes of discussion, each of the basic groups is taken in sequence for illustration.

(1) With dynamic flood proofing. Prediction measure could be synthesized with *"dynamic"* flood proofing of structure as distinct from *"static"* flood proofing. The former is contingent upon the receipt of flood warning while the latter is permanent. (Bhavnagri, et al., 1966).

(2) With intensive physical control. Synthesis of flood forecasting with reservoir flood storage regulation, operation of release basin, parallel channels and diversions is possible. The role of flood forecasting in regulation of flood control reservoirs is based on how much the capacity for flood damage reduction could be increased by making storage available before the flood arrival (Klemes, 1973). The rate of reservoir release can be increased up to bankfull stage in order that more storage could be made available, when the flood arrives, thus decreasing the downstream flood damages.

(3) With extensive physical control of watersheds. If the upland watersheds are relatively large and if there is sufficient time for flood-forecast dissemination, both land treatment measure and structural measure could be prepared in advance to reduce the runoff and subsequent flooding and sediment flow along streams and channels. For the land treatment measures, diversions and farm ponds could be prepared in advance to accept the predicted floods; terraces and contours drainage could be improved and for the structural measures, flood water retarding structures; silt and debris basins and grade stabilization structures could be readied not only to control floods but also to control erosion and sediment.

However, despite the prediction, there are three discriminatory factors which should be recognized in the synthesis: 1) both land-use measures (with their vegetal-biological cover) and structural measures are apparently more effective on erosion and sedimentation control than localized flood peak attenuation; 2) the effects of these two joint measures are perhaps more readily detectable on flood-peak attenuation in the growing season, when the influence of the nonstructural measures are most marked, and 3) structural measures alone cannot be fully effective without proper land-treatment measures first, to conserve soil and water (Renne, 1967; Gambell, 1969).

(4) With flood insurance. By means of flood forecast and flood warning, the annual flood-insurance premiums charged for insurance of contents of property could be reduce . Synthesis of the prediction measure with flood insurance assumes that the contents will be removed to a higher level than the predicted flood level. Without the prediction measure, it is "assumed that none of the contents will be removed from structures prior to a flood," an assumption used by the Corps of Engineers in their "Guidelines for Flood Insurance Studies" (1970).

The objective is therefore to determine the optimal policy which will maximize the expected annual net return of the synthesized measures. The expected annual net return objective functions are listed below:

(1) With zoning and dynamic flood-proofing measure, Z,

$$\max. \sum_{\imath=1}^{N_\imath} \delta^Z_\imath\, NB^Z_\imath = \sum_{\imath=1}^{N_\imath} \delta^Z_\imath\, X^Z_\imath - \sum_{\imath=1}^{N_\imath} \delta^Z_\imath\, C^Z_\imath\,, \qquad (4\text{-}2)$$

(2) With intensive physical control measure, St,

$$\max. \sum_{\imath=1}^{N_\imath} \delta^{St}_\imath\, NB^{St}_\imath = \sum_{\imath=1}^{N_\imath} \delta^{St}_\imath\, X^{St}_\imath - \sum_{\imath=1}^{N_\imath} \delta^{St}_\imath\, C^{St}_\imath \qquad (4\text{-}3)$$

(3) With flood insurance, In,

$$\max. \sum_{\imath=1}^{N_\imath} \delta^{In}_\imath\, NB^{In}_\imath = \sum_{\imath=1}^{N_\imath} \delta^{In}_\imath\, X^{In}_\imath - \sum_{\imath=1}^{N_\imath} \delta^{In}_\imath\, C^{In}_\imath \qquad (4\text{-}4)$$

(4) As a prediction measure alone by itself, P,

$$\max. \sum_{\imath=1}^{N_\imath} \delta^P_\imath\, NB^P_\imath = \sum_{\imath=1}^{N_\imath} \delta^P_\imath\, X^P_\imath - \sum_{\imath=1}^{N_\imath} \delta^P_\imath\, C^P_\imath, \qquad (4\text{-}5)$$

where $\delta_\imath$ = a digital indicator with 1 or 0 value, indicating whether a measure is included or not in the synthesis; $\imath$ = and index, indicating how many measures are included in each group, ($\imath$=1,2,...,N); NB = the expected annual net benefit of each basic group; $X_\imath$ and $C_\imath$ = the expected annual benefit and public cost of the pairwise synthesized measures.

The total synthesis of the whole categories of basic groups would result in:

$$\max.\ \sum_{\iota=1}^{N_\iota} \delta_\iota^{P}\, NB_\iota^{P} + \left[\sum_{\iota=1}^{N_\iota} \delta_\iota^{Z}\, NB_\iota^{Z} + \sum_{\iota=1}^{N_\iota} \delta_\iota^{St}\, NB_\iota^{St} + \sum_{\iota=1}^{N_\iota} \delta_\iota^{In}\, NB_\iota^{In} \right] \pm \phi\left[T\left(\sum_{\iota=1}^{N_\iota} \delta_\iota^{Z} Y_\iota^{Z} + \sum_{\iota=1}^{N_\iota} \delta_\iota^{St}\, Y_\iota^{St} + \sum_{\iota=1}^{N_\iota} \delta_\iota^{In}\, Y_\iota^{In} \right)\right], \tag{4-6}$$

when the first term in the objective function indicates the prediction measure operating alone; the second, third and fourth terms indicating the general synthesis with the other basic categories of measures and the last function ϕ, allowing for any positive or negative external diseconomies Y_ι, as a result of synthesis. The optimal policy could be found by dynamic programming either with one-dimensional or two-dimensional state variables, depending upon whether hydrologic dependence of the interactive measures is present.

(5) Synthesis with extensive physical control measures is shown separately because of the different nature of the measure, namely

$$\max.\ \sum_{\iota=1}^{N_\iota} \delta_\iota^{Ex}\ NB_\iota^{Ex} = \sum_{\iota=1}^{N_\iota} \delta_\iota^{Ex}\ X_\iota^{Ex} - \sum_{\iota=1}^{N_\iota} \delta_\iota^{Ex}\ C_\iota^{Ex} \tag{4-7}$$

or

$$\max.\ \sum_{\iota=1}^{N_\iota} \delta_\iota^{Ex}\ NB_\iota^{Ex} = \left(\sum_{\theta=1}^{N_\theta} \delta_\theta^{Lu}\ X_\theta^{Lu} - \sum_{\theta=1}^{N_\theta} \delta_\theta^{Lu}\ C_\theta^{Lu} \right) + \left(\sum_{\kappa=1}^{N_\kappa} \delta_\kappa^{St}\ X_\kappa^{St} - \sum_{\kappa=1}^{N_\kappa} \delta_\kappa^{St}\ C_\kappa^{St} \right) \pm \phi\left[T\left(\sum_{\iota=1}^{N_\iota} \delta_\iota^{Lu}\ Y_\iota^{Lu} + \sum_{\iota=1}^{N_\iota} \delta_\iota^{St}\ Y_\iota^{St} \right)\right] \tag{4-8}$$

The special nature of the extensive physical control measure is the partition of the objective function into land use (Lu), and structural measures (St), and the possibility of external transformed positive or negative benefits resulting from flood and soil erosion control affection water quality and environmental health. This is accounted for by the ϕ function.

(c) <u>The Performance Models of the Synthesized Measures</u>. The performance model of the synthesized measures calls for an overall economic model, to partition benefits and costs. Under this overall economic assessment model are the several respective hydrologic-technological submodels which will be mentioned as the measures are incorporated.

(1) <u>With the prediction measure by itself</u>. The amount of preventable damages through prediction are: a) moveable items of appliances, furniture and dry goods, b) temporary evacuation of livestocks and humans, and c) rescheduling of commercial, industrial and agricultural activities.

The expected annual benefit of the prediction measure is the amount of economic losses that are preventable through **prediction.** It is measured under the approaches *with* and *without* prediction. As estimated by Day (1970) and White (1973), it is of the order of two to five percent of the total flood damage in urban areas.

The expected annual benefit due to reduction in preventable flood losses is however modified by the accuracy of the forecast, the forecast period, and the level of human response to the forecast. Hence:

$$B^{P} = r_e^{P}\, r_\tau^{P} \sum_{j=1}^{N_r} \sum_{i=1}^{N_j} F_{(i,j)} \sum_{k=1}^{N_j} P_{(i,j,k,m)} \left[B_{(i,j,k)}^{P} - C_{(i,j,k)}^{P}\right] \tag{4-9}$$

where B^P = the expected annual benefit due to the prediction measure alone P; r_e^P = the fraction of floodplain occupants that respond to the prediction; r_τ^P = the fraction of desirable benefits due to advanced forecast period τ; N_r = the total number of river reaches; N_j = the total number of levels at each reach j; $F_{(i,j)}$ = the probability of a flood of level i occurring in reach j in any year; $P_{(i,j,k,m)}$ = the probability of an actual flood of level i, for reach j, resulting in a predicted flood level k, for prediction network m. $C^P_{(i,j,k)}$ = the expected annual private cost incurred by floodplain occupants in response to the prediction (see Appendix B).

The technological submodels are already listed in Chapter 2 for analysis of this measure.

(2) <u>With dynamic flood proofing</u>. The expected annual benefit function from dynamic flood proofing contingent on prediction, is that portion of benefit $B^{F|P}$ such that

$$B^{F|P} = r_e^{F|P}\, r_\tau^{F|P} \sum_{j=1}^{N_r} \sum_{i=1}^{N_j} F_{(i,j)} \sum_{k=1}^{N_j} P_{(i,j,k,m)} \left[B_{(i,j,k)}^{F|P} - C_{(i,j,k)}^{F|P}\right], \tag{4-10}$$

with $B^{F|P}_{(i,j,k)}$ = the expected annual benefit of the dynamic flood proofing of structures and $C^{F|P}_{(i,j,k)}$ = the expected annual private cost of dynamic flood proofing. The other symbols are previously defined.

Bhavnagri et al. (1966) have formalized the hydrologic submodel for flood-damage computation for dynamic flood proofing, with the expected value of contour characteristic damages before and after dynamic flood proofing. This serves as a submodel for formalized computation of flood damages to structures in the floodplain.

(3) <u>With intensive and extensive physical flood-control measure</u>. If prediciton is integrated with the intensive and the physical flood-control measure, one needs to distinguish whether prediction is used **for** storage regulation of reservoirs or stage regulation of channels, **diversions** and parallel channels. For

storage regulation, the benefit function above is modified thus:

$$B^{St|P} = r_{\tau}^{St|P} \sum_{j=1}^{N_r} \sum_{i=1}^{N_j} F_{(s_i,j)}$$

$$\sum_{k=1}^{N_j} P_{(s_i,j,s_k,m)} [B_{(s_i,j,s_k)}^{St|P} - C_{(s_i,j,s_k)}^{St|P}] \quad (4\text{-}11)$$

where flood level i is replaced by storage s_i, for the reservoir at reach j, resulting in a predicted storage requirement s_k. The response $r_e^{St|P} = 1$ since there is either regulation or no regulation. The benefit $B_{(s_i,j,s_k)}^{St|P}$ occurring to storage regulation is the expected reduction in annual flood damage estimated on the basis that reservoir regulation is with or without prediction.

The hydrologic submodel will be a predictive stochastic streamflow model with watershed-management systems together with storage-reservoir routing. Optimal operation procedure for reservoir releases have been shown by Burton, Hall, and Howell (1963), with the optimal regulation policy determined by dynamic programming.

(4) With insurance measure. The effects of the prediction measure on the depth-damage curves for contents of residential, commercial and industrial buildings are to reduce the annual insurance premiums or contents of property. The prediction measure could result in a lower annual premium rate if human response to flood warnings alters the depth-damage curves for moveable contents. The benefit function is the same as for the prediction measure, except that the efforts are now directed to reduction of insurance premiums.

(5) The composite performance model. The synthesis of the composite measures result in evaluating the optimal investment policy for the maximum expected net benefit return.

$$\max.\ B^{P} + [B^{F|P} + B^{St|P} + B^{In|P}] - C^{P}, \qquad (4\text{-}12)$$

where B^P, $B^{F|P}$, $B^{St|P}$ are previously defined symbols: $B^{In|P}$ = the expected annual benefit of the reduction in annual insurance premiums for contents of structure and C^P = the total annual cost of the prediction measure, C^P = the public cost of the forecasting measure, whereas $C_{(i,j,k)}^{P}$ = the private cost of the prediction measure such as evacuation, reoccupation, etc. The same distinction applies to the other benefit functions outlined above (Day et al., 1969).

(d) The Results of the Relevant Synthesized Model's Analysis as Applied to the Particular Test Basin, the Arkansas River Basin. The scope of the prediction measure, flood forecasting and flood warning is limited mainly to the weather system of the mesoscale range. As well as hydrologic forecasting, the meteorological forecasting related to the microscale localized convective system which causes flash flooding, is not yet fully operational. Nevertheless, the mesoscale system in the case study of the Arkansas River Basin contains a very large amount of moisture that is brought there by the convergence flow of moist air from the Gulf of Mexico. Consequently the mesoscale system is potentially significant in terms of flood damage caused by *slow floods*.

In the Arkansas River case, there is no flood warning system fully operational, as far as the writer could establish, and there are not available data for integrating flood warning in the operational flood-control regulation of the Pueblo and John Martin Dams as well as the proposed Fountain Dam.

Nevertheless, the prediction measure for the Arkansas case could be implemented. The case study has found that for the present level of economic development in the Arkansas River alluvial floodplains, flood forecasting and flood warning could be introduced based on an optimal configuration of recording and telemetering raingages fixed at an optimal density of one raingage per 530 square miles (Table 3-3). Based on an assessment of about five percent preventable damages in the economic sector, the benefit-to-cost ratio of the forecasting system is 2.54, with a raingage-performance accuracy parameter b = 0.25, and a total human response. Since the subwatersheds adjacent to the Arkansas River are relatively large and the time of concentration is more than 6 to 12 hours, the advanced forecast time is adequate, a criterion required by the Grayman and Eagleson flood-forecasting model based on the convective frontal system.

4.3 Synthesis of Floodplain Zoning and Proofing with the Other Basic Categories of Measures.

(a) General Statement. As alternatives to be considered, floodplain zoning and proofing together with flood insurance could join structural measures in developing a unified program for managing flood losses (Unified National Program for Managing Flood Losses, 1966). In fact, floodplain zoning and flood insurance are both seen to be complementary and mandatory measures in recent years and is a strong element in official flood-control policy in the United States (Flood Insurance, 1973, Flood Disaster, 1973; and Flood Disaster Protection Act, 1973).

However quantitative criteria (Whipple, 1969) are needed besides optimization-investment procedure, to evaluate the synthesis of nonstructural and structural measures in reducing flood losses. In this context, the nonstructural means may be acting alone (floodplain zoning and flood insurance) or as supplement to structural means. The quantitative criteria will indicate to what extent zoning is practicable or what combination of intensive physical flood control, zoning and/or flood insurance is feasible. If the floodplain is fairly varied, with some sectors in the river reaches experiencing much higher flood hazard than others, then the quantitative criteria should indicate with the optimization of investment, which synthesized alternatives of categories of measures should be applicable. Account should be taken of certain dynamic factors along the river reaches, particularly the economic effects of project induced economic growth.

If the basic groups of measures are: 1) zoning and flood proofing, 2) intensive physical control, 3) extensive physical control, and 4) flood insurance, the combinatorial arrangement of four basic groups allow for seven possible ways to combine:

$$\sum_{x=2}^{4} \binom{n-1}{x-1} = \sum_{y=1}^{3} \binom{3}{y} = 7. \qquad (4\text{-}13)$$

However, if the physical control group omits extensive physical control, then there are only three basic categories: 1) zoning and flood proofing, 2) intensive physical control, and 3) flood insurance. Then the combinatorial arrangement is about half of the above, thus

$$\sum_{x=2}^{3} \binom{n-1}{x-1} = \sum_{y=1}^{2} \binom{2}{y} = 3. \tag{4-14}$$

The formula given does not take account of zoning measure acting alone as a category, but this possibility must be included in the development of discriminatory criteria for measure synthesis. The four basic combinations are: 1) zoning and intensive measures (Z + St), 2) zoning and flood insurance (Z + In), 3) zoning, intensive measures and flood insurance (Z + St + In) and 4) the additional consideration is the zoning measure acting alone (Z).

(b) Statements of Objectives. The objective is to establish an economic optimum by maximizing the net benefit function of the system. The latter is a summation of net benefits for the various alternatives, selecting options for the different sectors of the river reaches that will maximize the resulting total net benefit.

The various combinations of subsystems of measures are represented and considered in the evaluation of flood loss reduction obviated by the various alternatives under consideration. There are two objectives to be pursued in this approach, the *combination* of basic alternatives of measures and the *level* of optimum combination, since these measures are interdependent and are physically interrelated. The increased use of one means that less of the others need be applied.

Zoning is defined in this paper as existing improvements which are bought up, destroyed or relocated, and future improvements which are precluded, from the restrictive zoned area.

Whipple (1969) has defined the first condition only in his paper and hence his quantitative criteria are not general enough to cater to a wider range of situations. Zoning may also be defined as the prevention of all future construction without interfering with existing installation.

The objective functions of zoning either alone or in combination with the other measures are listed.

(1) Zoning alone,

$$\sum_{\iota=1}^{N_\iota} \delta_\iota^Z \, NB_\iota^Z = \left[\sum_{\iota=1}^{N_\iota} \delta_\iota^Z X_\iota^Z - \sum_{\iota=1}^{N_\iota} \delta_\iota^Z C_\iota^Z\right]_E + \left[\sum_{\iota=1}^{N_\iota} \delta_\iota^Z X_\iota^Z - \sum_{\iota=1}^{N_\iota} \delta_\iota^Z C_\iota^Z\right]_{NG} \tag{4-15}$$

where the subscripts E and NG represent existing and normal growth, repsectively. For purposes of space saving later, the above two left hand expressions may be obtained thus:

$$\sum_{\iota=1}^{N_\iota} \delta_\iota^Z \, NB_\iota^Z = \left[\sum_{\iota=1}^{N_\iota} \delta_\iota^Z X_\iota^Z - \sum_{\iota}^{N_\iota} \delta_\iota^Z C_\iota^Z\right]_{E,NG} \tag{4-16}$$

where E,NG represent the respective net benefit function for existing and normal growth.

(2) Zoning with structural measures,

$$\sum_{\iota=1}^{N_\iota} \delta_\iota^Z \, NB_\iota^Z + \sum_{\iota=1}^{N_\iota} \delta_\iota^{St} \, NB_\iota^{St} = \left[\sum_{\iota=1}^{N_\iota} \delta_\iota^Z X_\iota^Z - \sum_{\iota}^{N_\iota} \delta_\iota^Z C_\iota^Z\right]_{E,NG} + \left[\sum_{\iota}^{N_\iota} \delta_\iota^{St} X_\iota^{St} - \sum_{\iota}^{N_\iota} \delta_\iota^{St} C_\iota^{St}\right]_{E,NG} + \phi\left[T(\delta_\iota^{St} Y_\iota^{St})\right]_{PG,LEB}, \tag{4-17}$$

where the first two terms on the right-hand expression represent the expected annual net benefits of zoning and structural measures respectively and the third term represents the transformed effects of the structural measure, viz. i) the dynamic effect of land enhancement benefits, LEB, and 2) the additional residual loss due to project induced growth, PG.

(3) Zoning with insurance,

$$\sum_{\iota}^{N_\iota} \delta_\iota^Z NB_\iota^Z + \sum_{\iota=1}^{N_\iota} \delta_\iota^{In} NB_\iota^{In} = \left[\sum_{\iota=1}^{N_\iota} \delta_\iota^Z X_\iota^Z - \sum_{\iota=1}^{N_\iota} \delta_\iota^Z C_\iota^Z\right]_{E,NG} + \left[\sum_{\iota=1}^{N_\iota} \delta_\iota^{In} X_\iota^{In} - \sum_{\iota=1}^{N_\iota} \delta_\iota^{In} C_\iota^{In}\right]_{E,NG} \tag{4-18}$$

(4) Zoning with structural and insurance measures,

$$\sum_{\iota=1}^{N_\iota} \delta_\iota^Z NB_\iota^Z + \sum_{\iota=1}^{N_\iota} \delta_\iota^{St} NB_\iota^{St} + \sum_{\iota=1}^{N_\iota} \delta_\iota^{In} NB_\iota^{In} = \left[\sum_{\iota=1}^{N_\iota} \delta_\iota^Z X_\iota^Z - \sum_{\iota=1}^{N_\iota} \delta_\iota^Z C_\iota^Z\right]_{E,NG} + \left[\sum_{\iota=1}^{N_\iota} \delta_\iota^{St} X_\iota^{St} - \sum_{\iota=1}^{N_\iota} \delta_\iota^{St} X_\iota^{St}\right]_{E,NG} + \phi\left[T(\delta_\iota^{St} Y_\iota^{St})\right]_{PG,LEB} + \left[\sum_{\iota}^{N_\iota} \delta_\iota^{In} X_\iota^{In} - \sum_{\iota}^{N_\iota} \delta_\iota^{In} C_\iota^{In}\right]_{E,NG} \tag{4-19}$$

(c) The Performance Models of Synthesized Measures. To illustrate the application of the above evaluative criteria, one can assume that there are three types of improvements in the floodplain subject to flood damages: 1) existing facilities, 2) normal economic growth, and 3) project-induced economic growth. Normal growth includes improvements that will be built regardless of whether a flood-control project is constructed. Project-induced growth is that group of improvements that will be built only *if* the project is constructed. For any given sector of the floodplain, let the *total values* of these three groups of facilities at a given price level be designated as V_T, V_T', and V_T''.

If floods are not controlled, the *rate* of average annual flood loss applicable to property in any given sector be represented by d. If a flood-control program is effected, the reduced rate of damage (residual damage) may be designated as d'. Hence if different degrees of flood control are considered, different sets of d' are obtained.

The *return* from the property over and above the annual costs of the facilities built upon it is referred to as *site income*. The rate-of-site income of existing and normal growth is designated by s and of project induced growth by s', in each case expressed as an annual fraction of the total value of the properties involved.

(1a) Zoning alone. Zoning alone is applicable to a given sector only when a positive net benefit is indicated,

$$\delta_\iota^Z NB_\iota^Z = V_T(d-d') + V_T'(d-d') - (V_T + V_T')(s) - \delta_\iota^Z C_\iota^Z$$

$$= (V_T + V_T')(d-d') - (V_T + V_T')(s) - \delta_\iota^Z C_\iota^Z \tag{4-20}$$

(1b) Structural measures alone. Structural measures alone should take account of project-induced growth and increased residual flood damages, and is applicable to a sector when again, a positive net benefit is indicated.

$$\delta_\iota^{St} NB^{St} = V_T(d-d') + V_T'(d-d') + V_T''(s') - V_T''(d')$$

$$- \delta_\iota^{St} C_\iota^{St} = (V_T + V_T')(d-d') + V_T''(s')$$

$$- V_T''(d') - \delta_\iota^{St} C_\iota^{St} \tag{4-21}$$

where the last two terms on the right hand expression are: (a) $V_T''(s')$ = the land enhancement benefit due to structural measures and (b) $V_T''(d')$ = the increase in residual flood damaged due to project-induced growth.

Hence comparing the two sets of net benefits indicates that zoning will be more profitable than the structural measure for that protected sector only if

$$\delta_\iota^Z NB_\iota^Z > \delta_\iota^{St} NB_\iota^{St} \tag{4-22}$$

or

$$(V_T + V_T')(d-d') - (V_T + V_T')(s) - \delta_\iota^Z C_\iota^Z$$

$$> (V_T + V_T')(d-d') + V_T''(s') - V_T''(d') - \delta_\iota^{St} C_\iota^{St} \tag{4-23}$$

i.e.

$$V_T''(d') + \delta_\iota^{St} C_\iota^{St} > (V_T + V_T')(s) + V_T''(s') + \delta_\iota^Z C_\iota^Z \tag{4-24}$$

that is, zoning will be more profitable than the structural measure of protection, if residual flood damages and annual cost of the structural measures is greater than the site income and the annual cost of zoning (the annual cost of land value sacrificed under zoning restriction).

(2) Zoning and structural measures. Zoning and structural measures are applicable to a given sector of a river stretch when a positive net benefit exists,

$$\delta_\iota^Z NB_\iota^Z + \delta_\iota^{St} NB_\iota^{St} = (V_T + V_T')(d-d') - (V_T + V_T')(s)$$

$$+ V_T''(s') - V_T''(d') - \delta_\iota^{Z|St} C_\iota^{Z|St} \tag{4-25}$$

(3) Zoning and insurance measures. Zoning and insurance are expected to produce a higher net benefit than zoning alone, because the result of indemnification of the residual damages after zoning restriction is applied leads to minimization of economic dislocation after a flood,

$$\delta_\iota^Z NB_\iota^Z + \delta_\iota^{In} NB_\iota^{In} = (V_T + V_T')(d-d') - (V_T + V_T')(s)$$

$$- \delta_\iota^Z C_\iota^Z + \alpha_{In}(V_T + V_T')(d') - \delta_\iota^{In} C_\iota^{In} \tag{4-26}$$

$$\delta_\iota^Z NB_\iota^Z + \delta_\iota^{In} NB_\iota^{In} = (V_T + V_T')(d-d'-s) - \delta_\iota^Z C_\iota^Z$$

$$+ (V_T + V_T')(\alpha_{In} - \beta_{In})d', \tag{4-27}$$

if $C_\iota^{In} = \beta_{In}(V_T + V_T')(d')$, the annual cost of the insurance program for that sector where α_{In} = the benefit coefficient due to minimization of economic damage with insurance and β_{In} = the cost coefficient of the insurance program.

(4) Zoning, structural, and insurance measures.

$$\delta_\iota^Z NB_\iota^Z + \delta_\iota^{St} NB_\iota^{St} + \delta_\iota^{In} NB_\iota^{In} = (V_T + V_T')(d-d'-s)$$

$$- \delta_\iota^{Z|St} C_\iota^{Z|St} + V_T''(s') - V_T''(d')$$

$$+ (V_T + V_T')(\alpha_{In} - \beta_{In})d' \tag{4-28}$$

The *synthesized performance* should take account of the standard of zoning restriction applied to the sector and the area from which urban development is excluded and the complementary amount of flood proofing and filling measure to be applied, as a supplement to the zoning measure. The synthesized model will have to take into account both land use and structural measures upstream and downstream of the sector, e.g. channel improvement upstream may cause downstream flooding and such exogenous interaction should be incorporated in the synthesis. The land value model under zoning restriction will have to take note of the amount of urban development existing prior to the zoning exclusion as well as the degree of urbanization where it is not excluded.

The land use synthesized model will contain the basic submodel for optimal zoning, optimal fill and flood proofing for each location. The procedure is to use the basic submodel for local optimal fill, proofing and zoning in the land use model combining efficiency of land use, engineering alternatives and insurance measures.

The basic submodel for each sector is

$$\max \delta_{\iota}^{Z} NB_{\iota}^{Z} = \varepsilon[D_{ij\lambda}]^{(\cancel{Z})} - \varepsilon[D_{ij\lambda}]_{fps}^{(Z)} - [C^{F}{}_{ij\lambda}]_{fs}^{Z}$$

$$- [C_{ij\lambda}^{P}]_{ps}^{Z} - [C_{ij\lambda}^{ROD}]_{fps}^{Z} \qquad (4\text{-}29)$$

where the most convenient way to refer to the order of subscripts is thus: 1) land specification subscript parameters: i = land use, j = location, λ = flood hazard, 2) flood mitigation subscripts: f = fill to level f, p = flood proofing to level p, 3) development policy: s = specific development policy involving either structural or nonstructural measures or a combination of both and with a minimum flood-zoning standard. Therefore the *total system* for the land use model or the floodplain model is,

$$\max. \sum^{I}\sum^{J} \delta_{\iota}^{Z|St\ In}\, NB_{\iota}^{Z|St\ In} = \sum^{I}\sum^{J} \varepsilon[D_{ij\lambda}]^{(\cancel{Z})}$$

$$- \sum^{I}\sum^{J} \varepsilon[D_{ij\lambda}]_{fps}^{(Z)} - \sum^{I}\sum^{J} [C_{ij\lambda}^{F}]_{fs}^{Z} - \sum^{I}\sum^{J} [C_{ij\lambda}^{P}]_{ps}^{Z}$$

$$- \sum^{I}\sum^{J} [C_{ij\lambda}^{ROD}]_{fps}^{Z} - \varepsilon[C_{s\lambda}]_{zfps}^{St} + \varepsilon[OB_{s\lambda}]_{zfps}^{St}$$

$$- \varepsilon[OC_{s\lambda}]_{zfps}^{St} + (\alpha_{In} - \beta_{In}) \sum^{I}\sum^{J} \varepsilon[D_{ij\lambda}]_{fps}^{Z} \qquad (4\text{-}30)$$

where I = the total number of land uses; J = the total number of locations; $\varepsilon[D_{ij\lambda}]^{(\cancel{Z})}$ = the expected annual flood damages for land use i, at location j without the zoning measure (Z); $\varepsilon[D_{ij\lambda}]^{(Z)}$ = the expected residual flood damages for land use i, at location j with the zoning measure, (Z); $[C_{ij\lambda}^{F}]_{fs}$ = the expected annual cost of fill to level f for i,j,λ, activity, given public investment in s, and with a flood hazard λ; $[C_{ij\lambda}^{P}]_{ps}$ = the expected annual cost of flood proofing of structures to level p, given public investment in s, for i,j,λ, activity, with a flood hazard λ; $[C_{ij\lambda}^{ROD}]_{fps}$ = the expected residual off-site annual flood damages associated with the i,j,λ activity after private investment in fill to level f and flood proofing to level p, after public investment in s; $\varepsilon[C_{s\lambda}]_{zfps}^{St}$ = the expected annual cost of the structural measures with policy s; $\varepsilon[OB_{s\lambda}]_{zfps}^{St}$ = the expected other present annual benefits associated with policy s; $\varepsilon[OC_{s\lambda}]_{zfps}^{St}$ = the expected other present annual costs associated with s, but not accounted for anywhere else; $(\alpha_{In} - \beta_{In})\sum^{I}\sum^{J} \varepsilon[D_{ij\lambda}]_{fps}^{Z}$ = the expected, annual net benefit in minimizing economic dislocation with flood insurance indemnification of the expected residual flood damages, for all land uses, I, and all locations, J.

Simplified into their basic components, the objective is to maximize the overall economic efficiency objective,

$$\max. \varepsilon[NB]^{Z|St\ In} = \varepsilon[NB]^{Z} + \varepsilon[NB]^{St} + \varepsilon[NB]^{In} \qquad (4\text{-}31)$$

with a combination of land-use regulations, development policies (varying floodplain-restriction standards) and engineering structural measures subject to various physical and institutional constraints.

The Submodel for the Test Area: the Arkansas River Basin. The problem at hand in the Arkansas Test case is to determine whether zoning alone or zoning and insurance as synthesized measures are applicable to urban sectors situated along the Arkansas main stem and its major tributaries. The other two alternatives listed as items (2) and (4) under the subheading (c) above of the performance models will be discussed in relation to structural synthesis, which is to be dealt with in Section 4.4.

Conceptually the synthesis of these two nonstructural measures will prove the most important because great hopes are placed on such integrating measures to reduce the future flood losses.

One must separate here two apparently interlocking issues: 1) the need for an overall national minimum flood standard, where the flood problems are seen in the national perspective; and 2) the need for local optimum in zoning restriction in order that its competitive level may be assessed and compared with the other flood-control measures in a localized regional context.

The national perspective on flood-control recognizes the kind of zoning restrictions and criteria must be in keeping with the changes in vulnerable property located in the floodplain, i.e. the vulnerability to catastrophic losses has increased with a larger proportion of losses coming from extreme flood events. Hence there is the argument for the reasonableness of the 100-year flood level, which is to be used as a basis for floodplain regulation and rates assessment for flood insurance. The need for the local optimum zoning standard is to evaluate its relative potential competitiveness of the zoning measure with the other measures, taken singly or conjunctively.

To reconcile these two apparently conflicting demands, optimization could yield the optimal flood-restriction level for local zoning as well as the indication of its relative performance from the optimum, if the 100-year flood standard is adopted. In the United States, the 100-year flood standard is favored by at least 21 states and all the major agencies such as the US Corps of Engineers, the Geological Survey, the Tennessee Valley Authority and National Oceanic Atmospheric Agency (Flood Disaster, Public Law 1973). But this 100-year standard has never been written into Federal laws. The 100-year standard means that any structure in a flood-prone area should have its lower floor above the stipulated level of the flood, which has a one percent chance of recurring each year, i.e., the 100-year average return-period flood.

The synthesis of measures of land use and flood insurance involves prohibitory zoning such that area A in quadrant (C) of Fig. 4-1 is the direct measure of zoning benefit. Zoning restriction level is at J, where J is systematically varied at 5, 10, 25, 50, 75, 100, 125, 150, 175, 200, 225, and 250 year average return period. Residual flood damages characterized by B is indemnified by flood insurance, as a fiscal strategy that yields direct benefit in minimizing the economic dislocation resulting from flooding (see Appendix C).

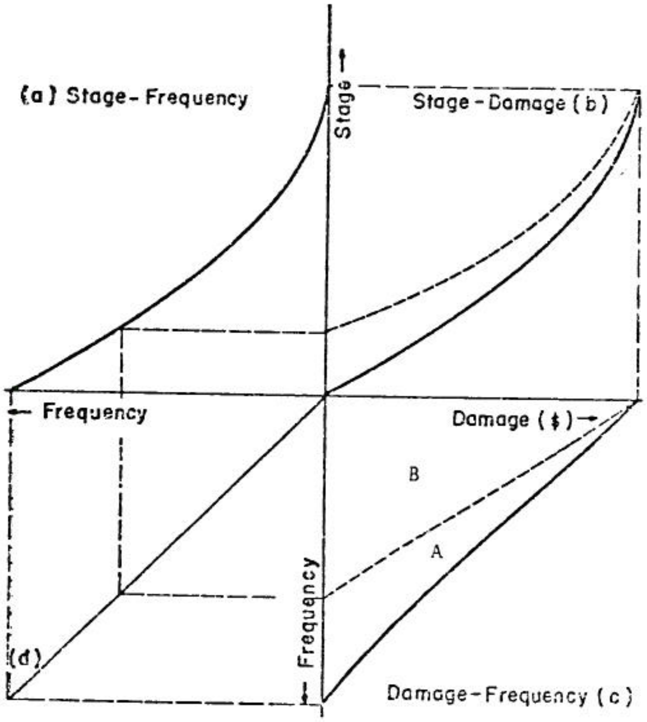


Fig. 4-1 Performance of the Synthesis of Prohibitory-Zoning and Flood-Insurance Measures

Hence the gross benefit of the joint nonstructural measures is

$$[B_a^{Z|J}]_{ijt\lambda} + [B_a^{In|J}]_{ijt\lambda} \qquad (4\text{-}32)$$

where $[B_a^{Z|J}]_{ijt\lambda}$ = the expected annual benefit of flood-loss reduction for land use i, location j, flood hazard λ with zoning restriction level at J, and $[B_a^{In|J}]_{ijt\lambda}$ = the expected annual benefit due to insurance as an integrated component of zoning, for the same land use i, location j, flood hazard λ and for the full period of zoning t.

The total $[C_a^{Z,\ In|J}]_{ijt\lambda}$ of zoning and insurance for an urban area is

$$[C_a^{Z,\ In|J}]_{ijt\lambda} = [C_a^{Z|J}]_{ijt\lambda} + [C_a^{In|J}]_{ijt\lambda} \qquad (4\text{-}33)$$

where $[C_a^{Z|J}]_{ijt\lambda}$ = the annual loss of capital, income and production (in this case land capital) and $[C_a^{In|J}]$ = the annual cost of the insurance program administrative, co-insurance, expense loading, etc.).

The annual net benefit in land-use zoning and insurance with the minimum flood level J is therefore:

$$[NB^{Z,In|J}]_{ijt\lambda} = [B_a^{Z|J}]_{ijt\lambda} + [B^{In|J}]_{ijt\lambda} - [C_a^{Z|J}]_{ijt\lambda} - [C_a^{In|J}]_{ijt\lambda}; \qquad (4\text{-}34)$$

(d) Results of the Relevant Synthesized Model Analysis as Applied to the Particular Test Basin, the Arkansas River Basin. The results of the synthesis of land-use zoning and flood-insurance measures for the urban area scattered along the Arkansas River are:

(1) The prohibitory zoning and insurance as joint measures are applicable to urban areas of the Arkansas River floodplains except for Pueblo and the Dry Creek in Pueblo City. In the latter areas, the annual cost of land sacrificed under the zoning restriction is very high.

(2) The relative competitiveness of flood insurance and restrictive zoning is influenced by the trade-off between two pairs of performance indices: zoning is superior to insurance when the trade-off between the expected flood-loss reduction is much greater than the annual cost of land sacrificed under the zoning restrictions. Zoning is inferior to insurance, or even inapplicable, when the cost of urban land is very high as in the central business district of Pueblo.

(3) The relative competitiveness of flood insurance versus land-use zoning is high since B/C = 1.66, when the cost weightage is assumed to be $\beta_{In} = 0.5$ rather than 0.73 as used by the Corps of Engineers (1970).

(4) In case the cost of land is relatively inexpensive, as it is the case along some urban stretches of the Arkansas River main stem, except in Pueblo and along the Dry Creek, zoning as a measure alone or integrated with flood insurance becomes more advantageous than flood insurance, as demonstrated by data in Tables 4-1 through 4-6. Results are:

Minimum Standard of 100-Year Return Flood

		B/C
(i)	Synthesized measures (zoning plus insurance)	$\frac{\$563,047}{\$288,247} = 1.95$
(ii)	Zoning alone	$\frac{\$485,423}{\$241,058} = 2.01$
(iii)	Insurance alone	$\frac{\$\ 85,905}{\$\ 51,750} = 1.66$

Global optimum of the system

(i)	Synthesized measures (zoning plus insurance)	$\frac{\$544,282}{\$238,243} = 2.28^*$

The global optimum is for different optimal flood standards from the lowest of 10-year to the highest of 125-year return-period floods.

(5) With the important qualification of relatively low cost of land, the above conclusions support the congressional testimony of Bernstein (Flood Insurance and Disaster: 93rd Congressional Hearings, June 1973). He claimed that a firm stand on the importance of land-use measures will, in the long run, prove to be of even greater importance than the sudden increase in flood or other insurance measures.

4.4 Synthesis of Intensive and Extensive Flood-Control Measures with the Other Categories of Measures

(a) General Description. Synthesis of intensive and extensive measures are done separately because the role of each basic category of measures is different.

TABLE 4-1 PROHIBITORY ZONING AND INSURANCE IN FREMONT COUNTY

Location	Annual Benefit from Zoning ($)	Annual Benefit from Insurance ($)	Gross Annual Benefit ($)	Total Annual Cost ($)	Annual Net Benefit ($)	B/C	Zoning level (Years)
Florence	14,584	5,240	19,824	8,193	11,631	2.42	25*
	17,108	3,144	20,252	9,951	10,302	2.04	100
	18,171	2,262	20,433	10,931	9,502	1.87	200
Cotopaxi	5,689	3,114	8,803	7,023	1,780	1.25	100
	6,463	2,472	8,935	7,065	1,870	1.27	125*
	7,219	1,844	9,063	7,973	1,090	1.14	200
Chandler & Oak Creek	132,165	32,869	165,034	58,166	106,867	2.84	25*
	156,050	13,043	169,093	69,243	99,851	2.44	100
	161,608	8,430	170,038	77,973	92,066	2.18	200
Coal Creek	6,897	8,299	15,196	12,145	3,051	1.25	25*
	12,188	3,907	16,095	15,921	174	1.01	100
	13,708	2,646	16,354	16,679	-326	0.98	200
Portland	13,204	21,004	34,208	20,698	13,509	1.65	10*
	31,046	6,194	37,240	33,508	3,732	1.11	100
	33,128	4,467	37,595	38,100	-506	0.99	200

TABLE 4-2 PROHIBITORY ZONING AND INSURANCE IN PUEBLO COUNTY

Location	Annual Benefit from zoning ($)	Annual Benefit from Insurance ($)	Gross Annual Benefit ($)	Total Annual Cost ($)	Annual net Benefit ($)	B/C	Zoning Level (Years)
		Partly Residential & Partly Central Business District (Pueblo)					
Fountain Creek (Below 8th Bridge)	137,816	65,591	203,407	116,578	86,830	1.75	25*
	179,946	30,623	210,569	180,284	30,285	1.17	100
	189,517	22,679	212,196	214,031	-1,835	0.99	200
		Central Business District (Pueblo)					
Fountain Creek (Above 8th Bridge)	0	185,073	185,073	277,988	-92,914	0.67	5
	57,275	137,535	194,810	1,331,552	-1,136,741	0.15	100
	82,645	116,478	199,123	1,651,820	-1,452,697	0.12	200
Dry Creek	0	2,796	2,796	2,623	174	1.07	5*
	565	2,327	2,892	19,225	-16,333	0.15	100
	1,049	1,926	2,975	21,797	-18,823	0.14	200

(1) Synthesis of Extensive Measures, which are essentially land-use treatment and structural measures, are possible with such nonstructural measures as flood forecasting (if the watershed is large enough), flood zoning and flood insurance. The *hierarchical-multilevel* approach outlined in Chapter 3 on the analysis of extensive physical flood control could be used to synthesize such basic categories of measures as are outlined above, with the effects studied of changing land use, synthesis of high and low flows, analysis of flood-land encroachment and designation of flood-land regulatory zones.

However, the role of extensive measures are limited to local floods of relatively small duration and flood peaks. The effects of upstream flood control by small dams are not felt by downstream flood control, although sedimentation control at upland watersheds has its influence felt downstream. Black (1972), in a series of laboratory studies, concluded that large dams are the most effective in reducing flood peaks for larger, regional or subregional climatic flood-producing events, whereas small dams are likely to be most effective for more *localized* flood producing conditions involving limited showers, snowmelt, reduced infiltration rates, etc.

(2) Synthesis of Intensive Measures, which are relatively capital intensive, have been criticized more for their feared environmental impacts than for their useful preventive role in abating flood damages in urban floodplains subjected to intense land use.

TABLE 4-3 PROHIBITORY ZONING AND INSURANCE IN OTERO COUNTY

Location	Annual Benefit from zoning ($)	Annual Benefit from Insurance ($)	Gross Annual Benefit ($)	Total Annual Cost ($)	Annual net Benefit ($)	B/C	Zoning Level (Years)
King's Arroyo	6,535	4,282	10,817	8,972	1,844	1.21	25*
	8,768	2,427	11,195	12,118	-922	0.92	100
	9,961	1,438	11,399	13,298	-1,299	0.86	200
Anderson Arroyo	12,371	2,456	14,827	4,934	9,893	3.01	10*
	14,171	962	15,133	6,406	8,727	2.36	100
	14,596	609	15,205	7,304	7,901	2.08	200
La Junta & North La Junta (Reach 2 Urban)	163,017	85,126	248,143	106,212	141,931	2.34	25*
	214,328	42,537	256,865	120,506	136,359	2.13	100
	231,816	28,022	259,838	131,738	128,101	1.97	200
Rocky Ford	20,541	6,889	27,430	11,900	15,529	2.31	25*
	25,301	2,938	28,239	13,529	14,710	2.09	100
	26,761	1,726	28,487	14,937	13,551	1.91	200

TABLE 4-4 COMPARISON OF INDIVIDUAL MEASURES WITH SYNTHESIZED MEASURES IN FREMONT COUNTY

Location	Zoning alone				Insurance alone				Zoning & Insurance				
	Annual Benefit	Annual Cost	B/C	Zoning level	Annual Benefit	Annual Cost	B/C	Zoning level	Annual Benefit	Annual Cost	B/C	Zoning level	Remarks
Florence	16,631	7,554	2.20	75	5,240	3,157	1.66	-	19,824	8,193	2.42	25*	Change in optimum
	17,108	8,057	2.12	100	3,144	1,894	1.66	-	20,252	9,951	2.04	100	When synthesized
	18,171	9,568	1.90	200	2,262	1,362	1.66	-	20,433	10,931	1.87	200	
Cotopaxi	5,689	5,576	1.02	100	3,114	1,876	1.66	-	8,803	7,023	1.25	100	No change
	6,463	5,147	1.26	125*	2,472	1,489	1.66	-	8,935	7,065	1.27	125*	
	7,219	6,862	1.05	200	1,844	1,111	1.66	-	9,063	7,973	1.14	200	
Chandler & Oak Creek	146,909	49,875	2.95	50*	32,869	19,800	1.66	-	165,034	58,166	2.84	25*	Change
	156,050	61,385	2.54	100	13,043	7,857	1.66	-	169,093	69,243	2.44	100	
	161,608	72,895	2.22	200	8,430	5,078	1.66	-	170,038	77,973	2.18	200	
Coal Creek	10,073	10,321	0.98	50	6,897	4,155	1.66	-	15,196	12,145	1.25	25*	Change
	12,188	13,568	0.90	100	12,188	7,342	1.66	-	16,095	15,921	1.01	100	
	13,708	15,086	0.91	200	13,708	8,256	1.66	-	16,354	16,679	0.98	200	
Portland	23,744	16,098	1.48	25*	21,004	12,653	1.66	-	34,208	20,698	1.65	10*	Change
	31,046	29,777	1.04	100	6,194	3,731	1.66	-	37,240	33,508	1.11	100	
	33,128	35,410	0.94	200	4,467	2,691	1.66	-	37,595	38,100	0.99	200	

TABLE 4-5 COMPARISON OF INDIVIDUAL MEASURES WITH SYNTHESIZED MEASURES IN PUEBLO COUNTY

Location	Zoning alone				Insurance alone				Zoning & Insurance				
	Annual Benefit	Annual Cost	B/C	Zoning level	Annual Benefit	Annual Cost	B/C	Zoning level	Annual Benefit	Annual Cost	B/C	Zoning level	Remarks
Fountain Creek	137,816	77,065	1.79	25*	65,591	39,512	1.66	-	203,407	116,578	1.75	25*	No change in optimum when synthesized
	179,946	161,837	1.11	100	30,623	18,448	1.66	-	210,569	180,284	1.17	100	
	189,517	200,369	0.95	200	22,679	13,662	1.66	-	212,196	214,031	0.99	200	
			Central Business District: Pueblo										
Fountain Creek (Above 8th Bridge)	0	166,498	0	5	185,073	111,490	1.66	-	185,073	277,988	0.67	5	No zoning practicable
	57,275	1,248,699	0.05	100	137,335	82,852	1.66	-	194,810	1,331,552	0.15	100	
	82,645	1,581,653	0.05	200	116,478	70,167	1.66	-	199,123	1,651,820	0.12	200	
Dry Creek (Pueblo)	0	938	0	5	2,796	1,684	1.66	-	2,796	2,623	1.07	5*	No zoning
	565	17,823	0.03	100	2,327	1,402	1.66	-	2,892	19,225	0.15	100	
	1,049	20,637	0.05	200	1,926	1,160	1.66	-	2,975	21,797	0.14	200	

TABLE 4-6 COMPARISON OF INDIVIDUAL MEASURES WITH SYNTHESIZED MEASURES IN OTERO COUNTY

Location	Zoning alone				Insurance alone				Zoning and Insurance				
	Annual Benefit	Annual Cost	B/C	Zoning level	Annual Benefit	Annual Cost	B/C	Zoning level	Annual Benefit	Annual Cost	B/C	Zoning level	Remarks
King's Arroyo	6,535	6,393	1.02	25*	4,282	2,580	1.66	-	10,817	8,972	1.21	25*	No change in optimum when synthesized
	8,768	10,656	0.82	100	2,427	1,462	1.66	-	11,195	12,118	0.92	100	
	9,961	12,432	0.80	200	1,438	866	1.66	-	11,399	13,298	0.86	200	
Anderson Arroyo	12,371	1,942	6.37	10*	2,456	1,480	1.66	-	14,827	4,934	3.01	10*	No change in optimum
	14,171	5,827	2.43	100	962	580	1.66	-	15,133	6,406	2.36	100	
	14,596	6,937	2.10	200	609	367	1.66	-	15,205	7,304	2.08	200	
LaJunta & N. La Junta (Reach 2 urban)	-	-	-	-	85,126	51,281	1.66	-	248,143	106,212	2.34	25*	Change
	214,328	94,882	2.26	100*	42,537	25,625	1.66	-	256,865	120,506	2.13	100	
	231,816	114,857	2.02	200	28,022	16,880	1.66	-	259,838	131,738	1.97	200	
Rocky Ford	-	-	-	-	6,889	4,150	1.66	-	27,430	11,900	2.31	25*	Change
	25,501	11,759	2.15	100*	2,938	1,770	1.66	-	28,239	13,529	2.09	100	
	26,761	13,897	1.93	200	1,726	1,040	1.66	-	28,487	14,937	1.91	200	

For many of the central business districts and for most of the industries situated in the principal business areas, zoning restriction may not be applicable. Hence the synthesis of intensive physical flood-control measures becomes vitally important, because the same degree of flood prevention or protection may be achieved by synthesizing channel improvements, auxiliary channel flood walls or levees, diversion tunnels or upstream reservoirs with insurance, flood forecasting or flood proofing. In this sense, zoning ordinances, subdivision regulations and building costs are not applicable.

Certain major physical constraints may prevent the use of structural measures. These include: the type and density of structures on, above and along the rivers may restrict channel enlargements to provide larger flood flows, the right-of-way acquisition may be too expensive for auxiliary channels, the flood walls or levees may be infeasible because of covered conduit in the business section of the city and the immediate proximity of important buildings, with highways and bridges along and across the streams. In this situation, a combination of detention reservoir at an upstream site with flood forecasting, flood proofing and flood insurance may be applicable.

The positive aspect of channelization is speeding the runoff of the flood hydrograph, but it also could sharpen and increase flood peaks downstream if either the slope, width or roughness is changed. Detention storage can be justified economically when the downstream floodplain suffers relatively large damages in relation to substantial upstream low cost storage.

(b) Statement of Objectives. The objective in synthesis is to identify the mix of measures through combination of measures, with the optimal levels of protection in each combination determined through combinatorial screening of mixes.

Resource allocation could be carried out through three approaches: 1) classical programming, 2) linear programming and 3) dynamic programming. Classical programming is highly amenable to analytical solution, with marginal analysis providing the resource allocation, but its main constraint is in its objective function which needs to be continuous, convex and quadratic. Linear programming is relatively efficient but the objective function and constraints are limited to linear performance functions of continuous variables, with the production function bounded by a convex region and the variables must be additive and mutually independent. However in relation to resource allocation for complex large interdependent flood control systems, linear programming is relatively inefficient in comparison to dynamic programming. The advantages of dynamic programming over classical and linear programming are: 1) its capability in optimizing nonconvex, nonlinear return functions, 2) its capacity to use arbitrary performance criterion instead of the least cost, fixed effectiveness criterion or fixed cost, maximum effectiveness criterion used in linear programming, 3) it obtains an absolute or global optimum solution rather than a relative optimal solution, the former specifying the optimal control at every state of the system for every sequence of time, 4) constraints simplify and hasten the speed of solution rather than complicate it as in the other two methods, 5) continuity of the performance variables are not required as in the other two methods because the performance functions could be discretized and 6) it optimizes the resource allocation without the need for a special analytic structure of the performance variables, although convexity is useful and can be used effectively to simplify the search process (Larson, 1968; de Neufville et al., 1968, 1971; and Gottfried et al., 1973).

Five major defects are listed by de Neufville et al., (1968) in relation to the calculus method: 1) inability to discriminate between relative maxima and minima, 2) inability to optimize without derivatives especially when the performance functions are either not differentiable or in discretized sets, 3) inability to maximize when the functions are piecewise linear as in linear programming, 4) inability to maintain solution stability, and 5) inability to yield to sensitivity analysis of performance parameters. Hence problem-oriented enumerative techniques in dynamic programming are developed to bypass the limitation of calculus and linear programming to solve nonlinear, nonconvex problems with an assurance of efficiency and global optimal policy being obtained, especially for stage-wise problems of low dimensionality.

(c) The Performance Models. The performance model is again an overall economic synthesis model in which are embedded all the submodels of economic and technological performances. Maximization of the total net return is

$$\max. \sum_{\iota}^{N_\iota} \delta_\iota^{St|P} \, NB_\iota^{St|P} + \sum_{\iota}^{N_\iota} \delta_\iota^{Z|St} \, NB_\iota^{Z|St}$$

$$+ \sum_{\iota}^{N_\iota} \delta_\iota^{In|St} \, NB_\iota^{In|St} + \sum_{\iota}^{N_\iota} \delta_\iota^{Ex|St} \, NB_\iota^{Ex|St} \qquad (4\text{-}35)$$

where St = structural measure; P = prediction measure; Z = zoning; filling and flood proofing measure; In = flood insurance and Ex = extensive measures such as soil and vegetative control at a localized area if necessary.

The net benefit component functions for the various synthesized measures could be summarized into a neat expression by

$$\max. \sum_{\Omega}^{N_\Omega} \sum_{\iota}^{N_\iota} \delta_\iota^{\Omega|St} \, NB_\iota^{\Omega|St} , \qquad (4\text{-}36)$$

where Ω = the number of the basic category of measures such as prediction, zoning, intensive and extensive physical control and flood insurance; ι = the number of measures in each basic group; δ_ι = the binary indicator whether any one of a list of measures in each basic group is included or omitted, hence δ_ι could either be 1 or 0; $\Omega|St$ = the combination of Ω basic groups that could be synthesized given that some elements of structural measures are to be used.

The technologic-hydrologic submodels are many depending on the nature and manner of synthesis. Since 1967, the Hydrologic Engineering Center has been developing relatively efficient submodels of flood hydrograph computations; computation of average annual damages at each damage center for existing conditions and for each plan of development, e.g. development for reservoirs and channels; the water surface profiles for river channels of any cross section for either subcritical or supercritical flow conditions and the effects of hydraulic structures such as bridges, culverts, weirs, embankments, and dams in the computation. Water surface profiles are determined for various frequency floods for both natural and modified channel conditions such as channel improvements, levees and floodways. The input for the latter may be in English or metric units.

Reservoir System Analysis performs multi-purpose routing of a reservoir-system based on uniform or varying unit-time interval and varying flow requirements at reservoirs, diversions and downstream control points. In addition, there is the reservoir-system operation for flood control which could simulate the sequential operation of a system of reservoirs of any configuration for controlling historical or synthetic floods to determine: 1) flood-control storage requirements of reservoirs, 2) the influence of a system of flood-control reservoirs on the spatial and temporal distribution of runoff in a basin and 3) operation criteria for minimizing flooding.

The Submodel of the Study. Although these submodels and computer programs listed above are useful, they do not preclude the writer to develop his submodel for the special needs of the problem. One of the dominating problems is the hydrologic interdependence of reservoir flood storage with downstream channel or levee capacity and to probe the hydrologic dependence and its effect on optimum levels of protection in combination or mixes of measures. The writer has developed with some assistance from the faculty, the submodel of synthesis, utilizing hydrologic dependence as a basis of performance. The selection of an upstream reservoir with a downstream improved channel creates hydrologic interdependence of the two structural measures. The larger the size of the reservoir, the smaller the size of the improved channel is needed, and vice versa. The hydrologic interdependence may be represented by the reduction in flood-peak parameter for evaluating the performance of the basic mix of measures. Residual flood damages found to be not optimal for flood protection by the structural mix, will be protected by nonstructural measures such as zoning, proofing and/or flood insurance. The only effective was to evaluate the optimal mix is by combinatorial screening.

Synthesis of Structural Measures and Flood Insurance, in the Case of the Arkansas River Example. Restrictive zoning has been found to be inapplicable to the city of Pueblo, because of the relatively high cost of urban land sacrificed under the restrictive zoning. Since the present evacuation or relocation are extremely costly and impractical at present, structural measures together with flood insurance is the next alternative mix studied.

Various structural alternatives have hitherto been analyzed by the Corps of Engineers, manely: 1) on-stream and off-stream dams, with diversion structures (1968); 2) massive flood channelization for the standard flood at the Fountain Creek; and 3) flood-storage dam at the Fountain Creek, 1.5 miles north of Pueblo City limits (1969).

Both on-stream and off-stream storage reservoirs with diversions were shown to be excessive in cost, while channelization for the standard project flood of the Fountain Creek along Pueblo requires an extensive amount of land and the cost of concrete-lined channel were found to be very high. The minimum width of channel of 300 ft gave a B/C ratio of 0.70.

The construction of the Fountain Flood-Control Reservoir, with standard-project flood protection, with the Fountain Creek channelization deleted, was the next alternative.

Given the high cost of zoning in Pueblo City, the synthesis of mix is to determine the optimal combination of structural measures with nonstructural measures, which in this case is the flood insurance. The structural mix is an upstream flood-storage reservoir and a downstream channelization.

Two-dimensional state dynamic programming is applied for the resource allocation. It is shown in Chapter 3 in the analysis of intensive, physical flood-control measures. The additional state requirement is due to flood-peak dependence in various structural measures.

Since the Fountain Creek joins the Arkansas River, the isolation of the Fountain Creek river system is necessary, since dependence analysis is needed for the Fountain Reservoir. The rest of the stagewise system upstream and west of Pueblo remains the same, with the Pueblo Dam being assumed fully operational in the synthesis.

Unlike the system of backward numbering adopted earlier in the one-dimensional state dynamic programming, the system numbering in the two-dimensional state is reversed, with the upstream stage where the dam is, being numbered 1, corresponding to the order of solution involving decreasing dependence as one travels downstream.

The function $f_1^{j_1}(Q,\$)$ is the maximum return function from allocating fund \$ for decreasing the flood peak Q by the Fountain Reservoir:

$$f_1^{j_1}(Q,\$) = \max_{\substack{0 \le Q_1 \le Q \le Q_T \\ 0 \le \$_1 \le \$ \le \$_T \\ \ell_1 \in J}} g_1[Q_1,\$_1,D_1,\ell_1;\lambda] \qquad (4\text{-}37)$$

in which $g_1[Q_1,\$_1,D_1,\ell_1;\lambda]$ = the return function, Q_1 = the flood peak reduction by storage dam, S_1 = the amount of fund allocated for the structural measure, ℓ_1 (Fountain Reservoir) and λ = the pricing level of 1967.

The function $f_2^{j_2}(Q,\$)$ is the maximum return from allocating the fund \$ for reducing the flood peak Q, in the two-stage subsystem, the Fountain Reservoir, the downstream channelization and the downstream residual flood insurance.

Therefore as shown by Fig. 4-2 and 4-3,

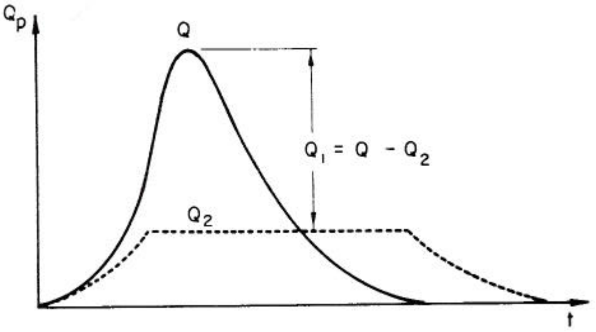


Fig. 4-3 Attenuation of Flood Hydrograph Peak

$$f_2^{j_2}(Q,\$) = \max_{\substack{0 \le Q_2 \le Q \le Q_T \\ 0 \le \$_2 \le \$ \le \$_T \\ \ell_2 \in J}} [g_2(Q_2,\$_2,D_2,\ell_2;\lambda) + f_1^{j_1}(Q_1,\$_1)] \qquad (4\text{-}38)$$

The reduction of hydrograph flood peak by the reservoir storage is $Q_1 = Q - Q_2$, $Q_2 = Q - Q_1$, where Q_2 = the downstream channel peak flow. Hence

$$f_2^{j_2}(Q,\$) = \max_{\substack{0 \le Q_2 \le Q \le Q_T \\ 0 \le \$_2 \le \$ \le \$_T \\ \ell_2 \in J}} [g_2(Q_2,\$_2,D_2,\ell_2;\lambda) + f_1^{j_1}(Q-Q_2,\$-\$_2)] \qquad (4\text{-}39)$$

where ℓ_2 = the mix of structural flood-control measures (reservoir plus channel) and flood insurance; j_2 = a vector of sample choice: the Fountain Reservoir downstream, downstream channelization and the residual flood risk covered by insurance, and J = the set space of feasible structural and nonstructural measures (reservoir, channel and insurance).

The general recursive relationship is easily obtained (Haimes, Y.Y., 1972):

$$f_I^{j_I}(Q,\$) = \max_{\substack{0 \le Q_I \le Q \le Q_T \\ 0 \le \$_I \le \$ \le \$_T \\ \ell_I \in_I J}} [g_I(Q_I,\$_I,D_I,\ell_I;\lambda) + f_{I-1}^{j_{I-1}}(Q_{I-1},\$_{I-1})] \qquad (4\text{-}40)$$

and $j_I = j_{I-1} + \ell_I$.

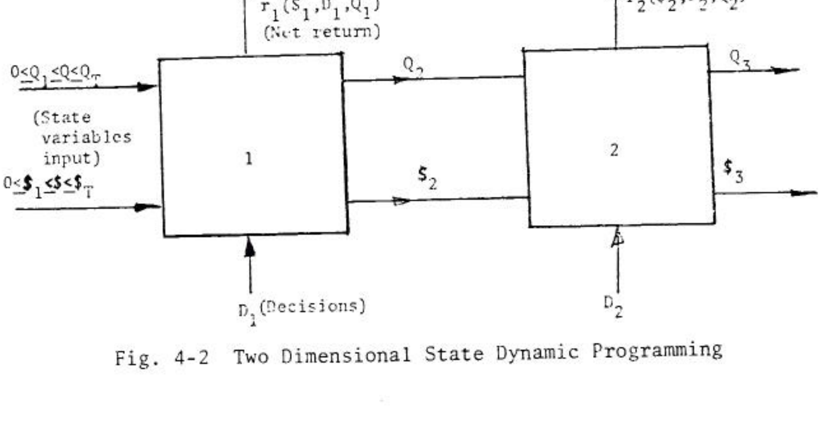


Fig. 4-2 Two Dimensional State Dynamic Programming

Since λ is fixed at 1967 price level, ℓ_I are measures ε J and D_I is a function of $\$_I$; for convenience of programming the above recursive relationship is broken down into simplified equations, so that for the Fountain Dam Project at Pueblo

$$f_1^{j_1}(Q,\$) = \max_{\substack{0\leq Q_1\leq Q\leq Q_T \\ 0\leq \$_1\leq \$\leq \$_T \\ \ell_1 \,\varepsilon\, J}} g_1(Q_1,\$_1) \tag{4-41}$$

and for

$$f_2^{j_2}(Q,\$) = \max_{\substack{0\leq Q_2\leq Q\leq Q_T \\ 0\leq \$_2\leq \$\leq \$_T \\ \ell_2 \,\varepsilon\, J}} [g_2(Q_2,\$_2) + f_1^{j_1}(Q-Q_2,\$_1)] \tag{4-42}$$

The *solution strategy* with the two-dimensional state variables (Q and \$) is to keep one variable temporarily fixed, while varying the second variable (Nemhauser, 1966). One must have a *table* containing the *optimal* functions of net returns for all values of the first state variable Q fixed at each computer run, for each of the second state variables \$. With this strategy, the global optimum could be found.

The solution procedure can be handled in two steps:

Step one. To determine the *optimal* return function for the various mixes of measures, for a given flood level Q temporarily fixed at each computer run. The combinatorial screening or scheduling is carried out for:

(i) single-numbered mutually exclusive measures,

(ii) pairwise interdependent measures, and

(iii) mutually inclusive interdependent measures.

The scheduling is aided by J, the set space of *feasible* measures, which is,

$$J = \binom{n}{m}\binom{n_p-1}{n_p-1-d_f} \tag{4-43}$$

and by further simplification,

$$J = \binom{n}{m}\left(\frac{(n_p-1)!}{(n_p-1-d_f)!\,(d_f)!}\right) \tag{4-44}$$

where n = the total number of measures available, m = the number of measures taken in the mix, n_p = the flood-protection level number, i.e., x-year average return period of flood protection (50-year unit interval), and d_f = the degrees of freedom of measures, $d_f = m - 1$. In fact, J ε Θ, where Θ is the *total* set space of measures. There are theoretically five major groups as classified in Chapter 2. J is the feasible set from *the total set* Θ.

Step two. The solution strategy is to realize that the optimum of the subsystem (1) and (2) of the Fountain Reservoir channel improvement and flood insurance is not necessarily the optimum of the whole *Pueblo County* flood-control system. Therefore, with a given Q fixed for each computer run, the one-dimensional dynamic programming allocation model is used to evaluate the *optimal policy* for each Q temporarily fixed. Hence, a final tabulation is obtained containing the *optimal* mix of measures synthesized in the manner described above, with various fixed values of Q and \$ (see Appendix E).

The flood-dependence problem affects the downstream flow. The Corps of Engineers has established that dependence as far as Reach 4, near the Apishapa River, close to the Pueblo County line. Hence the necessity for considering the whole Pueblo County flood-control system.

Combinatorial Screening of Mixes. The combinatorial screening is effective because there is a lesser likelihood of missing out an optimal mix of measures. For instance, the Corps of Engineers *one-shot-in-the-dark* deterministic approach shows a reservoir for the Standard-Project-Flood flood protection but it may not be the optimal choice.

To illustrate the use of the combinatorial screening, let it be assumed that one needs the flood protection up to the 400-year return-period floods. The number of *feasible* measures are three (reservoir, channel improvement and flood insurance, and that one does not know a priori what mix of measures could be selected.

Then with n = 3 feasible measures are m = 1, or 2, or 3, and n_p = 8, then the d_f = 0, 1, or 2 since d_f = m-1 with n_p = the number of flood protection levels, which is obtained from the 400-year flood divided by a unit of 50-year return period. In other words, the flood-control measures are incremented at every 50-year interval to reduce the computations. A finer grid can be provided when desired.

Data Provided:	$n = 3$, $n_p = 8$; Q = 400-year R.P. Flood		
Nos. of measures (m):	1	2	3
Degrees of freedom (d_f):	0	1	2
Nos. fo possible combinations:	3	21	21

For nine sets of Q with n_p = 8, 7, 6, 5, 4, 3, 2, 1, and 0, the digital computer CDC 6400 runs only 6 seconds (see Appendix D).

(d) <u>The Results of Synthesis of Three Measures: Fountain Reservoir, Channel Improvement and Insurance for Pueblo City and Downstream up to Reach 4.</u>

(1) Since zoning is found not to be feasible for Pueblo City, the synthesis of mixes of measures has resulted in $D_1C_2I_5$ as the optimum.

(2) The mix $D_1C_2I_5$ is a combination of reservoir, concrete-lined channel and insurance, with flood protection provided up to the 400-year return-period flood.

(3) Subscripts D_1, C_2, I_5 mean that the total 400-year return-period is factored into three interval

components, which are 50-, 100- and 250-year return-period intervals of flood frequency.

(4) The optimal mix has the global optimum net return. It is necessary to go through this process of synthesis because one is out to obtain the *best* mix and to establish its optimal competitiveness with respect to the other synthesized measures. On the other hand, when the Corps of Engineers designed the Fountain Reservoir for Pueblo City, the interest was in providing for the standard 300-year project flood protection, in the physical-control sense.

(5) The results are summarized in Table 4-7, and the graph in Fig. 4-4 shows the relative position in the annual net benefit between the global optimum from $D_1C_2I_5$ mix with the Corps of Engineers' Fountain Reservoir. The difference in net return is significant. This is shown in the Table 4-7.

(6) Flood insurance for Pueblo City has a higher *benefit* weightage here than in the previous synthesis of land-use zoning and insurance. The increase in benefit weightage is about 46 percent because of expected land-enhancement benefit due to the increased flood protection from the reservoir and the improved channel.

(7) Sensitivity analysis is carried out for the cost weightage of 0.76 (as used by the Corps of Engineers, 1970) instead of 0.50 as used in this study. There is a significant difference in the optimal net benefit (about 20 percent) from the mix of $D_1C_2I_5$ measures, if the cost weightage is increased in insurance from 0.50 to 0.76.

(8) In addition, the channel component begins to become competitive when the cost of insurance begins to rise. A comparison of the two sets of tables in mixes, shows a rapid elimination of the insurance component in favor of the channel-improvement component.

(9) The B/C ratio criterion usually underrates the productivity of a project with high annual costs. The extent of the distortion is shown by de Neufville and Stafford (1971). When a project must bear both the initial capital costs and the recurring costs of operation and maintenance (like the flood insurance), the benefit-cost criterion fails to provide a clear picture of the value of a project. Hence, the *net present value* criterion is used to maximize the value of a system especially when the capital resources are limited and must be allocated to *most* productive projects. Both methods, net present value criterion and net

TABLE 4-7 FLOOD CONTROL SYSTEM OF PUEBLO COUNTY

LEVEL OF FLOOD PROTECTION UP TO 400-YEAR RETURN-PERIOD FLOOD

Optimum Measures at Fountain Creek	Annual Cost $\$10^3$	Net Annual Benefit $\$10^3$	Gross Annual Benefit $\$10^3$	B/C Ratio	Remarks
Insurance Cost Factor $\beta_{In} = 0.50$:					
C_1I_7	520.00	512.60	2,426.40	1.99	No flow dependency. Increasing flow dependency from D_1 to D_8
$D_1C_2I_5$	1,390.00	841.40*	2,231.40	1.61	
D_2I_6	1,550.00	802.20	2,352.20	1.52	
D_3I_5	1,640.00	788.00	2,428.00	1.48	
D_4I_4	1,790.00	736.00	2,526.00	1.41	
D_5I_3	1,840.00	745.80	2,585.80	1.41	
D_6I_2	1,910.00	748.80	2,658.80	1.39	
D_7I_1	2,010.00	723.80	2,733.80	1.36	
D_8	1,870.00	556.40	2,426.40	1.30	
Insurance, Cost Factor $\beta_{In} = 0.76$ (Corps of Engineers)					
C_1I_7	700.00	341.28	1,041.28	1.49	No flow dependency
$D_1C_2I_5$	1,510.00	714.02*	2,240.02	1.47	
$D_2C_2I_4$	1,710.00	690.01	2,400.01	1.40	
$D_3C_3I_2$	1,700.00	702.09	2,402.90	1.41	
$D_4C_3I_1$	1,760.00	588.09	2,348.09	1.33	
D_5C_3	1,850.00	571.16	2,421.16	1.31	
D_6C_2	1,800.00	561.18	2,361.18	1.31	
D_7C_1	2,000.00	522.20	2,522.20	1.26	
D_8	1,920.00	486.64	2,406.64	1.25	

Note: 1) Asterisk indicate global optimum

2) Downstream reaches No. 7 to 4 inclusive are entirely under flood insurance, up to 400-year flood frequency

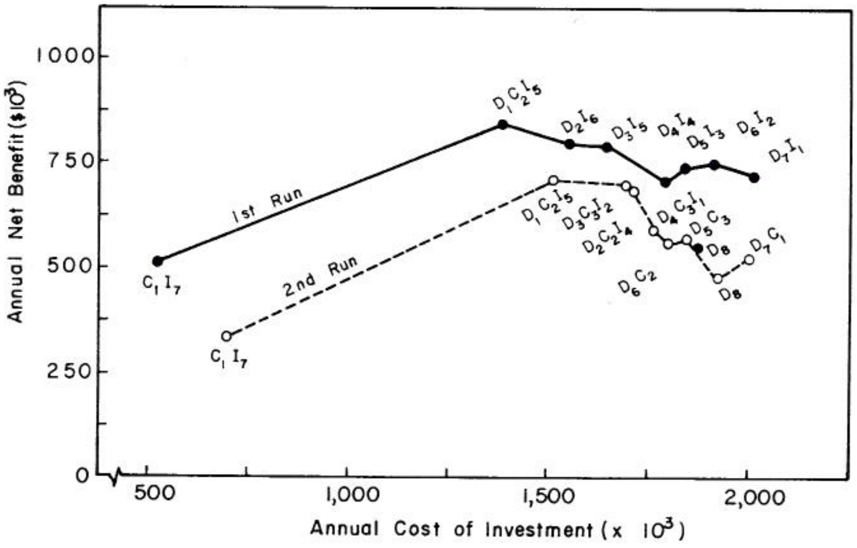


Fig. 4-4 Sensitivity Analysis of Flood-Control Measures to Alternate Weightage of Flood-Insurance Cost: $\alpha = 0.5$ and $\alpha = 0.76$ (Corps of Engineers). Envelope Curves Indicate the Two Different Weightages.

annual benefit criterion are numerically equivalent. Protection is defined loosely here. It is not meant to be only physical control protection. It is a protection through a combination of physical, social and fiscal measures and factors.

4.5 Synthesis of Flood-Insurance Measure with the Other Categories of Basic Measures

(a) General Statement: Flood insurance as a fiscal measure has two primary objectives: 1) to help prevent unwise used of land where flood-damage risks are relatively high, and 2) the prompt restoration of the flooded areas to economic health. In pursuance of these twin objectives, minimization of future flood-damage hazard and the rapid restoration of the flooded areas to economic health, the flood-insurance measure with federal-private joint participation is a unique compromise between two extreme positions--the individual bearing the losses and the Federal Government bearing all the losses. Hence, a realistic program to deal with flood hazards should adopt some middle ground; private assumption of risk and responsibility in floodplain occupancy supplemented by a national public insurance program. The occupants of flood-prone areas must pay a considerable part of the floodplain occupancy costs, yet some parts of the costs covering public risks could be borne by public programs. The Federal Government is, therefore, a risk averter and could operate on geographic and time scales that individuals cannot.

However, the flood-insurance programs could operate conjunctively or jointly with the other basic category of programs or measures. In many instances flood-insurance programs increasingly would have to be complementary to other flood-control measures, not necessarily competitive against them, because in itself flood insurance would not reduce flood damages to present properties, although it might serve to discourage unwise occupancy of high flood-risk areas (Insurance and Other Programs for Financial Assistance to Flood Victims, 1966).

(1) With the prediction measure. Flood insurance would still be dependent upon not only a continuance but an extension of the flood-forecasting and flood-warning programs. The more effective the prediction measure is, the lower would be the insurable flood damages. Hence, the needs of the flood-insurance measure may in fact aid in improving flood-forecasting and flood-warning measure.

(2) With zoning, filling and flood-proofing measures. As a valuable adjunct to flood insurance, land-use planning of flood prone areas is to keep development out of areas where flood risks are higher than probable gains. Such land-use planning would reduce the creation of high risk zones, and help to prevent the damages arising in present areas because of the effects of new structures on streamflow when floods do occur. The long-term solution to the flood-damage problem in the highest flood-risk zones would often be a conversion of the land to other uses. If existing properties are situated below the restricted zoning level, and where the cost of restoration is greater than the present value of the damaged structure, then it is reasonable to buy the property from the owner, applying the insurance to the purchase price, rather than paying him the insurance for restoration of the structures. The risk exposure in such a situation could be relatively high.

(3) With intensive physical flood-control measures. Even with flood-protection works, some risk of flood damage remains, since flood control is never absolute because the highest levee or flood wall or dam can be topped someday. Moreover, there is an economic optimum to the relative degree of protection and at some point greater protection may cost more than it is worth. Hence, flood insurance with the residual risk may be practical and economically feasible. However, the flood insurance premiums would be relatively low in these protected areas because of the infrequency of floods after the protection works are built, but loss may be large when thay also occur. Therefore, flood insurance would cover the loss sustained in the occurrence of rare event accompanied by catastrophic losses that remain buried in the residual *average* annual damages too small to justify protective works for such contingencies (Krutilla, 1966).

(4) With a program of disaster relief to flood victims. An effective program of flood insurance would still require a program of relief to flood victims. The need for public disaster relief arises because there may be some individuals who do not have flood insurance, in spite of the mandatory nature of the public flood-insurance program. But the aid to underprivileged poor families would amount to a maximum ceiling of $3,000 for low-income family. The aid is to indemnify the *uninsured* property losses of poor families, and thereafter, to aid such families in meeting extraordinary disaster related expenses. Relief might also take the form of subsidized loans from the Small Business Administration in the USA which have previously been extended to disaster victims, but the priority is to employers who would otherwise have to lay off their employees and workers.

Careful attention is required in administering the flood insurance program in conjunction with the other basic structural and nonstructural measures, to remove inequity and to reduce flood-damage hazards. Two factors are involved: 1) the extent of improvements man has made within the flood-prone area, which affects the monetary damage due to a flood of given magnitude, and 2) the method of pooling the risks, minimizing and distributing burdens equitably among the property owners protected by such insurance. Under the second factor the hydrologic method of estimating flood-damage risk consists of two basic elements: the correct flood-magnitude frequency distribution, and the correct depth-damage relationship. Under existing constraints of limited manpower and time, the writer feels that inequity in charging insurance premiums could arise because of the present urgency of the flood-insurance program and the current methodology adopted in assessing risk hazards (Kunreuther et al, 1970).

(b) Statement of Objectives: The objective function in the synthesized model is again the maximization of expected annual net benefit of the insurance measure with the other basic categories of measures such that

$$\text{max.} \sum_{\Omega}^{N_\Omega} \sum_{\iota}^{N_\iota} \delta_\iota^{\Omega|\text{In}} \, \text{NB}_\iota^{\Omega|\text{In}} \qquad (4\text{-}45)$$

where Ω = the number of basic groups of measures synthesized; ι = the number of measures in each basic group and $\Omega|\text{In}$ = the number of basic groups synthesized, given the flood-insurance measure as the basic group.

(c) The Performance Models of Synthesized Measures. The performance models of synthesized measures are already indicated by the above expression and its effective basic components are in Ω. A general model of its performance is

$$\text{max.} \sum_{\Omega}^{N_\Omega} \sum_{\iota}^{N_\iota} \delta_\iota^{\Omega|\text{In}} \, \text{NB}_\iota^{\Omega|\text{In}} = \sum_{\iota}^{N_\iota} \delta_\iota^{\text{In}|\text{P}} \, \text{NB}_\iota^{\text{In}|\text{P}}$$

$$+ \sum_{\iota}^{N_\iota} \delta_\iota^{\text{In}|\text{Z}} \, \text{NB}_\iota^{\text{In}|\text{Z}} + \sum_{\iota}^{N_\iota} \delta_\iota^{\text{In}|\text{St}} \, \text{NB}_\iota^{\text{In}|\text{St}} + \sum_{\iota}^{N_\iota} \delta_\iota^{\text{Di}|\text{In}} \, \text{NB}_\iota^{\text{Di}|\text{In}} \qquad (4\text{-}46)$$

where $\text{In}|\text{P}$ = the insurance program given the flood-prediction measure; $\text{In}|\text{Z}$ = the insurance program given the zoning and flood proofing; $\text{In}|\text{St}$ = the insurance program given the structural measure and $\text{Di}|\text{In}$ = the public disaster program given the flood-insurance measure.

(d) The Results of the Synthesized Model Analysis as Applied to the Test Region, the Arkansas River Basin. The results of the analysis as applied to the Arkansas test region is already given in the previous section 4.4, with insurance supplementing structural measures at the Fountain Creek and flood insurance for the sequential stages from river reaches no. 7 to no. 4 in *Pueblo County*. All the downstream and upstream counties excluding Pueblo have zoning and flood-insurance coverage along the urban sectors of the river. These results are shown in Tables 4-1 to 4-6.

Chapter 5
REGIONAL INPUT-OUTPUT MODEL FOR FLOOD CONTROL

The input-output model approach does not seem to have been well tested so far in relation to regional flood control system. This type of model has been used in other areas of water resources development. An example is the multi-regional water allocation systems of western U.S. (Lofting and Davis, 1968; Lofting and McGauhey, 1968; Davis, 1968; and Jona Bargur, 1969). The model was used in studying the impact of droughts on regional economic performance (Millan, 1972). But as an aid to the solution of regional flood problems, its potential has not been yet widely investigated.

A regional input-output model represents structural interdependencies of a regional economy. The model is a form of linear systems analysis which could be used to evaluate the impact of flood control upon the regional economy, sector by sector. This is done in terms of an economic stimulus, if any, to one or more sectors which may experience a flood-loss reduction by using flood control. The effect is compared then with the alternative of no flood control.

The purpose of this chapter is: (a) to present a methodology of economic systems performance by the input-output analysis, in studying the economy-flood control linkage, and (b) to test the methodology on the Arkansas River Basin example.

The objective of this analysis is: (a) If all data relevant to establishing the economic viability of a flood-control scheme are assembled as completely as feasible, and (b) If all the factors which need to be taken into account are recognized and carefully considered, then, "it will generally be possible to arrive at a reasonable defensible decision" (Lofting, 1972, quoting United Nations, 1958, panel of experts on river basin development).

5.1 Regional Input-Output Model Applied to Flood-Control Systems

For the purpose of developing a general model applicable to flood control, suppose there are several regions or districts in a hydrologic basin requiring the flood protection. Then by applying the alternatives with and without flood protection, one may develop theoretically two separate tables of inter-regional transactions.

Table 5-1 is the **alternative** without flood protection and Table 5-2 is the alternative with the flood control.

The basic inter-regional accounting system is shown in Table 5-1. Quadrant I is the final demand (use quadrant), essentially the required net output of the regional productive system. Quadrant II is the inter-regional transaction matrix which describes the technology of the inter-district economy under study. Quadrant III shows a row vector of value added (wages, salaries, and profits, etc., including taxes) in the primary inputs row.

TABLE 5-1 BASIC INTER-REGIONAL ACCOUNTING SYSTEM WITHOUT FLOOD PROTECTION

		Purchasing Sectors								Gross Output
		Intermediate Use			Final Use (Net Output)					
Region		Region 1	2	3	Investment	Consumption	Government	Exports	Total Final Use	Production
Producing sector	1	X_{11}	X_{12}	X_{13}	I_1	C_1	G_1	E_1	Y_1	X_1
	2	X_{21}	X_{22}	X_{23}	I_2	C_2	G_2	E_2	Y_2	X_2
	3	X_{31}	X_{32}	X_{33}	I_3	C_3	G_3	E_3	Y_3	X_3
		(Quadrant II)			(Quadrant I)					
Primary inputs (value added)		V_1	V_2	V_3	V_I	V_C	V_G	V_E		V
Secondary inputs* (value added)		U_1	U_2	U_3	U_I	U_C	U_G	U_E		U
		(Quadrant III)			(Quadrant IV)					
Total Production		X_1	X_2	X_3	I	C	G	E	Y	X

TABLE 5-2 BASIC INTER-REGIONAL ACCOUNTING SYSTEM WITH FLOOD PROTECTION

		Purchasing Sectors								Gross Output
		Intermediate Use			Final Use (Net Output)					
		Regions 1	2	3	Investment	Consumption	Government	Exports	Total Final Use	Production
Producing Sections	Regions 1	M_{11}	M_{12}	M_{13}	I'_1	C'_1	G'_1	E'_1	N'_1	M_1
	2	M_{21}	M_{22}	M_{23}	I'_2	C'_2	G'_2	E'_2	N'_2	M_2
	3	M_{31}	M_{32}	M_{33}	I'_3	C'_3	G'_3	E'_3	N'_3	M_3
Primary inputs (value added)		L_1	L_2	L_3	L_I	L_C	L_G	L_E		L
Secondary inputs* (value added)		W_1	W_2	W_3	W_I	W_C	W_G	W_E		W
Total Production		M	M	M	I'	C'	G'	E'	N'	M

The secondary inputs in quadrant III would include tangible and intangible flood damages for a given level of flooding.

The tangible flood damages are:

(a) urban property damage (residential, commercial and industrial, which include buildings damaged or destroyed, damage or loss to inventories and production facilities);

(b) rural property damage (crops, livestock, etc.);

(c) transportation and communication systems (highways, railways, bridges) and,

(d) utility system (gas, light, power, water and sewage facilities).

The intangible flood damages are:

(a) loss of income; rehabilitation;

(b) loss of life; injury - (casualties);

(c) emergency short-term aid (Red Cross, evacuation);

(d) long-term recovery costs (loan costs for reconstruction) and,

(e) any other non-pecuniary effects not classified.

The production or technical coefficient matrix therefore takes account of the economic dislocation effects of flooding at a given level, since X_i includes U_i, where $i = 1,2,3$. Without flood protection the technical coefficient is

$$X_{ij} = a_{ij} X_j, \quad i,j = 1,2,3. \tag{5-1}$$

and therefore,

$$a_{ij} = \frac{X_{ij}}{X_j}, \quad i,j = 1,2,3. \tag{5-2}$$

	Sector				
	S_1	S_2	S_3	Net Output	Gross Output
S_1	a_{11}	a_{12}	a_{13}		
S_2	a_{21}	a_{22}	a_{23}		
S_3	a_{31}	a_{32}	a_{33}		

With flood protection it is theoretically possible for the inter-regional transaction matrix to change. The changes may be reflected by an optimal flood protection to be provided, or the protection at any other level to be specified.

Table 5-2 shows the basic inter-regional accounting system with a given specified level of flood protection. The secondary inputs in flood protection are the sum of the expected present value of cost of flood protection, the expected residual damage and the expected residual rehabilitation cost.

The production or technical coefficients with the flood protection alternative then become

$$b_{ij} = \frac{M_{ij}}{M_i}, \quad i,j = 1,2,3. \tag{5-3}$$

Subdivision Into An Inter-industry Model. The inter-regional input-output model, thus far outlined for illustrative purposes, is highly aggregated. In this case the problem arises that an economic breakdown by production sectors is necessary. Then there is an imbedded provision for it. The detail subdivision is made in the endogenous sector, with agriculture, manufacturing and services shown as examples (Table 5-3).

5.2 Mathematical Equation for the Input-Output Model

Given a regional economy divided into n production sectors the balance equations which state that the aggregate sales of a particular sector are equal to the total purchases of that sector are (Davis, 1971):

$$X_i = X_{ij} + \dots + X_{in} + Y_i, \quad i,j = 1,\dots,n \qquad (5\text{-}4)$$

where X_i = the total output of industry i, X_{ij} = the amount of output of industry i sold to industry j, and Y_i = the final demand for the output of industry i.

It is assumed that the inputs into each sector are a direct and stable function of the output of that sector, i.e.,

$$X_{ij} = a_{ij}\, X_j, \quad i,j = 1,\dots,n. \qquad (5\text{-}5)$$

Then

$$X_i = a_{ij}\, X_j + Y_i; \quad i,j = 1,\dots,n \qquad (5\text{-}6)$$

which may be written more compactly as

$$\underline{X} = \underline{AX} + \underline{Y}, \text{ and} \qquad (5\text{-}7)$$

the general solution of the system may now be expressed as

$$\underline{X} = (\underline{I}-\underline{A})^{-1}\underline{Y}, \qquad (5\text{-}8)$$

where $\underline{X}$ = the column vector of total output, $\underline{Y}$ = the column vector of final demand, a_{ij} = the technical coefficient computed as $X_{ij}/X_j = a_{ij}$, and A = the input regional coefficient matrix.

5.3 Forecast of Flood Damage in Floodplains

One can utilize the input-output model of the economic system to analyze the flood damage and to forecast the flood damage of the future. The forecast, however, must be short-term because of the underlying assumptions of input-output and the working constraints, e.g., assumptions about the general equilibrium of the economic system and on the stability of the transaction coefficients (Shefer, 1973).

Suppose that in 1974 one could estimate the matrix of present flood-damage coefficients (with the flood protection provided). The present Damage Matrix $[\underline{P}^{74}]$ is the expected residual damage with protection level specified at p_o.

The future Damage Matrix $[\underline{P}^{79}]$ in five years time will be

$$[\underline{P}^{79}]_{6x1} = [\underline{P}^{74}]_{6xn}\, [\underline{I}-\underline{A}^{74}]^{-1}_{nxn}\, [\underline{Y}^{79}]_{nx1} \qquad (5\text{-}9)$$

where $[\underline{P}^{79}]$ = the projected residual matrix of flood damages computed for 1979 given the level of flood protection provided in 1974, $[\underline{P}^{74}]$ = the matrix of direct flood damage coefficients in 1974 after the flood-protection level p_o is provided, $[I-A^{74}]^{-1}$ = the inverse of the identity matrix $[\underline{I}]$ minus the matrix of direct intersectoral transaction coefficients computed for the year 1974, and maintained constant, and $[\underline{Y}^{79}]$ = the projected final demand vector for the year 1979.

Simplifying the above assumption gives an alternative equation

$$[\underline{P}^{79}]_{6x1} = [\underline{P}^{74}]_{6xn}\, [\underline{X}^{79}]_{nx1}, \qquad (5\text{-}10)$$

since

$$[\underline{X}^{79}]_{nx1} = [\underline{I}-\underline{A}^{74}]^{-1}_{nxn}\, [\underline{Y}^{79}]_{nx1}, \qquad (5\text{-}11)$$

where $[\underline{X}^{79}]_{nx1}$ = the column vector of total output.

TABLE 5-3 REGIONAL, TECHNICAL COEFFICIENT MATRIX

	Industry Purchasing	Endogenous Sector									Exogenous Sector	Gross Output
		District 1			District 2			District 3				
	Industry Producing	Ag. 1	M. 2	S 3	Ag. 1	M. 2	S. 3	Ag. 1	M. 2	S. 3		
District 1	Ag. 1	ℓ_{11}	ℓ_{12}	ℓ_{13}	m_{11}	m_{12}	m_{13}	n_{11}	n_{12}	n_{13}		
	M. 2	ℓ_{21}	ℓ_{22}	ℓ_{23}	m_{21}	m_{22}	m_{23}	n_{21}	n_{22}	n_{23}		
	S. 3	ℓ_{31}	ℓ_{32}	ℓ_{33}	m_{31}	m_{32}	m_{33}	n_{31}	n_{32}	n_{33}		
District 2	Ag. 1	o_{11}	o_{12}	o_{13}	p_{11}	p_{12}	p_{13}	q_{11}	q_{12}	q_{13}		
	M. 2	o_{21}	o_{22}	o_{23}	p_{21}	p_{22}	p_{23}	q_{21}	q_{22}	q_{23}		
	S. 3	o_{31}	o_{32}	o_{33}	p_{31}	p_{32}	p_{33}	q_{31}	q_{32}	q_{33}		
District 3	Ag. 1	r_{11}	r_{12}	r_{13}	s_{11}	s_{12}	s_{13}	t_{11}	t_{12}	t_{13}		
	M. 2	r_{21}	r_{22}	r_{23}	s_{21}	s_{22}	s_{23}	t_{21}	t_{22}	t_{23}		
	S. 3	r_{31}	r_{32}	r_{33}	s_{31}	s_{32}	s_{33}	t_{31}	t_{32}	t_{33}		

The two major limitations of this economy-flood damage linkage are:

(a) $[\underline{I}-\underline{A}]^{-1}_{nxn}$ = the constant production coefficient matrix $\underline{A}$, which explains the necessity for short-term forecast, and,

(b) $[\underline{P}^{74}]_{6xn}$ = the constant damage-coefficient matrix, a simplification made for the forecast of damages (Tables 5-4 and 5-5).

The base-year 1974 flood-damage matrix with the flood protection (p_o) is reduced to damage-coefficient matrix by,

$$d_{i,j} = \frac{D_{m_i s_j}}{D_i}, \quad (i = 1,2,\ldots,6) \text{ and } (j = 1,2,\ldots,n), \qquad (5\text{-}12)$$

where M_i ($i = 1,2,\ldots,6$) represents the flood-control measures, namely M_1 meterological, M_2 flood warning, M_3 zoning, M_4 extensive watershed treatment, M_5 structural and M_6 insurance.

Note that the projected residual flood damages $[\underline{P}^{79}]_{6x1}$, obtained from the forecast equation, could be factored back to absolute damages as shown in Table 5-6, where

$$D^{79}_{m_i s_j} = d_{ij} D^{79}_{i}, \qquad (5\text{-}13)$$

($i = 1,2,\ldots,6$), ($j = 1,2,\ldots,n$), and d_{ij} assumed constant between 1974 and 1979.

However, if no flood protection is provided, the sectors will have a present-day matrix of expected flood losses without protection, similar in form to those above. The forecasting could be made in a similar way.

There is a further limitation in using the above method. Applying the constant damage coefficients presumes that the flood-damage frequency distribution

TABLE 5-4 BASE YEAR 1974 FLOOD DAMAGE

j	SECTORS				Total Residual Damages	Gross Output
i	s_1	s_2	....	s_n		
M_1	$D^{74}_{m_1 s_1}$	$D^{74}_{m_1 s_2}$	....	$D^{74}_{m_1 s_n}$	D^{74}_1	
M_2	$D^{74}_{m_2 s_1}$	$D^{74}_{m_2 s_2}$	....	$D^{74}_{m_2 s_n}$	D^{74}_2	
M_3	$D^{74}_{m_3 s_1}$	$D^{74}_{m_3 s_2}$	....	$D^{74}_{m_3 s_n}$	D^{74}_3	
M_4	$D^{74}_{m_4 s_1}$	$D^{74}_{m_4 s_2}$	....	$D^{74}_{m_4 s_n}$	D^{74}_4	
M_5	$D^{74}_{m_5 s_1}$	$D^{74}_{m_5 s_2}$	....	$D^{74}_{m_5 s_n}$	D^{74}_5	
M_6	$D^{74}_{m_6 s_1}$	$D^{74}_{m_6 s_2}$	....	$D^{74}_{m_6 s_n}$	D^{74}_6	

TABLE 5-5 BASE YEAR 1974 DAMAGE-COEFFICIENT MATRIX $[\underline{P}^{74}]_{6xn}$ WITH FLOOD PROTECTION (P_o)

j	SECTORS				Total Residual Damages	Gross Output
i	s_1	s_2	....	s_n		
M_1	d^{74}_{11}	d^{74}_{12}	....	d^{74}_{1n}	1.0	
M_2	d^{74}_{21}	d^{74}_{22}	....	d^{74}_{2n}	1.0	
M_3	d^{74}_{31}	d^{74}_{32}	....	d^{74}_{3n}	1.0	
M_4	d^{74}_{41}	d^{74}_{42}	....	d^{74}_{4n}	1.0	
M_5	d^{74}_{51}	d^{74}_{52}	....	d^{74}_{5n}	1.0	
M_6	d^{74}_{61}	d^{74}_{62}	....	d^{74}_{6n}	1.0	

TABLE 5-6 FORECASTING FLOOD DAMAGE AS PROJECTED FOR DAMAGE-MATRIX FOR YEAR 1979

j	Sectors				Total Residual Damages	Gross Output
i	s_1	s_2	$\ldots . s_j \ldots$	s_n		
M_1	$D^{79}_{m_1 s_1}$	$D^{79}_{m_1 s_2}$	$\ldots\ldots\ldots$	$D^{79}_{m_1 s_n}$	D^{79}_1	
M_2	$D^{79}_{m_2 s_1}$	$D^{79}_{m_2 s_2}$	$\ldots\ldots\ldots$	$D^{79}_{m_2 s_n}$	D^{79}_2	
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	
M_i	$D^{79}_{m_i s_1}$	.	$D^{79}_{m_i s_j} = d_{ij} D^{79}_i$	.	D^{79}_i	
$\vdots$	$\vdots$	$\vdots$		$\vdots$	$\vdots$	
M_6	$D^{79}_{m_6 s_1}$	$D^{79}_{m_6 s_2}$	$\ldots\ldots\ldots$	$D^{79}_{m_6 s_n}$	D^{79}_6	
					$[\underline{P}^{79}]_{6x1}$	

does not change with time. In fact, this does not appear to be the case, especially when an extensive land clearance for agricultural development takes place. An adjustment, therefore, should be made in the damage-input matrix if flood-peak frequency changes due to deforestation or other factors. This could be done with a slight adjustment of the damage-coefficient matrix, $[\underline{P}^{74}]_{6xn}$.

5.4 Testing of the Inter-regional Input-Output Model in the Case of the Arkansas River Basin

The regional input-output model is tested on the Arkansas River Basin above the John Martin Dam. The six counties of relevance are Fremont, El Paso, Pueblo, Crowley, Otero and Bent.

Due to the lack of actual data on inter-sectoral transactions, the writer of this study has managed to obtain the required information by using the following procedure:

(a) the Chenery-Moses inter-regional input-output model and their simplifying assumptions are used (Bagur, J., 1969, Chenery & Clark, 1964), in order to overcome the difficulties from the lack of specific data required by the Isard inter-regional input-output model;

(b) the basic gravity model of Isard is utilized (1960) to characterize interactions amongst the districts, and finally

(c) the regional input-output study by Gray and McKean (March, 1974), for Boulder, Larimer and Weld Counties, Colorado, is adopted as a basis for aggregating sectors and classification of data sources.

The Chenery-Moses inter-regional input-output model (adequately described in Bagur's work, 1969) is developed specially for a situation when there is a lack of specific data. Unlike the Isard regional model which requires independent input transaction coefficients, the Chenery-Moses model assumes: (a) constant trade patterns by type of input, and (b) constant distribution of imports among the industries. For instance Z_i^k, the total supply of commodity i in region k, is

$$Z_i^k = M_i^k + (X_i^{kk} + \sum_{\substack{\ell=1 \\ \ell \neq k}}^{n} X_i^{k\ell}) \qquad (5\text{-}14)$$

where k, ℓ = the producing and consuming regions respectively, with the first superscript the producing region and the second superscript the consuming region; Z_i^k = the total supply of commodity i in region k, M_i^k = the imports of commodity i in region k, X_i^{kk} = the amount of commodity i produced in region k for the use in region k, and $X_i^{k\ell}$ = the amount of commodity i produced in region k for use in region ℓ.

To obtain $X_{k\ell}$, the inter-regional flow of commodity, the basic gravity model of Isard is applied, such that

$$X_i^{k\ell} = G(\frac{P_k \, P_\ell}{d_{k\ell}}), \qquad (5\text{-}15)$$

where P_k, P_ℓ = the annual commodity outputs in the producing and consuming regions k and ℓ, $d_{k\ell}$ = the distance between the centroids of the two regions and G = a commodity interaction constant.

The use of the Gray and McKean study is relevant because it provides a back-up reference in the structuring of the sectors, and the strong similarity expected in interdependence of the regional economic structure. The tri-counties data (Boulder, Larimer and Weld) are data nearest in proximity to the Arkansas River Basin.

The sources of economic data are taken from the references listed under the classification of the input-output code provided by Gray and McKean, but the base year of the economic data for this study is 1969. The Corps of Engineers have based the project proposals on 1969 prices and the writer's study is made to fit in with this base-year evaluation in order to maintain a common price denominator.

Gray and McKean's study has sixteen sectors for the tri-county region. The writer of this study has aggregated sixteen sectors into five: livestock, agriculture, industry, trade and services, and education. Since there are six counties, there are thirty sectors. The Arkansas inter-regional input-output table will therefore have a 30 x 30 transaction matrix.

Typical examples of the 1969 Arkansas inter-regional transaction table, transaction coefficients and direct and indirect requirements matrix are shown in the computer printout in the Appendix F.

5.5 Results of the Inter-Regional Input-Output Analysis

In analyzing and synthesizing the inter-regional interdependent economic system of the six counties, the overall general conclusion is that the highly developed Arkansas River region has a thriving economy with an estimated gross regional product of $3.9 billion for the six counties. The estimated annual loss to flood damage and sediment damage, without flood protection, is $4,666,000 (1967 prices). This represents about 0.1 percent of the gross regional product or about 1 percent of the regional income.

If one were to take out the El Paso County (relatively free of flooding), with a gross regional product of $2.10 billion, the percentage of estimated annual loss due to flood and sediment damage becomes ($4,534,000/$1.8 billion) x 100 = 0.25 percent of the gross regional product (excluding El Paso County), or ($4,534,000/$224,868,000) x 100 = two percent of the regional income. The reason for excluding El Paso County is the relatively high gross regional product with very low flood loss.

The two percent expected annual loss in regional income of the counties (excluding El Paso) is certainly indicative of the flood and sediment problems along the main stem of the Arkansas River and most of its tributaries upstream of the John Martin Dam. The two percent loss in regional income is as high as in some very developing countries, where the proportion of national income affected by floods and droughts is between 2 to 2.5 percent, on the average (White, 1972). Hence, the writer confirms the finding by the Corps of Engineers that the flood problems do exist along the main stem of the Arkansas River and most of its major tributaries, including Fountain Creek.

It is also revealing to note that if a standard-project flood were to strike the six counties simultaneously, the total flood and sediment damage is estimated to be $139,837,000 without the flood protection. This represents ($139,837,000/$512,132,000) x 100 = 27 percent of the total regional annual income or ($126,172,000/$287,264,000) x 100 = 44 percent of the regional income excluding El Paso County. Of this amount, the central business district of Pueblo City would sustain ($72,685,000/$126,172,000) x 100 = 58 percent. This confirms the existence of the *saddle* threat to the highly concentrated residential, commercial and industrial center of Pueblo City. In fact, under the standard-project flood, the whole central business district of Pueblo would be submerged to an expected estimated depth of 10 feet throughout the business area, and the flood water would pond behind the Arkansas River levees up to a depth of 15 feet (COE, 1969), involving 677 acres of downtown business district, the railroad yard and the other large industrial complexes.

5.6 Results of Economy-Flood Linkage

The results of the study of economy-flood linkage through the input-output intersectoral model reveal some interesting factors. The Corps of Engineers, basing their flood-protection strategy mainly on the structural (Fountain Flood Control Dam and channelization), obtained substantially a greater reduction (57 percent) in direct physical flood damage, involving a smaller coverage of total economic output, $\underline{X}$.

The writer of this study, basing the investigative strategy on the systems analysis and synthesis, establishing the most competitive of mixes and blending them in the most harmonious way involving every measure except the meterological ones, was able to merely demonstrate a lesser reduction (31 percent) in direct physical flood damage, involving a larger coverage of the total economic output, $\underline{X}$. The question is whether there is a planning paradox. The paradox could be explained by recalling that there have been two different standards or yardsticks involved herein (see Table 5-7).

The Corps of Engineer's design is not based on a competitive selection of flood-control measures, by analyzing and synthesizing them to obtain a global optimality of mixes of measures. The criterion of protection used was the standard-project flood protection for urban areas (Fountain Reservoir for Pueblo City) and the 100-year flood protection by channelization of the main stem of the Arkansas River. The synthesis of measures in the Corps's approach is not based on systems analysis and synthesis but rather on an experience-guided methodology. The flood strategy is protection rather than prevention-oriented, by controlling the river.

The impact of structural measures planned by the Corps of Engineers (in this case of the Fountain Reservoir and the river channelization) affects a relatively smaller portion of the human and economic resources of floodplains.

This study has used a different standard. To cut down the flood losses at present and in the future, the *optimal* flood-control strategy must be found. This is done by a laborious but necessary process of analyzing and synthesizing all flood-control measures, guided by the simple rule of economic efficiency in the maximization of the net benefit in order to rank the competitive flood-control measures.

Flood protection is established to be optimal for the 400-year return flood frequency for the Arkansas River system. With the weightage of benefits and costs as shown in Chapters 3 and 4, it is established that the nonstructural measures are more competitive in their ranking than the structural measures, except in the special area of Pueblo City. Restriction zoning is both inapplicable and costly for Pueblo City, so that forms of structural protection are required. The optimal measure of mixes of protection has been established to be a combination of flood control reservoir, channel improvement, and flood insurance, i.e., $D_I C_2 I_5$.

The nonstructural measures are applicable to the less developed urban areas along the main stem of the Arkansas River. In their competitive order of ranking, they appear as follows: flood warning, zoning and insurance (see Table 5-8), with structural measures being of the lowest priority.

TABLE 5-7 ECONOMY-FLOOD LINKAGE: THE ARKANSAS BASIN

(I) Annual Sediment and Flood Losses (1969 prices)

	COE' Project ($\$10^3$)	Writer's Project ($\$10^3$)
(1) Without Flood protection	4,785	4,660
(2) With flood protection	2,067 (43.2%)	3,210 (68.8%)
(3) Direct reduction in flood damage	2,718 (56.8%)	1,450 (31.2%)

(II) Total Economic Output X, Susceptible to Flood Hazard

	COE' Project ($\$10^3$)	Writer's Project ($\$10^3$)
(1) Without flood protection	429,417	751,177
(2) With flood protection	290,288 (67.6%)	637,369 (84.8%)
(3) Direct reduction in total output X	139,129 (32.4%)	113,808 (15.2%)

TABLE 5-8 THE RESULTS OF STRUCTURAL AND NONSTRUCTURAL MIX OF FLOOD-CONTROL MEASURES (PRICES 1969)

Measures	Average Annual Benefits ($\$10^3$)	Other Benefits ($\$10^3$)	Average Annual Cost ($\$10^3$)	B/C	Remarks
M_1 (Meteor.)	-	-	-	-	
M_2 (F.W.)	131.00	-	50.14	2.61	Overall B/C:
M_3 (Zoning)	570.00	-	280.92	2.03	
M_4 (Sediment)	132.48	-	132.48	1.00	$\frac{2653.41}{1680.93} = 1.58$
M_5 (Struct.)	684.58	1,024.71	1,150.74	1.49	
M_6 (Insur.)	-	110.64*	66.65	1.66	

* minimizing damage dislocation

It is relevant to recall the apparent paradox outlined above. A greater direct flood-loss reduction in the physical sense does not imply per se a more competitive flood-control measure, especially when different levels of protection are involved. Structural measures are relatively effective as long as their designed levels are not excluded. By raising the protection level, different results are obtained.

In the systems approach no a priori protection level has been set, since the optimality of systems analysis, synthesis and combinatorial screening of competitive mixes of measures would reveal the optimal level of protection. In the study undertaken, the 400-year return flood-frequency level has been obtained as an optimum. At this point, two different philosophical approaches to protection should be compared: the physical measures only and a mix of best measures of all feasible measures, with protection taken as physical, social and fiscal. The fiscal protection is in the sense that flood insurance does not remove the flood risk--but indemnifies against the flood losses by providing the risk coverage. A common yardstick is necessary in studying flood control measures, otherwise it is difficult to establish relative competitiveness of measures according to the weighting of cost and benefit factors so far adopted.

The apparent paradox may be thus explained. The Corps of Engineers in their project of 1969 shows a greater physical flood-loss reduction capacity (56.8 percent) with a lesser involvement of economic resources. The writer shows a comprehensive systems approach with a smaller flood-loss reduction (31.2 percent) but with a larger involvement of human and economic resources at the optimal protection level of the 400-year return period flood. This is due to the dominance of nonstructural measures in the flood-control mixes in this latter approach. The paradox is resolved, by the fact that the overall B/C value of the Corps of Engineer's approach is 1.31 as compared to the overall optimal B/C ratio of the other approach of 1.58 (see Tables 5-8 and 5-9).

The larger involvement of human and economic resources implies a larger reordering of the way of life and of human and economic floodplain occupancy, in keeping with the current new, federal policy of flood-control planning.

TABLE 5-9 THE RESULTS OF ONLY STRUCTURAL MIX OF FLOOD-CONTROL MEASURES (PRICES 1969)

Measures	Average Annual Benefits ($\$10^3$)	Other Benefits ($\$10^3$)	Average Annual Cost ($\$10^3$)	B/C	Remarks
M_1 (Meteor.)	-	-	-	-	
M_2 (F.W.)	-	-	-	-	
M_3 (Zoning)	-	-	-	-	
M_4 (Sediment)	-	-	-	-	
M_5 (Struct.)	2,717.92	3,831.72	4,993.80	1.31	
M_6 (Insur.)	-	-	-	-	

Chapter 6
DISCUSSION OF RESULTS

This chapter has two separate headings: 1) a discussion of measure's effectiveness using criteria for measuring effectiveness as a result of different and alternative measures analyzed and discussed in Chapters 3 and 4, and 2) a discussion of the specific problems related to the Arkansas River example.

6.1 General Discussion of Results

The system analysis and synthesis of flood-control measures have incorporated diverse values of effectiveness in its objective functions. These diverse values are related to the measurement of benefits and costs, and the objective function as the economic efficiency criterion for increasing national income by maximizing expected annual net return. The need now arises to explain the diverse values and the criteria associated with them in denoting their relative effectiveness.

Historically, the Flood Control Act of 1936 had established the dominance of benefit-cost analysis in assessing flood-control projects. Later, this so called benefit-cost ratio has been extended to other areas of water resources development (National Water Commission, 1973). However, it is now realized that benefit-cost analysis has at least three major restrictions: 1) benefit-cost analysis is more suited to measuring the benefit-cost relationship for a particular project or measure, which traditionally has been solely structural, 2) it does not indicate whether there is a better alternative, though it will reveal whether the investment effort is worthwhile, and 3) it underrates the productivity of a project when annual costs are relatively high compared to the annual benefits and the initial capital cost, e.g., in flood-insurance measure or in flood-forecasting and flood-warning measure (Levine 1969; de Neufville, 1971).

The other decision criterion for measuring effectiveness in flood-control measures is the net benefit function which needs to be maximized,

$$\max.\ NB = F[y(t) - x(t)],$$

where $y(t)$ and $x(t)$ are the benefit and cost functions, respectively. Here the objective is to make the benefit large and the cost small. In this cost-effectiveness approach for analysis of alternative measures (English, J.M., 1968), the choice is between fixed cost or fixed effectiveness, since one cannot simultaneously maximize effectiveness (benefit) and minimize cost.

In the synthesis of time-dependent structural measures (channelization) with land use and flood proofing, James (1964) has used the fixed effectiveness approach but the optimal mix of his measures is conditioned by the a priori fixed effectiveness used and therefore does not represent the global optimal mix for that location. The second approach is the fixed cost approach, which is the identification of the alternative mixes of measures that are competitive for the given fixed investment.

6.2 Criteria of Measure's Effectiveness

In the allocation of limited resources for flood control, efficient allocation is a desirable goal. However, there is a need for some common measure of system's effectiveness which could be expressed in terms of some parameter of the system's worth. The traditional benefit-cost analysis is ruled out due to the aforementioned restrictions but nevertheless, a value model is required as a guide in the analysis, synthesis, evaluation and optimization of alternative measures. In the cost-effectiveness approach to be applied to flood-control measures, the writer will use the terminology *flood-control effectiveness* or *flood-control worth* to obtain maximum desired benefits at the minimum expenditure of resources, which implies maximizing the expected net benefit function. Therefore, the evaluation of an integrated flood-control system worth or an integrated system effectiveness in an operational sense is directly related to the performance function of expected annual net return.

Since the five basic categories of flood-control measures show different capacities in different directions, such as reduction in expected value of flood loss, reduction in risk, a combination of reduction in flood loss and in risk, intangible effects and land-enhancement benefits, there must therefore be criteria for measuring multidimensional effectiveness and multidimensional costs. Lind, (1967) has presented what could appear to be the criteria for measuring multidimensional effectiveness. Effectiveness is taken to mean benefit but such benefit arises from the following: 1) as benefits measured by the *reduction in the expected value of flood loss* such as structural flood-control systems, flood proofing, flood warning and evacuation systems; 2) as benefits measured by the *reduction in risk* as in flood insurance, with floodplain occupants willing to pay a premium to change the distribution of his losses by insuring against the contingency or risk or probability of a catastrophe (defined here as losses above a defined level); 3) as benefits measured by a *combination* of reduction in flood losses and reduction in risk, e.g. flood zoning which reduces flood losses where property is exposed to hazards of flooding and reduces the cost of risk bearing by excluding certain activities from the floodplain that otherwise would be located there; 4) as benefits measured by *intangible factors*, such as reduction of the loss of life, enhancement of the security of the people, inprovement of sanitation, protection against epidemics and preservation of environmental and ecological qualities; and 5) as measured by *land enhancement benefits* for some activities that had previously been located outside the floodplain and which could now move into the floodplain as a result of a reduction in the cost of flooding. The benefit can be derived from any flood-control device whether by reducing the expected value of flood losses, by reducing risk, or by reducing intangible losses. Therefore, the introduction of almost any measure of flood protection can create land-enhancement benefits, with one notable exception, namely the flood zoning. Nevertheless, the writer is of the position that there is a high degree of correlation between the sets of criteria outlined above in evaluating the multidimensional effectiveness.

Having dealt with the effectiveness of flood-control measures, the next criteria are those for measuring multidimensional costs which are either private or public costs of the flood-control measure as well as the capital cost and the annual cost of each measure, integrated or otherwise. Hence cost-effectiveness of flood-control measures taken in the sense described above is actually the expected net return and it is this net return that is so amenable to effective resource allocation through either a linear programming or a dynamic programming model. Hence, cost-effectiveness of flood-control measures is concerned in its modern application with the evaluation of a flood-control system worth. It is important as a major subtopic in the problem of efficient resource allocation.

6.3 Criteria for Comparing and Ranking of Alternative Flood-Control Measures

Maximization of benefits minus costs is certainly an acceptable criterion for comparing and ranking of alternative measures in flood control if the following three conditions are satisfied: 1) if benefits and costs can be measured in the same units; 2) when costs are viewed as benefits foregone, the maximization of benefits minus costs is the same as maximizing total benefits, and when treated in this sense it is taken to mean maximizing *flood-control measure effectiveness*, in the cost-effectiveness terminology adopted by the writer; and 3) if it satisfies the economic efficiency criterion. In this study the national economic objective is assumed to be the primary one, over all other objectives, since national policies on flood control and cutting down the nation's future flood losses are involved.

6.4 Absence of Dichotomy between Economic Efficiency Objective and Social Security Objective

Hitherto in evaluating the performance effectiveness of integrated flood-control systems, often a distinction is made between catastrophic flooding and small flooding. The distinction reveals an apparent conceptual dichotomy in the sense that the larger the flood threat, the greater is the importance of the social security objective relative to the economic efficiency objective (James, 1965). Thus, standard project-flood protection is for the rarer, larger flood event with social security objective in mind, whereas for smaller flooding the economic efficiency objective is the guide. In the cost-effectiveness approach adopted by the writer, both social security and economic efficiency objectives are not conceptually separated. If the area is an urban one subject to intense urban land use, and flood damages due to catastrophic flooding are high, the cost-effectiveness approach will include this relatively high cost of urban floodplain occupancy in the net benefit function and the two-tier system of selection of measures with their combinatorial screening for optimal mixes will indicate at what level of flood protection that the system will become optimal. The case study of the Fountain Creek, for example, shows an optimal mix of earth dam, channelization and flood insurance for Pueblo City at the 400-year flood-recurrence interval, compared to the other standard of an a priori selection of social security objective resulting in a 300-year recurrence interval standard project-flood protection. But the latter is not optimal.

6.5 Discussion of Results Obtained for the Case Study of the Arkansas River

Certain issues arisen in previous chapters are brought together and discussed herein. They are important issues since they affect the desirability of a project proposal rather than its optimality of performance. So far it is demonstrated how an optimal mix of flood-control measures may be applied, as tested on the Arkansas River flood control. However, the acceptance of a flood-control proposal is not synonymous with the public acceptability of that project.

6.6 Controversial Issues Involving Risk and Protection

Basically the controversial issue is related to a selection of risk and protection. If one accepts the sound proposition that there is no such thing as a complete protection from flood hazard, then there follows the corollary that there will be always a probability of floods higher than anything that was experienced previously. The question therefore arises as to what level of risk should be faced in order to live under the uncertainty of the random stochastic processes of flood phenomenon. In this risk-taking approach, two kinds of attitude are current: protective and preventive, the latter attitude having some optimal level of risk.

The protective concept regards all highly urbanized areas as needing the standard project-flood protection in order to reduce the flood threat to both property and human lives. But the irony of this protective concept is in fact the indirect cause of greater residual flood damages due to subsequent nearly irreducible floodplain encroachment.

The preventive concept is one that attempts to prevent the above nearly irreducible practice from occurring. It devises comprehensive measures to properly manipulate human and economic life on floodplains, and to adjust rationally human and economic resources to the river flood phenomenon rather than to consciously control the river. In this process, it is not the protection of the economic and social status quo of floodplain occupancy that is at issue but rather a radical reordering of floodplain use, which in the long run, is intended to cut down the total flood losses of a nation. With this preventive concept, full initiative is allowed to local authorities and floodplain occupants. What is more important, it allows them to assume a greater role in risk-taking decisions. In fact, it is the ultimate legislative weapon, namely by instilling a greater consciousness among flood-prone communities and a greater sharing in the burden of potential flood losses by virtue of occupancy and use of floodplains.

6.7 Integrated Structural and Nonstructural Flood-Control Measures Versus Solely Structural Measures

Tables 6-2 through 6-5 show the flood-control measures and their associated flood damages of alternatives with and without flood protection for the example of the Arkansas River flood control. In Tables 6-3 and 6-5 the measures are shown against various economic sectors of each county, with the total economic output specified.

TABLE 6-1 MIX OF MEASURES VS. SOLELY STRUCTURAL MEASURE
ANNUAL FLOOD DAMAGES AND ANNUAL ECONOMIC OUTPUT

(I) Annual Flood Damages Only:

	Mix of Structural Measures and Insurance ($\$10^3$)	Structural Measures Only ($\$10^3$)
(1) Without flood protection	3,258	3,377
(2) With flood protection	1,933 (59.3%)	659 (19.5%)
(3) Reduction in flood damages	1,325 (40.7%)	2,718 (80.5%)

(II) Annual Economic Output Involved:

(1) Structural component:	71,205*/37,957**	154,393/15,264
(2) Zoning component:	55,664/59,843	nil
(3) Insurance component:	349,284/349,284	nil

(Note: *Without protection: **With protection).

TABLE 6-2a FLOOD CONTROL MEASURES AND DIRECT FLOOD DAMAGES IN ($\$10^3$) STRUCTURAL AND NONSTRUCTURAL ALTERNATIVES (WITH AND WITHOUT FLOOD PROTECTION)

	Fremont					El Paso					Pueblo				
Measures	L.	Ag.	I.	Ts.	Ed.	L.	Ag.	I.	Ts.	Ed.	L.	Ag.	I.	Ts.	Ed.
M_1 (Meteor.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M_2 (F. Warn.)	-	-	2/1	-	-	-	-	-	-	-	2/1	32/16	70/35	22/11	-
M_3 (Zoning)	-	-	228/31 A	30/4	-	-	-	-	-	-	-	-	-	-	-
M_4 (Sediment)	-	120/120	39/39	30/30	-	-	88/88	19/19	19/19	-	-	165/165	59/59	59/59	-
M_5 (Struct.)	1/1 C	22/22	-	-	-	1/1 C	3/3	2/1	2/1	-	16/16 C	360/360	636/117 B	263/37	-
M_6 (Insur.)	-	-	31/31	4/4	-	-	-	30/30	7/7	-	-	-	116/116	37/37	-
Remarks			(Z+I)					(str. + I)					(Str. + I)		

	Crowley					Otero					Bent				
Measures	L.	Ag.	I.	Ts.	Ed.	L.	Ag.	I.	Ts.	Ed.	L.	Ag.	I.	Ts.	Ed.
M_1 (Meteor.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M_2 (F. Warn.)	-	6/3	-	2/1	-	-	46/23	20/10	16/8	-	-	20/10	10/5	14/7	-
M_3 (Zoning)	-	-	-	-	-	-	-	179/33 A	142/26	-	-	-	55/17 A	69/22	-
M_4 (Sediment)	-	101/101	6/6	6/6	-	-	220/220	68/68	68/68	-	-	55/55	12/12	12/12	-
M_5 (Struct.)	20/20 C	226/226	-	90/22	-	8/8 C	433/433	-	-	-	8/8 C	201/201	-	-	-
M_6 (Insur.)	-		-	-	-	-	-	33/33	26/26	-	-	-	17/17	22/22	-
Remarks								(Z+I)					(Z+I)		

TABLE 6-2b FLOOD CONTROL MEASURES AND DIRECT FLOOD DAMAGES IN ($\$10^3$) STRUCTURAL AND NONSTRUCTURAL ALTERNATIVES (WITH AND WITHOUT FLOOD PROTECTION)

Measures		Total Damage (No protection) / Total Damage (With protection) D/D_* ($\$10^3$)	Percentage of Column total ($\frac{\text{With protection}}{\text{no protection}}$)		Analysis of Benefits & Costs				
					Average Annual Benefits ($\$10^3$)	Other Benefits ($\$10^3$)	Total Benefits ($\$10^3$)	Avg. Annual Costs ($\$10^3$)	B/C
M_1 (Meteor.)		-	-		-	-	-	-	-
M_2 (F. Warn.)		$\frac{262}{131}$	$\frac{5.62\%}{2.81\%}$		131.00	0.00	131.00	50.14	2.61
M_3 (Zoning)		$\frac{703}{133}$	$\frac{15.07\%}{2.85\%}$	Percentage of column total is percentage expressed in terms of total damage without protection (4666)	570.00	0.00	570.00	280.92	2.03
M_4 (Sediment)		$\frac{1146}{1146}$	$\frac{24.56\%}{24.56\%}$		132.48	0.00	132.48	132.48	1.00
M_5 (Struct.)		$\frac{2232}{1477}$	$\frac{47.84\%}{31.65\%}$		684.58	1024.71	1709.29	1150.74	1.49
M_6 (Insur.)		$\frac{323}{323}$	$\frac{6.92\%}{6.92\%}$		0.00	110.64*	110.64 2653.41	66.65 1680.93	1.66
Remarks	Total	$\frac{4666}{3210}$	$\frac{100.00\%}{68.80\%}$	Flood damage reduction 1450 % damage reduction 31.20%	(*minimizing damage dislocation)		Overall B/C = $\frac{2653.41}{1680.93}$ = 1.58		

With the previously described assumptions applied to benefits and costs, it was found that the combination of structural and nonstructural measures on the whole is generally more competitive than the alternative of structural measures only.

There is however one exception. Restrictive zoning is not either feasible or practical for the heavily urbanized, commercialized and industrialized Pueblo City. Hence as a substitute, structural measures must be included together with nonstructural measures by using the flood insurance. The optimal mix is $D_1C_2I_5$, a flood-control reservoir and channel-improvement measures, with flood insurance as a complementary measure. The nonstructural measures, though competitive, do involve by their very nature a larger economic output. The results, summarized in Tables 6-3 and 6-5, demonstrate these effects.

The control measure in form of flood warning and evacuation has been excluded, because its role is primarily related to preventable loss of life and to damage reduction for removable goods.

6.8 Economy-Hydrology Sectoral Implications

Table 6-2a reveals the sectoral implications of hydrologic and economic factors in relation to flood-control measures.

Block A in Table 6-2a under Fremont, Otero and Bent shows the effect of zoning for the standard 100-year return-period flood and the complementary measure of flood insurance. Residual flood damage after zoning is taken over by risk coverage of flood insurance. The economic output after zoning must, therefore, be equal to or greater than the economic output involved by insurance. These areas are urbanized areas but of a level of urbanization less intense than Pueblo City.

Block B in Table 6-2a involves the structural and nonstructural measures related to the Fountain Creek and other downstream reaches, nos. 4 to 7, all within the Pueblo County and urbanized areas.

Block C refers to the livestock and agricultural sectors, which in Table 6-2a show themselves as the unprotected areas. There are two reasons for this. First, zoning and insurance together are applicable to urban areas while in agricultural areas the flood risk to agricultural crops is seasonal. Second, the channelization is eliminated by the Corps of Engineers because of uncertainty in environmental impact and the danger of an excessive lowering of the groundwater table in the alluvial floodplain between Pueblo and Lamar. As far as the writer can see, no zoning or insurance programs are currently available for the agricultural floodplains. In addition, the impact of damage due to deposited sediments on land in the agricultural sector needs investigation since the twin problems of flood and sediment damages are found to be important.

6.9 Flood Problem of Pueblo City

Downtown businesses and industrial interests in Pueblo City are apt to exercise pressure for the Fountain Flood Control Reservoir as proposed by the Corps of Engineers rather than use the optimal $D_1C_2I_5$ mix of measures, namely an earth-dam flood-control reservoir for the 50-year return-period flood protection, a channel for the next segment of the 100-year return-period flood, and the 250-year return-period flood insurance for the residual components, making a total protection from the 400-year return-period flood.

The reasons for being against the optimal mix is not the position which is against the economic efficiency criterion, but rather than the Fountain Reservoir would benefit particular interests by using the structural flood protection, by maximizing the appreciation value of the land and structures, and by inducing growth.

In this alternative, the contribution by the Federal Government, in the event the Fountain Flood Control Reservoir is to be built, should be carefully analyzed.

Based on principles of equity, the contribution from the nonfederal sources should be increased from the 7 percent, estimated by the Corps of Engieners, to 28 percent as estimated by the writer, using the principle outlined by Whipple (1968). The formula for the capital cost sharing is based on the actual proportion of direct benefits due to flood damage reduction.

Due to normal growth, the benefit B_1 due to flood-damage reduction is $B_1 = [X^{St}_{DR}]_{NG} + [X^{St}_{DR}]_E$, where $[X^{St}_{DR}]_{NG}$ is the annual flood-damage reduction due to the normal growth, and $[X^{St}_{DR}]_E$ is the annual flood damage of the present.

TABLE 6-3 FLOOD CONTROL MEASURES AND TOTAL ECONOMIC OUTPUT IN ($$10^3$) STRUCTURAL AND NONSTRUCTURAL ALTERNATIVES (WITH AND WITHOUT FLOOD CONTROL)

	Fremont					El Paso					Pueblo				
Measures	L.	Ag.	I.	Ts.	Ed.	L.	Ag.	I.	Ts.	Ed.	L.	Ag.	I.	Ts.	Ed.
M_1 (Meteor.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M_2 (F. Warn.)	-	-	$\frac{526}{526}$	-	-	-	-	-	-	-	$\frac{1223}{1223}$	$\frac{2595}{2595}$	$\frac{94657}{94657}$	$\frac{55867}{55867}$	-
M_3 (Zoning)	-	-	$\frac{22332}{16050}$	$\frac{5175}{3647}$	-	-	-	-	-	-	-	-	-	-	-
M_4 (Sediment)	-	$\frac{451}{451}$	$\frac{2343}{2343}$	$\frac{3174}{3174}$	-	-	$\frac{2189}{2189}$	$\frac{9972}{9972}$	$\frac{20054}{20054}$	-	-	$\frac{3059}{3059}$	$\frac{18240}{18240}$	$\frac{34253}{34253}$	-
M_5 (Struct.)	$\frac{15}{15}$	$\frac{42}{42}$	-	-	-	$\frac{89}{89}$	$\frac{38}{38}$	$\frac{539}{539}$	$\frac{1084}{542}$	-	$\frac{1148}{1148}$	$\frac{3427}{3427}$	$\frac{100953}{18571}$	$\frac{60511}{11029}$	-
M_6 (Insur.)	-	-	$\frac{7516}{7516}$	$\frac{1708}{1708}$	-	-	-	$\frac{63535}{63535}$	$\frac{29813}{29813}$	-	-	-	$\frac{144709}{144709}$	$\frac{86680}{86680}$	-
Remarks			(Z+I)		-			(Str. + I)					(Str. + I)		

	Crowley					Otero					Bent				
Measures	L.	Ag.	I.	Ts.	Ed.	L.	Ag.	I.	Ts.	Ed.	L.	Ag.	I.	Ts.	Ed.
M_1 (Meteor.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M_2 (F. Warn.)	-	$\frac{29}{29}$	-	$\frac{142}{142}$	-	-	$\frac{1689}{1689}$	$\frac{4284}{4284}$	$\frac{5872}{5872}$	-	-	$\frac{249}{249}$	$\frac{636}{636}$	$\frac{1711}{1711}$	-
M_3 (Zoning)	-	-	-	-	-	-	-	$\frac{14288}{13923}$	$\frac{19422}{18797}$	-	-	-	$\frac{1304}{2129}$	$\frac{3143}{5297}$	-
M_4 (Sediment)	-	$\frac{110}{110}$	$\frac{57}{57}$	$\frac{97}{97}$	-	-	$\frac{1847}{1847}$	$\frac{3330}{3330}$	$\frac{5705}{5705}$	-	-	$\frac{156}{156}$	$\frac{174}{174}$	$\frac{335}{335}$	-
M_5 (Struct.)	$\frac{72}{72}$	$\frac{127}{127}$	-	$\frac{749}{183}$	-	$\frac{188}{188}$	$\frac{1866}{1866}$	-	-	-	$\frac{63}{63}$	$\frac{294}{294}$	-	-	-
M_6 (Insur.)	-	-	-	-	-	-	-	$\frac{6520}{6520}$	$\frac{8803}{8803}$	-	-	-	-	-	-
Remarks								(Z+I)						(Z+I)	

Measures	$\frac{\text{Total Output X (No protection)}}{\text{Total Output X (with protection)}}$ $\frac{X}{X^*}$ ($$10^3$)	$\frac{\text{With protection}}{\text{Without protection}}$	
M_1 (Meteor.)	-	-	
M_2 (F. Warn.)	$\frac{169,478}{84,739}$	$\frac{22.56\%}{11.28\%}$	
M_3 (Zoning)	$\frac{55,664}{59,843}$	$\frac{7.41\%}{7.97\%}$	
M_4 (Sediment)	$\frac{105,546}{105,546}$	$\frac{14.05\%}{14.05\%}$	
M_5 (Struct.)	$\frac{71,205}{37,957}$	$\frac{9.48\%}{5.05\%}$	
M_6 (Insur.)	$\frac{349,284}{349,284}$	$\frac{46.50\%}{46.50\%}$	
Remarks	$\frac{751,177}{637,369}$	$\frac{100.00\%}{84.84\%}$	Total output reduction, X = 113,808 % Total output reduction, X = 15.16%

TABLE 6-4a FLOOD CONTROL MEASURES AND DIRECT FLOOD DAMAGES IN ($$10^3$) SOLELY STRUCTURAL MEASURES (1969) (WITH AND WITHOUT PROTECTION)

	Fremont					El Paso					Pueblo				
Measures	L.	Ag.	I.	Ts.	Ed.	L.	Ag.	I.	Ts.	Ed.	L.	Ag.	I.	Ts.	Ed.
M_1 (Meteor.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M_2 (F. Warn.)	-	-	2/2	-	-	-	-	-	-	-	2/2	32/32	70/70	22/22	-
M_3 (Zoning)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M_4 (Sediment)	-	120/120	39/39	30/30	-	-	88/88	19/19	19/19	-	-	165/165	59/59	59/59	-
M_5 (Struct.)	1/0	22/4	332/35	43/8	-	1/0	3/1	2/1	2/1	-	16/0	360/113	777/19	248/40	-
M_6 (Insur.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Remarks: Corps of Engineers Project 1969: Entire component on the structural measure.

	Crowley					Otero					Bent				
Measures	L.	Ag.	I.	Ts.	Ed.	L.	Ag.	I.	Ts.	Ed.	L.	Ag.	I.	Ts.	Ed.
M_1 (Meteor.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M_2 (F. Warn.)	-	6/6	-	2/2	-	-	46/46	20/20	16/16	-	-	20/20	10/10	14/14	-
M_3 (Zoning)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M_4 (Sediment)	-	101/101	6/6	6/6	-	-	220/220	68/68	68/68	-	-	55/55	12/12	12/12	-
M_5 (Struct.)	20/0	226/55	-	90/22	-	9/0	433/125	187/49	148/44	-	8/0	201/69	109/33	137/43	-
M_6 (Insur.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Remarks: Corps of Engineers Project 1969: Entire component on the structural measure.

TABLE 6-4b FLOOD CONTROL MEASURES AND DIRECT FLOOD DAMAGES IN ($$10^3$) SOLELY STRUCTURAL MEASURES (1969) (WITH AND WITHOUT PROTECTION)

Measures		Total Damage (No protection) / Total Damage (with protection) D/D* ($$10^3$)	Percentage of Column Total (With protection / Without protection)	
M_1 (Meteor.)		-	-	
M_2 (F. Warn.)		262/262	5.48%/5.48%	
M_3 (Zoning)		-	-	Percentage of column total is percentage expressed in terms of total damage without protection (4785)
M_4 (Sediment)		1146/1146	23.95%/23.95%	
M_5 (Struct.)		3377/659	70.57%/13.77%	
M_6 (Insur.)				
Remarks	Total	4785/2067	100.00%/43.20%	Flood damage reduction 2,718 % damage reduction 56.80%

Analysis of Benefits & Costs Solely Structural Measure Class of Benefits	Avg. Annual Benefits ($$10^3$)	Avg. Annual Costs ($$10^3$)	B/C
(1) Flood Control (Damage reduction)	2717.92		
(2) Drainage	206.32		
(3) Reduction in Water Losses	1387.00		
(4) Recreation	860.00		
(5) Economic Development (National unemployed resources)	1378.40		
	6549.64	4993.80	1.31

TABLE 6-5 FLOOD CONTROL MEASURES AND TOTAL ECONOMIC OUTPUT IN ($\$10^3$) SOLELY STRUCTURAL MEASURE (1969) (WITH AND WITHOUT PROTECTION)

	Fremont					El Paso					Pueblo				
Measures	L.	Ag.	I.	Ts.	Ed.	L.	Ag.	I.	Ts.	Ed.	L.	Ag.	I.	Ts.	Ed.
M_1 (Meteor.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M_2 (F. Warn.)	-	-	$\frac{526}{526}$	-	-	-	-	-	-	-	$\frac{1223}{1223}$	$\frac{2595}{2595}$	$\frac{94657}{94657}$	$\frac{55867}{55867}$	-
M_3 (Zoning)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M_4 (Sediment)	-	$\frac{451}{451}$	$\frac{2343}{2343}$	$\frac{3174}{3174}$	-	-	$\frac{2189}{2189}$	$\frac{9972}{9972}$	$\frac{20054}{20054}$	-	-	$\frac{3059}{3059}$	$\frac{18240}{18240}$	$\frac{34253}{34253}$	-
M_5 (Struct.)	$\frac{10}{0}$	$\frac{28}{5}$	$\frac{6774}{710}$	$\frac{1544}{286}$	-	$\frac{58}{0}$	$\frac{25}{8}$	$\frac{356}{177}$	$\frac{717}{336}$	-	$\frac{759}{0}$	$\frac{2266}{708}$	$\frac{81565}{1984}$	$\frac{48889}{7845}$	-
M_6 (Insur.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Remarks															

	Crowley					Otero					Bent				
Measures	L.	Ag.	I.	Ts.	Ed.	L.	Ag.	I.	Ts.	Ed.	L.	Ag.	I.	Ts.	Ed.
M_1 (Meteor.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M_2 (F. Warn.)	-	$\frac{29}{29}$	-	$\frac{142}{142}$	-	-	$\frac{1689}{1689}$	$\frac{4284}{4284}$	$\frac{5872}{5872}$	-	-	$\frac{249}{249}$	$\frac{636}{636}$	$\frac{1711}{1711}$	-
M_3 (Zoning)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M_4 (Sediment)	-	$\frac{110}{110}$	$\frac{57}{57}$	$\frac{97}{97}$	-	-	$\frac{1847}{1847}$	$\frac{3330}{3330}$	$\frac{5705}{5705}$	-	-	$\frac{156}{156}$	$\frac{174}{174}$	$\frac{335}{335}$	-
M_5 (Struct.)	$\frac{47}{0}$	$\frac{84}{20}$	-	$\frac{495}{120}$	-	$\frac{140}{0}$	$\frac{1234}{354}$	$\frac{3109}{810}$	$\frac{4217}{1247}$	-	$\frac{41}{0}$	$\frac{194}{66}$	$\frac{538}{162}$	$\frac{1300}{406}$	-
M_6 (Insur.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Remarks															

Measures	$\frac{\text{Total Output X (No protection)}}{\text{Total Output X (With protection}}$ $\frac{X}{X^*}$ ($\$10^3$)	Percentage of column total $\frac{\text{With protection}}{\text{Without protection}}$	
M_1 (Meteor.)	-	-	
M_2 (F. Warn.)	$\frac{169,478}{169,478}$	$\frac{39.47\%}{39.47\%}$	
M_3 (Zoning)	-	-	
M_4 (Sediment)	$\frac{105,546}{105,546}$	$\frac{24.58\%}{24.58\%}$	
M_5 (Struct.)	$\frac{154,393}{15,264}$	$\frac{35.95\%}{3.55\%}$	
M_6 (Insur.)	-	-	
Remarks	$\frac{429,417}{290,288}$	$\frac{100.00\%}{67.60\%}$	Total output reduction, X = 139,129 % Total output reduction, X = 32.40%

There is, however, an additional element in form of the benefit B_2^* which is due to the project-induced growth. This benefit is the difference between the land-enhancement value X less the average annual residual damage B_2 due to project-induced economic growth, or

$$B_2^* = (X - B_2) \ . \qquad (6\text{-}1)$$

Hence the proportion for the reimbursable cost from the private sector benefiting from the project-induced economic growth is

$$\frac{B_2^*}{B_1} \times (100\%) \ . \qquad (6\text{-}2)$$

Table 6-6 shows the effects of the cost-sharing principle and Table 6-7 gives the final results of capital cost sharing for various return periods of flood protection.

TABLE 6-6 CAPITAL COST SHARING: EXISTING & FUTURE DEVELOPMENT, CORPS OF ENGINEERS FOUNTAIN DAM: STANDARD PROJECT-FLOOD PROTECTION (315-YEAR FLOOD FREQUENCY)

Status of economic development	Non-federal		Federal		Total	
	Original Area	Overflow Area	Original Area	Overflow Area	Original Area	Overflow Area
	($)	($)	($)	($)	($)	($)
(I) Existing development						
a) Flood damages without protection	-	-	226,444	229,408	226,444	229,408
b) Residual damages with protection	-	-	3,943	57,690	3,943	57,690
c) Benefits of damage reduction DR(present)	-	-	222,501	171,718	222,501**	171,718**
(II) Normal growth (NG)						
a) Flood damages without protection	-	-	220,626	158,700	220,626	158,700
b) Residual damages with protection	-	-	2,737	39,578	2,737	39,578
c) Benefits of damage reduction, DR(NG)	-	-	217,889	119,122	217.889**	119.122**
(III) Project induced growth Flood damages induced (with project)						
a) Residual flood damage, B_2	261,466	142,934	-	-	-	-
b) Land enhancement benefit, LEB(X) = 1/2 B_2	130,733	71,467	-	-	-	-
c) Net damages (LEB(X) - B_2)	-130.733*	-71.467*				

Reimbursable costs (Non-Federal) $= \frac{202,200}{731,230} \times 100\% = 28\%.$

TABLE 6-7 CAPITAL COST SHARING

Average Return-Period Flood protection (years)	Total Cost	Federal	Non-Federal
	($)	($)	($)
400	30,210,896	21,751,845	8,459,050
350	29,166,445	20,999,840	8,166,604
300	27,753,934	19,982,833	7,771,101
250	26,678,661	19,208,636	7,470,025
200	25,953,842	18,686,766	7,267,075
150	23,360,796	16,819,773	6,541,022
100	21,843,234	15,727,128	6,116,105
50	18,670,596	13,442,829	5,227,766

It is interesting to note that no land-enhancement benefit has been included in the original Corps of Engineers report (1969) on the premise "that it does not appear that the threat of flooding has in any way been a deterrent to development." If that is the case, the residual flood damage B_2 due to project-induced growth of 600 acres of urban development would have no offsetting land-enhancement benefit to subtract, and the nonfederal share would jump from 28 percent to 55 percent, namely 100 x 404,000/731,230 = 55%.

The benefit/cost ratio of the Fountain Reservoir project as estimated by the Corps is 1.22. Only about 32 percent of the benefit is assigned to direct flood-loss reduction at Pueblo City. The preponderance of other benefits, such as the recreation ($746,000) underscores the vulnerability of the proposal. If the project-induced growth is taken into account, the original benefit/cost ratio would not change significantly. The change would be about 4 percent because of the effects of weightage of other benefits.

Figure 6-1 shows how the project-induced growth would raise the residual damage. At the standard-project flood-protection level, the ratio of percentage increase in residual changes due to the project-induced growth and the normal growth is increased by a factor of two. Arvanitidis et al. (1970) have made contribution in clarifying the economic consequences of flood-control project and drafted evaluation procedures for the Corps of Engineers and their remarks on project-induced growth are relevant to this case study. Hence policy and procedural changes are required in assessing project induced growth benefits through damage reduction measures.

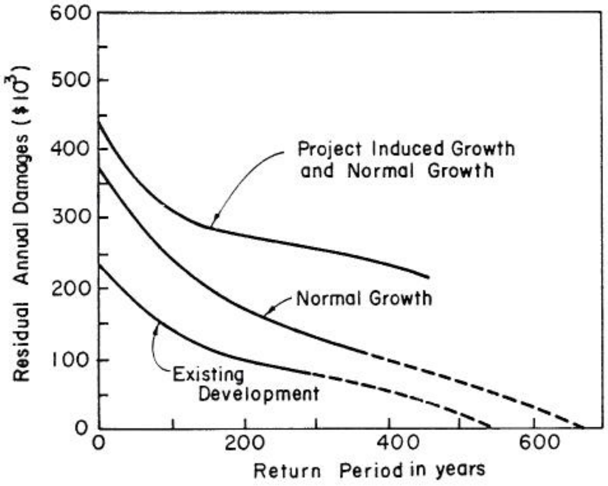


Fig. 6-1 Residual Flood Damages in Stages of Growth, the Fountain Dam for Pueblo City.

6.10 Project Yield

The efficiency of the optimal mix of structural and nonstructural flood-control measures is made apparent with the synthesized optimal mixes having an overall B/C ratio of 1.58 for an annual outlay of $1,680,930 (Table 6-2b). On the other hand, with only the structural protection the B/C ratio of the project is 1.31, with an annual outlay of $4,993,800, the result being an almost three-fold difference (Table 6-4b).

An additional benefit of the mix of structural and nonstructural measures is the decrease of environmental impact due to the channelization. There would be an absence of groundwater degradation and uncertainty associated with the water quality due to the recreation at the Fountain Reservoir. The only tradeoff is a massive reordering in an optimal manner of the human and economic resources on the floodplains.

6.11 Resilience in Economic Performance

Since the proposal of structural measures only (Corps of Engineers, 1968, 1969) has resulted in considerable damage for the standard-project flood (SPF), the writer undertook a sensitivity analysis with the regional intersectoral model, to assess the direct impact of wide-spread hypothetical standard-project flooding in the six counties.

The catastrophic hazard is examined under two contingencies: 1) either there is a fully viable economy and rapid recovery as expected in the Arkansas Region or 2) there is a partially flood-stricken economy with little economic resilience.

(I) Fully viable economy with rapid recovery

Protection status	SPF damage	Total economic output involved
	($)	($)
(a) no flood protection	139,837,000	252,675,000
(b) with flood protection	58,297,000	83,752,000

(II) Partially paralyzed economy with a slow recovery

Protection status	SPF damage	Total economic output involved
	($)	($)
(a) no flood protection	139,837,000	145,606,000
(b) with flood protection	58,297,000	56,518,000

The results above show that the same amount of standard-project flood damage may occur, but in a thriving robust economy, greater economic output is involved. In this contingency assessment, the evaluation is based on the Corps of Engineers' 1969 project. No similar data exists to assess the catastrophic impact of the mix of structural and nonstructural measures.

Chapter 7
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

7.1 Perception of the Flood Threat

Present perception of the flood threat and the level of response consciousness is very different from what they were years ago. Past perception of the flood threat was mainly limited to the then status quo, with protection conceived on the premise that once a level of protection was provided there would be no extraneous factors such as floodplain encroachment to undermine the level of protection. It is this very static, strategic concept that has given rise to a false sense of security and has in fact led to an exacerbated loss of life and property.

There are significant indications that such a static philosophy is giving way to a more dynamic one. The reasons for this reversal in philosophy are the following:

1) It is easier for man to work *with* the river than for him to work *on* the river or *against* the river; and

2) As an implication of this premise, it is more feasible to manage human and economic resources on floodplains rather than to manipulate the river.

The underlying basis of this strategic concept is an attempt to cut flood losses as quickly as possible, with as many comprehensive adjustments as practicable. In principle, this philosophy has a wide support among the several U.S. federal agencies. In fact, as the National Water Commission has discovered (1972), there are still many problems to be resolved.

7.2 Conclusions

Conclusions of this study are presented under three headings:

(1) General conclusions related to the approach and technique;

(2) Best strategy in flood-control planning for a test region; and

(3) Overall significance of the study and its potential usefulness.

General Conclusions Related to the Approach. The potential for developing a scientifically based methodology for flood control is extremely great. Based on a systematic classification of all flood-control measures, with the analysis of their significant aspects leading to the synthesis of their most important variables, the whole approach and methodology used are directed towards the evolution of the best strategy in flood-control planning. The search for this optimal strategy is underscored with tactical support of mixes of flood-control measures, ranked in their respective order of competitiveness. The first level of planning is then the identification of a sound strategy by a feasibility study of analysis and synthesis of flood-control measures for a flood-Prone environment.

The classification of flood-control measures is in fact an inventory of flood-fighting potentials. Out of this inventory, a systematic analysis of each measure reveals its particular advantages and disadvantages, with the constraining factors under which they must perform. This is called the strategical screening of flood-control measures to be considered.

The selection is synthesized into a most efficient combination of measures, so that the best mix of measures could be delivered.

The validity of this approach is verified by three considerations:

(1) The probability of subjectivity is reduced to a minimum;

(2) It is a prerequisite for a systematic approach; and

(3) It is a technique suited to systems analysis and synthesis.

Best Strategy in Relation to Test Area. The best or optimal strategy in relation to a test area, in this case the Arkansas River and its major tributaries, is linked to two factors:

(1) It will reveal the optimal global mix of flood-control measures in that particular case; and

(2) It will reveal the optimal, global efficiency in allocation of limited economic resources.

The first consideration implies the second, for the global optimality implies the improved global optimal resource allocation.

The gross divergence in results is obtained by the use of structural measures only in the case of the Arkansas River flood-control system, (the Corps of Engineers 1969 project) and the results of a mix of structural and nonstructural measures as suggested in this study. The 1969 project calls for the Fountain Creek Reservoir near Pueblo and the channelization of about 76 miles of the river between Pueblo and Las Animas, and another short stretch of the river between Brewster and Florence. It also includes the local flood-protection projects for four urban localities.

The overall B/C ratio for the 1969 project is 1.33, with the factors of recreation benefit and environmental impacts still unsettled. The 1969 solution for the Arkansas River system is aimed at providing a satisfactory level of flood protection for the existing developments, as well as for the agricultural activities in the area, (Congressional Hearing, 4904, 4905, June 1973). The solution is not claimed to be optimal.

The results of the present study reveal an optimal global mix of measures, structural and nonstructural, with an overall B/C ratio of 1.58. The optimal global efficiency of resource allocation is about one-third of the 1969 project.

The protection levels are the standard-project flood and the 400-year return-period flood, respectively for the 1969 project and this study approach.

Although it could be claimed that the absolute benefits in the 1969 project is greater, the flood-control benefit ranks low:

		in 10^3 US $	Percent
(1)	Flood control (damage reduction)	2,717.92	42
(2)	Drainage	206.32	3
(3)	Reduction in water losses	1,387.00	21
(4)	Recreation	860.00	13
(5)	Economic Development (National unemployed resources)	1,378.40	21
		6,549.64	100

The vulnerable factors are still the recreation, the reduction in water losses, and the unknown adverse effect of the steepening of the channel of the Arkansas River on the groundwater table.

Overall Significance of the Study. The significant points are:

(1) Given constant prices, technology and hydrology, the optimal global mix of flood-control measures and the optimal global efficiency in allocating the limited resources for these measures can be obtained;

(2) Without it, the best use of floodplain resources in relation to flood hazard cannot be obtained;

(3) In situations of fluctuating prices, and/or new hydrologic data, the optimal mix can be easily reappraised and/or readjusted prior to implementation;

(4) The approach and methodology demonstrated are conducive to rapid appraisal of the feasibility of a project.

7.3 Recommendations

The recommendations for future research would lie mainly in the areas of refinements. These include optimization under uncertainty. This optimization procedure has the possibility of incorporating the uncertainty about the productivity of future capital in the regional intersectoral input-output model; hence, it includes the dynamic aspects of contingency evaluation. A more flexible, contingency planning for the future is allowed where one looks for 1) optimal *stochastic strategies* for the accumulation of *capital stock* and 2) more dynamic aspects in stochastic planning that is flexible, since it contains built-in provisions for changing situations.

The optimization procedure carried out in this study uses *stochastic decision making*, or *decision-making under risk*, with known probabilities of occurrence associated with each return. The optimization under the *risk* is no more difficult than the optimization under *certainty*, because using the criterion of maximizing the expected net return (Nemhauser, 1966), one could obtain the approximate solutions to stochastic programming problems by replacing all random parameters by their expected values and by solving the resulting deterministic programming problem (Hadley, 1964). The values of the control variables so obtained are then used in the real world situation, as Hadley pointed out.

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APPENDIX A: FLOOD-WARNING MODEL DATA

Flood Warning Model Data

FIXCOS	is the capital cost of preparing and disseminating the flood forecast,
VARCOS	is the annual operations and maintenance cost of preparing and disseminating the forecast,
RADFC	is the share of the radar capital cost that is allocated to the river basin under consideration,
RADVC	is the share of the radar annual O& M costs allocated to the river basin,
GAGEFC	is the capital cost of a reporting raingage,
GAGEVC	is the annual O & M cost of a reporting raingage,
NGAGE	is the number of raingages in the river basin.

Input Computer Data for Flood Warning Submodel	Mathematical Symbols in text
FIXCOS = $12,000	C_c (Forecast)
VARCOS = $34,000/year	C_a (Forecast)
RADFC = $125,000	C_c (Radar)
RADVC = $50,000/year	C_a (Radar)
GAGEFC = $2,000	C_c (Raingage)
GAGEVC = $1,500/year	C_a (Raingage)

Other Input Parameters	Test Series A 1st Run	Test Series B 2nd Run
1. Raingage network: AEQ(a)	0.60	0.60
BEQ(b)	0.25	-0.15
2. Radar network: σ_{Y_t}	0.25	0.25
3. Storm characteristics:		
DUR (12 hrs)	12.00	12.00
RC (mile)	20.00	20.00
RO (mile)	10.00	10.00
4. Basin area covered		
TOTAR ($mile^2$)	2,640	2,640
5. Sociological characteristics:		
RF (r_e)	1.00	1.00
6. Economic characteristics:		
R	7% (0.07)	7% (0.07)
LT (years)	50	50
7. Hydrologic characteristics:		
T_c (hours)	>6-8	>6-8

APPENDIX B: COMPUTER PROGRAM FOR FLOOD WARNING AND TYPICAL RESULTS

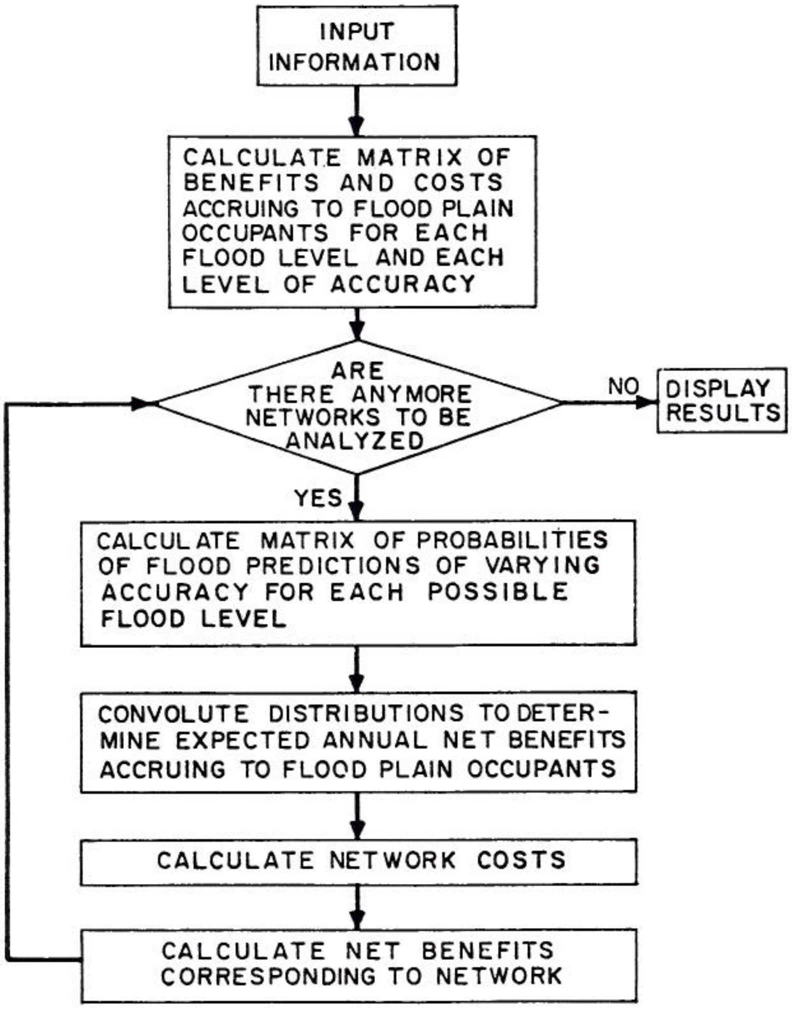

Fig. B-1 Flowchart of Expected Value Model

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TAI'S MODIFIED MIT COMPUTER PROGRAM IN FLOOD- WARNING SYSTEM.
********************************************************************
THE MIT COMPUTER PROGRAM FROM GRAYMAN AND EAGLESON REPORT NO. 168,
*DESIGN OF OPTIMAL PRECIPITATION NET WORKS* HAS NO EXPLANATION
IN THE REPORT'S APPENDIX AND SOME ERRORS.
THE MIT PROGRAM IS MODIFIED AND IS TO BE KNOWN AS THE TAI'S
MODIIFIED MIT PROGRAM.
THE EXPECTED VALUE MODEL IS USED. FORTRAN CODE ON LEFT IS LISTED.
NFL    = THE NUMBER OF DISCRETE FLOOD LEVELS.
  I    = AN INDEX FOR THE NUMBER OF RIVER REACHES.
  B    = THE BENEFIT ARRAY
BEN    = THE NET BENEFITS TO FLOOD PLAIN OCCUPANTS. IN REPORT, NCO(M)
COS    = THE COST OF THE MEASURING NETWORKS. IN REPORT NC(M)
NRAD   = THE MAXIMUM NO. OF RAINGAGES USED IN CALIBRATION OF THE
RADAR                                                      SEE ICO(K)
RATE   = THE INTEREST RATE. EXPRESS IN DECIMAL, 7 PER CENT IS 0.07.
NY     = THE NO. OF YEARS IN WHICH THE SYSTEM IS USED.
VARCOS= THE ANNUAL O AND M COST OF PREPARING AND DISSEMINATING
THE FLOOD FORECAST.
RADVC = THE SHARE OF THE RADAR ANNUAL OM COSTS ALLOCATED TO RIVER
CATCHMENT.
GAGEVC= THE ANNUAL OM COST OF A REPORTING RAINGAGE.
FCO    = THE COST TO FLOOD PLAIN OCCUPANTS IN EVACUATION, ETC.
FIXCOS= THE CAPITAL COST OF PREPARING AND DISSEMINATING FLOOD
FORECAST
RADFC= THE SHARE OF THE RADAR CAPITAL COST THAT IS ALLOCATED TO THE
RIVER BASIN UNDER CONSIDERATION.
GAGEFC= THE CAPITAL COST OF A REPORTING RAINGAGE.
ICO(K)= THE NO. OF EQUALLY SPACED RAINGAGES USED IN CALIBRATION
OR IN CONJUNCTION WITH THE RADAR. MAXIMUM NO. FOR ICO(K) IS NRAD.
NINS   = THE MAX. NO. FOR NRAD+NGAGE+1 SEE MAIN PROG. LINES 27,29
IGAGE = AN INDEX FOR THE NO. OF RAINGAGES USED IN THE MEASURING
SYSTEM WITHOUT RADAR.
AREA(I) = THE AREA OF THE CATCHMENT CORRESP. TO THE RIVER STRETCH
*I*.
DUR    = THE DURATION OF THE DESIGN STORM.
SIGYT =  A PARAMETER FOR RADAR ACCURACY.   SIGMA Y(T).
TOTAR = THE TOTAL AREA COVERED BY THE RADAR OR FORECASTING SYSTEM.
THIS TOTAR IS LARGER THAN THE AREA(I) OF THE RIVER STRETCH *I*.
RC     = THE CORRELATION RADIUS. THE DISTANCE AT WHICH THE CORRELATION
FUNCTION OF THE TOTAL STORM DEPTH RECOMES ZERO OR OSCILLATORY.
EL     THE CATCHMENT LENGTH FOR THE RIVER STRETCH *I*.
RO     = THE INDEPENDENT VARIABLE STORM RADIUS, RO, IS DEFINED AS
THE DISTANCE AT WHICH THE CORRELATION FUNCTION OF THE TOTAL STORM
RAINFALL EQUALS 0.5.
AEQ    = A PARAMETER DESCRIBING RAINGAGE ERROR.
BEQ    = A PARAMETER DESCRIBING RAINGAGE ERROR.
P(K,L)= PROBABILITY THAT A FLOOD OF LEVEL I IN REACH *I* WILL
RESULT IN PREDICTED FLOOD OF LEVEL K USING NETWORK (M).
F(I,J)= INCREMENTAL PROBABILITY FOR DISCRETE FLOOD LEVEL *I*
OCCURING IN REACH *I* IN ANY YEAR.
BI     = THE RENEFITS ASSOCIATED WITH ORJECTIVES *I).
J      = A COUNTER THAT IS USED IN J=2,NINS(LINE 33) OR J=NRADPP,NINS
J=13,23. UNDERSTAND J CLEARLY SINCE IT CROSSES FROM ICO(K), RAIN-
GAGES USED IN CALIBRATION OF RADAR, TO IGAGE(K), RAINGAGES USED
WITHOUT RADAR AS A PRECIP. MEASURING SYSTEM.
C(I,J)= THE COST INCURRED BY FLOOD PLAIN OCCUPANTS IN REACH *I*,
IN RESPONDING TO A CORRECTLY PREDICTED FLOOD OF LEVEL *I*.
Q(I,J) = THE STREAM FLOW PEAK. EXPRESS AS UNITS OF 1000 CFS.
THERE WILL BE ONE EXTRA VALUE OF Q SINCE THE UPPER BOUND  FOR Q IS
REQUIRED.    Q VALUE MUST BE LARGER THAN THE LAST RECORDED VALUE OF Q


 CAUTION IS REQUIRED IN THE FOLLOWING.
 ICO(KK) MAY START WITH ZERO VALUE SINCE THERE COULD BE  NO SINGLE
 RAINGAGE USED IN CALIBRATING THE RADAR.
 IGAGE(KK) CAN ONLY START WITH VALUE *1* SINCE USING *0* WILL THROW
 OUT THE ALGORITHM OF THE SUBROUTINE NETE2 FROM LINE 30.


 ASSUMPTIONS.
 PROGRAM BASED ON SELECTION OF VARIABLES BY JUDGEMENT SINCE TIME
 AND LARGE EXPENSE INVOLVED IN EXAMINING THE EFFECTS OF ALL INDEPNDENT
 VARIABLES IN DETERMINING THE OPTIMAL PRECIP. MEASURING NETWORK.
 PHYSIOGRAPHIC CHARACTERISTICS.
 AREA(I) = CATCHMENT AREA.  CARWID= CATCHMENT WIDTH.   EL(I)=
 CATCHMENT LENGTH.(I).    TOTAR = TOTAL AREA OF THE BASIN.
 MEASURING SYSTEMS CHARACTERISTCS*
 SIGYT= A MEASURE OF THE TECHNICAL ACCURACY OF THE RADAR SYSTEMS.
 AEQ    = A PARAMETER OF THE ACCURACY OF THE RAINGAGE NETWORKS.
 BEQ    = A PARAMETER MEASURE OF THE ACCURACY OF THE RAINGAGE NETWORKS.
 *CLIMATIC CHARACTERISTICS*
 AVERAGE NORMALISED SPATIAL CORRELATION FINCTION OF THE STORM DEPTHS
 RO     = THE DISTANCE AT WHICH RO = 0.5
 RC     = THE DISTANCE AT WHICH RC=0 OR OSCILLATORY.
 LINEAR CORRELATION FUNCTION ASSUMED SO THAT RC= 2*RO.
 HYDROLOGIC, ECONOMIC, AND SOCIAL CHARACTERISTICS*
 RF     = RESPONSE LEVEL 0 TO 1
```

```
SUBROUTINE BENT B2 COMPUTES THE MATRIX OF BENEFITS BEN(K,L) AND
COSTS, FCO(K.L)
SUBROUTINES NETC2 COMPUTES THE COST OF RADAR WITH RAINGAGE AND
RAINGAGE WITHOUT RADAR.
SUBROUTINE NETE2 COMPUTES PROBABLITY MATRIX P(K,L), THE PROBABLITY
OF PREDICTED FLOOD LEVEL K FOR AN ACTUAL FLOOD LEVEL L.
SUBROUTINE BEN 2
COMPUTES THE NET BENEFITS OF FLOOD WARNING SYSTEMS TO FLOOD PLAIN
 OCCUPANTS.


*************************************************************************

 PROGRAM MIT (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
 COMMON NFL,I,H,BEN,COS,NRAD,RATE,NY,VARCOS,RADVC,GAGEVC,FCO,
1FIXCOS,RADFC,GAGEFC,ICO,NINS,IGAGE,AREA,DUR,SIGYT,TOTAR,RC,EL,
2RO,AEQ,BEQ,P,F,BI,J,C,Q,RF
 DIMENSION NFL(25),AREA(25),EL(25),ICO(20),IGAGE(20),BN(40),
2COS(40),BENNET(40),F(25,25),B(25,25),C(25,25),BEN(25,25),Q(25,26),
3P(25,25),FCO(25,25),RF(1)
 IREAD=5
 IRITE=6
 READ IREAD,1000; NREACH
 SEC = SECOND(SEC)
 PRINT 111,SEC
111 FORMAT (1X,F10.3,* FROM MIT LINE 14 TO LINE 26* )
 DO 100 I=1,NREACH
 READ (IREAD,1001) NFL(I),AREA(I),EL(I)
 NF=NFL(I)
 NFLP=NFL(I)+1
 READ (IREAD,1002) (F(I,J),J=1,NF)
 WRITE(IRITE,2002) (F(I,J),J=1,NF)
 READ (IREAD,1002) (B(I,J),J=1,NF)
 WRITE (IRITE,2002) (B(I,J), J=1,NF)
 READ (IREAD,1002) (C(I,J), J=1,NF)
 WRITE(IRITE,2002) (C(I,J), J=1,NF)
 READ (IREAD,1003) (Q(I,J),J=1,NFLP)
 WRITE(IRITE,2003) (Q(I,J), J=1,NFLP)
100 CONTINUE
 READ (IREAD,1002) AEQ,BEQ,DUR,RC,RO,SIGYT,TOTAR
 READ (IREAD,1002) FIXCOS,VARCOS,RADFC,RADVC,GAGEFC,GAGEVC,RF,RATE
 READ (IREAD,1000) NRAD,NGAGE,NY
 READ (IREAD,1000) (ICO(K),K=1,NRAD)
 READ (IREAD,1000) (IGAGE(K),K=1,NGAGE)
 NINS=NRAD+NGAGE+1
 DO 101 J=1,NINS
101 BN(J)=0
 CALL NETC2
 DO 800 J=2,NINS
800 WRITE(6,8000) COS(J)
8000 FORMAT (1H ,6F12.3)
 NRADP=NRAD+1
 NRADPP=NRAD+2
 SEC = SECOND(SEC)
 PRINT 112, SEC
112 FORMAT (1X,F10.3, * FROM MIT LINE 44 TO LINE 66 *)
 DO 102 I=1,NREACH
 NF=NFL(I)
 CALL BENTB2
 IF (I.GT.1) GO TO 801
 DO 802 K=1,NF
 WRITE(6,8000) (BEN(K,L),L=1,NF)
 WRITE(6,8000) (FCO(K,L),L=1,NF)
802 CONTINUE
801 CONTINUE
 DO 103 J=2,NRADP
 CALL NETE2
 IF (I.GT.1) GO TO 803
 IF (J.GT.2) GO TO 803
 DO 804 K=1,NF
804 WRITE(6,8000) (P(K,L),L=1,NF)
803 CONTINUE
 CALL BEN2
103 BN(J)=BN(J)+BI
 DO 104  J=NRADPP,NINS
 CALL NETE2
 CALL BEN2
104 BN(J)=BN(J)+BI
 CALL NETE2
 CALL BEN2
104 BN(J)=BN(J)+BI
102 CONTINUE
 DO 105 J=2,NINS
 WRITE(6,8000) BN(J)
105 BENNET(J)=BN(J)-COS(J)
 BMAX=0
 DO 200 I=1,NREACH
 NF=NFL(I)
 DO 200 J=1,NF
```

```
 200 BMAX=BMAX+F(I,J)*(B(I,J)-C(I,J))
     WRITE(IRITE,1006) NY
     WRITE(IRITE,1005) BMAX
1005 FORMAT(* MAXIMUM POSSIBLE BENEFITS      *,F10.0)
1006 FORMAT(* AVERAGE ANNUAL BENEFITS BASED ON    *,I3,*  YEAR LIFE*)
     DO 107 K=1,NRAD
     KK=K+1
     IF (ICO(K).EQ.0) GO TO 108
     GD=TOTAR/ICO(K)
     WRITE(IRITE,1007) GD,BENNET(KK)
     GO TO 107
 108 WRITE(IRITE,1008) BENNET(KK)
1008 FORMAT(* RADAR WITHOUT RAINGAGES      *,F10.0,*  DOLLARS*)
 107 CONTINUE
1007 FORMAT(* RADAR+1 GAGE PER *,F6.1,* SQUARE MILES      *,F10.0,
    1 * DOLLARS*)
     DO 109 K=1,NGAGE
     KK=NRAD+1+K
     GD=TOTAR/IGAGE(K)
 109 WRITE(IRITE,1009) GD,BENNET(KK)
1009 FORMAT(* 1 GAGE PER *,F6.1,* SQUARE MILES      *,F10.0,* DOLLARS*)
1000 FORMAT(12,5)
1001 FORMAT (I2,2F10.0)
1002 FORMAT (10F8.0)
1003 FORMAT (11F7.0)
2002 FORMAT (1H ,10F8.0)
2003 FORMAT (1H ,11F7.0)
     CALL EXIT
     END

     SUBROUTINE BENT B2
     COMMON NFL,I,B,BEN,COS,NRAD,RATE,NY,VARCOS,RADVC,GAGEVC,FCO,
    1FIXCOS,RADFC,GAGEFC,ICO,NINS,IGAGE,AREA,DUR,SIGYT,TOTAR,RC,EL,
    2RO,AEQ,BEQ,P,F,BI,J,C,Q
     DIMENSION NFL(25),AREA(25),EL(25),ICO(20),IGAGE(20),BN(40),
    2COS(40),BENNET(40),F(25,25),B(25,25),C(25,25),BEN(25,25),Q(25,26),
    3P(25,25),FCO(25,25)
     NF=NFL(I)
     WRITE(6,7000) (B(I,K),K=1,NF)
     WRITE(6,7000) (C(I,K),K=1,NF)
7000 FORMAT(1H ,10F8.0)
     DO 100 K=1,NF
     DO 100 L=1,NF
 100 BEN(K,L)=B(I,K)
     DO 101 L=1,NF
     DO 101 K=L,NF
 101 BEN(K,L)=B(I,L)
     DO 102 L=1,NF
     DO 102 K=1,NF
 102 FCO(K,L)=C(I,L)
     RETURN
     END

     SUBROUTINE NETC2
     COMMON NFL,I,B,BEN,COS,NRAD,RATE,NY,VARCOS,RADVC,GAGEVC,FCO,
    1FIXCOS,RADFC,GAGEFC,ICO,NINS,IGAGE,AREA,DUR,SIGYT,TOTAR,RC,EL,
    2RO,AEQ,BEQ,P,F,BI,J,C,Q
     DIMENSION NFL(25),AREA(25),EL(25),ICO(20),IGAGE(20),BN(40),
    2COS(40),BENNET(40),F(25,25),B(25,25),C(25,25),BEN(25,25),Q(25,26),
    3P(25,25),FCO(25,25)
     NRADP=NRAD+1
     NRADPP=NRAD+2
     AV=(((1.+RATE )**NY)-1.)/(RATE*((1.+RATE)**NY))
     DO 100 K=2,NRADP
     KK=K-1
     VAR=VARCOS+RADVC+GAGEVC*ICO(KK)
     FIX=(FIXCOS+RADFC+GAGEFC*ICO(KK))/AV
 100 COS(K)=FIX+VAR
     DO 101  K=NRADPP,NINS
     KK=K-NRADPP+1
     VAR=VARCOS+GAGEVC*IGAGE(KK)
     FIX=(FIXCOS+GAGEFC*IGAGE(KK))/AV
 101 COS(K)=VAR+FIX
     RETURN
     END

     SUBROUTINE NETE2
     COMMON NFL,I,B,BEN,COS,NRAD,RATE,NY,VARCOS,RADVC,GAGEVC,FCO,
    1FIXCOS,RADFC,GAGEFC,ICO,NINS,IGAGE,AREA,DUR,SIGYT,TOTAR,RC,EL,
    2RO,AEQ,BEQ,P,F,BI,J,C,Q
     DIMENSION NFL(25),AREA(25),EL(25),ICO(20),IGAGE(20),BN(40),
    2COS(40),BENNET(40),F(25,25),B(25,25),C(25,25),BEN(25,25),Q(25,26),
    3P(25,25),FCO(25,25)
     NF=NFL(I)
     NRADP=NRAD+1
     IF (J.GT.MRADP) GO TO 101
     CS = 0.9 + 0.36*ALOG10(AREA(I)) - .028*DUR
     KK=J-1
     FAC=SIGYT
     IF (ICO(KK).EQ.0) GO TO 100
```

```
      A=TOTAR/ICO(KK)
      CK=2.3*SQRT(A/3.14159)/RC
      FAC=(1.-(1./CK)*(1.-EXP(-CK)))*SIGYT
  100 CONTINUE
      DSIGY=FAC*CS
      IF (I.GT.1) GO TO 102
      IF (J.EQ.2) GO TO 102
      WRITE(6,8000)CS,A,CK,FAC,DSIGY
 8000 FORMAT (1H ,9F8.3)
      GO TO 102
  101 CATWID=AREA(I)/EL(I)
      ELM=CATWID/(EL(I)*2.)
      BETA=EL(I)/RO
      KK=J-NRADP
      DUMM=2.*IGAGE(KK)/(ELM*BETA)
      SIGL=-AEQ*ALOG10(DUMM)-BEQ
      SIG=10.**SIGL
      DSIGY=SQRT(ALOG((SIG*SIG)+1.))
      IF (I.GT.1) GO TO 102
      IF (J.LT.14) GO TO 102
      WRITE(6,8000) CATWID,ELM,BETA,SIGL,SIG,DSIGY
 102  DMUY=-DSIGY*DSIGY/2.
      DO 200 K=1,NF
      QACT=(Q(I,K)+Q(I,K+1))/2.
      DO 200 L=1,NF
      XL=Q(I,L)/QACT
      XU=Q(I,L+1)/QACT
      YL=ALOG(XL)
      YU=ALOG(XU)
      UL=(YL-DMUY)/DSIGY
      UU=(YU-DMUY)/DSIGY
      CALL NDTR(UL,PRL,D)
      CALL NDTR(UU,PRU,D)
      IF (I.GT.1) GO TO 200
      IF (J.NE.2.AND.J.NE.13)GO TO 200
      IF (K.GE.3.OR.L.GE.3) GO TO 200
      WRITE(6,8000) QACT,XL,XU,YL,YU,UL,UU,PRL,PRU
  200 P(K,L)=PRU-PRL
      RETURN
      END

      SUBROUTINE BEN2
      COMMON NFL,I,B,BEN,COS,NRAD,RATE,NY,VARCOS,RADVC,GAGEVL,FCO,
     1FIXCOS,RADFC,GAGEFC,ICO,NINS,IGAGE,AREA,DUR,SIGYT,TOTAR,RC,EL,
     2RO,AEQ,BEQ,P,F,BI,J,C,Q,RF
      DIMENSION NFL(25),AREA(25),EL(25),ICO(20),IGAGE(20),BN(40),
     2COS(40),BENNET(40),F(25,25),B(25,25),C(25,25),BEN(25,25),Q(25,26),
     3P(25,25),FCO(25,25),RF(1)
      NF=NFL(I)
      BI=0.
      DO 100 K=1,NF
      DO 100 L=1,NF
 100  BI=BI+RF*(F(I,K)*P(K,L)*(BEN(K,L)-FCO(K,L))/100.)
      RETURN
      END

      SUBROUTINE NDTR(X,P,D)
      AX=ABS(X)
      T=1.0/(1.0+.2316419*AX)
      D=0.3989423*EXP(-X*X/2.0)
      P = 1.0 - D*T*((((1.330274*T - 1.821256)*T + 1.781478)*T -
     1  0.3565638)*T + 0.3193815)
      IF(X)1,2,2
    1 P=1.0-P
    2 RETURN
      END
```

SELECTED VARIABLE NAMES IN PROGRAM FOR FLOOD WARNING

Computer Variable Name	Mathematical Term Represented	Computer Variable Name	Mathematical Term Represented
NFL	N_j	TOTAR	
I	i	EL	
B		RO	
BEN	B_m	AEQ	a
COS	C_m	BEQ	b
NRAD		P(K,L)	$P_{(i,j,k,m)}$
RATE	R	F(I,J)	$F_{(i,j)}$
NY	L	BI	
VARCOS	C_a (Forecast)	J	j
RADVC	C_a (Radar)	C(I,J)	
GAGEVC	C_a (Raingage)	Q(I,J)	
FIXCOS	C_c (Forecast)	AREA(I)	
RADFC	C_c (Radar)	CATWID	
GAGEFC	C_c (Raingage)	EL(I)	
ICO(K)		TOTAR	
NINS		RO	
IGAGE		RC	R_c
AREA(1)		RF	r_e
DUR		BEN(K,L)	$B_{(i,j,k)}$
SIGYT	σ_t	FCO(K,L)	$C_{(i,j,k)}$

```
AVERAGE ANNUAL BENEFITS BASED ON     50  YEAR LIFE
MAXIMUM POSSIBLE BENEFITS         12268301.
RADAR WITHOUT RAINGAGES             -9611.  DOLLARS
RADAR+1 GAGE PER 1320.0 SQUARE MILES             1254. COLLARS
RADAR+1 GAGE PER  528.0 SQUARE MILES             1869. COLLARS
RADAR+1 GAGE PER  264.0 SQUARE MILES            -2154. COLLARS
RADAR+1 GAGE PER  132.0 SQUARE MILES           -14763. COLLARS
RADAR+1 GAGE PER   52.8 SQUARE MILES           -59913. COLLARS
RADAR+1 GAGE PER   35.2 SQUARE MILES           -99571. COLLARS
RADAR+1 GAGE PER   26.4 SQUARE MILES          -139815. COLLARS
RADAR+1 GAGE PER   13.2 SQUARE MILES          -302715. COLLARS
RADAR+1 GAGE PER    8.8 SQUARE MILES          -466561. COLLARS
RADAR+1 GAGE PER    5.3 SQUARE MILES          -794953. COLLARS
1 GAGE PER 2640.0 SQUARE MILES          51165. COLLARS
1 GAGE PER 1320.0 SQUARE MILES          60784. DOLLARS
1 GAGE PER  528.0 SQUARE MILES          66518. COLLARS
1 GAGE PER  264.0 SQUARE MILES          63623. COLLARS
1 GAGE PER  132.0 SQUARE MILES          50647. COLLARS
1 GAGE PER   52.8 SQUARE MILES           3674. COLLARS
1 GAGE PER   35.2 SQUARE MILES         -36877. COLLARS
1 GAGE PER   26.4 SQUARE MILES         -77701. COLLARS
1 GAGE PER   13.2 SQUARE MILES        -241765. COLLARS
1 GAGE PER    8.8 SQUARE MILES        -406133. COLLARS
1 GAGE PER    5.3 SQUARE MILES        -735008. COLLARS
```

APPENDIX C: COMPUTER PROGRAM FOR INTEGRATED ZONING AND FLOOD INSURANCE WITH TYPICAL RESULTS

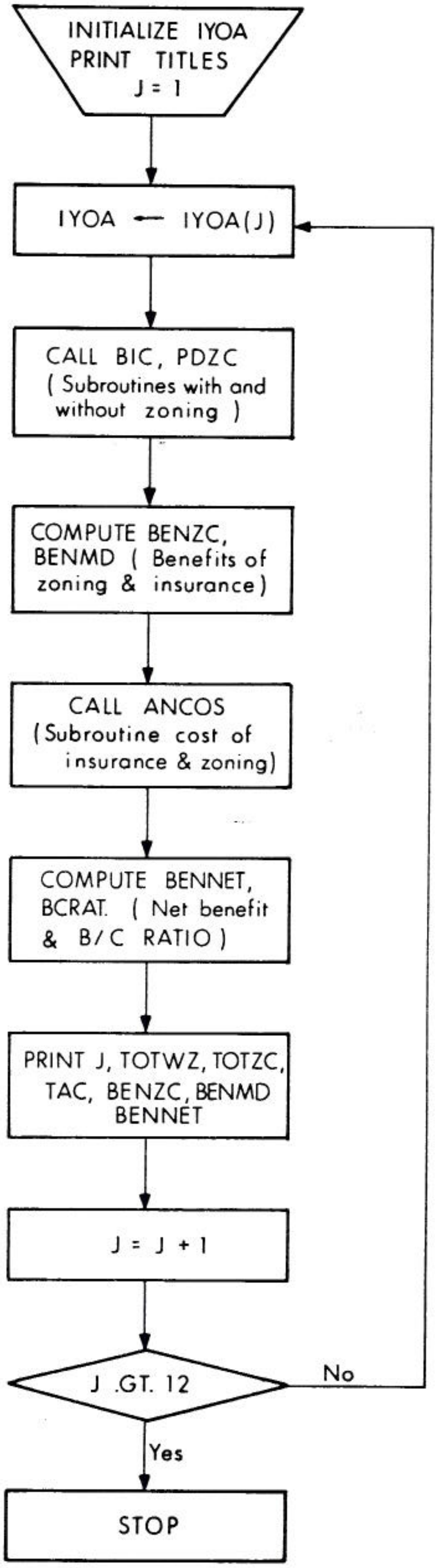

Fig. C-1 Flow Chart for Zoning and Flood Insurance

```
TAI'S PROGRAM INSUR.
*****************************************************************
IYOA    = SERIAL SEQUENTIAL INDEX   CORRESPONDING TO THE 5,10,25,50,
           75,100,125,150,175,200,225, AND 250 YEAR FLOOD FREQUENCY.
IYOA    = ASSIGNED VARIABLE TO IYOA.
BENZC   = BENEFIT OF ZONING.
TOTWZ   = TOTAL EXPECTED ANNUAL FLOOD DAMAGE WITHOUT ZONING.
TOTZC   = TOTAL RESIDUAL ANNUAL FLOOD DAMAGE WITH ZONING.
BENMD   = TOTAL ANNUAL BENEFIT OF MINIMIZING DAMAGE DISLOCATION.
BENNET  = AVERAGE ANNUAL NET BENEFIT.
BCRAT   = BENEFIT TO COST RATIO.

SOUROUTINE BIC COMPUTES TOTWZ, ANNUAL FLOOD DAMAGES WITHOUT ZONING.
Y(I)    = FLOOD PEAK DISCHARGE TO NEAREST THOUSANDTHS OF CFS
          CORRESPONDING TO SEQUENTIAL INDEX ABOVE IYOA.
P(I)    = THE PROBABILITY EXCEEDANCE IN PERCENTAGE VALUES.
D(I)    = THE ABSOLUTE FLOOD DAMAGE IN DOLLARS VALUES,NO ZONING.
DP      = INCREMENTAL PROBABILITY IN THE INTERVAL I.
DPADI   = INCREMENTAL AVERAGE ANNUAL FLOOD DAMAGE BELOW THE GIVEN
          FLOOD INDEX,IYOA.
DPADK   = INCREMENTAL AVERAGE ANNUAL FLOOD DAMAGE ABOVE THE GIVEN
          FLOOD INDEX,IYOA.
SUMK    = SUM OF THE INCREMENTAL FLOOD DAMAGES,DPADK.
SUM     = SUM OF THE INCREMENTAL FLOOD DAMAGES, DPADI.

SUBROUTINE PDZC COMPUTES TOTZC, ANNUAL RESIDUAL FLOOD DAMAGES,ZONING.
J       = THE INTERVAL INDEX MARKING THE DIVISIONS OF PROBABILITY
          AND DAMAGES AS A RESULT OF ALTERING THE DAMAGE-PROBABILITY
          CHARACTERISTIC BY RESTRICTIVE ZONING.
Y(I)    = ORIGINAL SERIES OF FLOOD PEAK DISCHARGES.
P(I)    = ORIGINAL SERIES OF PROBABILITY EXCEEDANCES.
D(I)    = THE ABSOLUTE RESIDUAL FLOOD DAMAGES WITH FLOOD ZONING TO
          J FLOOD LEVEL. THERE ARE 12 TEST LEVELS ALTOGETHER.

SUBROUTINE ANCOS COMPUTES THE EXPECTED ANNUAL COST OF ZONING
          AND INSURANCE PROGRAM.
CA      = INSURANCE COST WEIGHTAGE.
R       = THE DISCOUNT RATE, 7 PER CENT.
LT      = THE EXPECTED LIFE OF THE PROJECT.
CRF       = THE CAPITAL RECOVERY FACTOR.
ANLCIP    = THE ANNUAL EXPECTED LOSS OF CAPITAL, INCOME AND PRODUCTION.
TAC     = THE TOTAL EXPECTED COST
TAC     = THE TOTAL EXPECTED ANNUAL COST OF THE ZONING AND INSURANCE
          PROGRAM.
*****************************************************************

      PROGRAM INSUR(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      DIMENSION TOTWZ(20),TOTZC(20),TAC(20),BENZC(20),BENMD(20),
     1BENNET(20),BCRAT(20),IYOA(20)
      DATA (IYOA(I), I=1,12)/2,2,6,10,13,15,16,18,19,20,21,22/
        PRINT 100
100   FORMAT(10X,*THE NET ANNUAL BENEFIT AND B/C RATIO FOR VARYING*/
     110X,*FLOOD PLAIN STANDARDS IN INSURANCE PROGRAM WITH ZONING*)
      PRINT 200
200   FORMAT(1X,*J*,4X,*TOTWZ*,5X,*TOTZC*,6X,*TAC*,5X,*BENZC*,5X,*BENMD*
     1,4X,*BENNET*,5X,*BCRAT*)
      DO 400 J=1,12
      IYO   = IYOA(J)
      CALL  BIC(IYO,TOTWZ(J))
      CALL PDZC(IYO,TOTZC(J))
      BENZC(J) = TOTWZ(J) - TOTZC(J)
      BENMD(J) = 0.83*(TOTZC(J))
      CALL ANCOS(IYO,TAC,J )
      BENNET(J) = BENZC(J) + BENMD(J) - TAC(J)
      BCRAT(J) = (BENZC(J)+BENMD(J)) /TAC(J)
      PRINT 300, J,TOTWZ(J),TOTZC(J),TAC(J),BENZC(J),BENMD(J),BENNET(J),
     1BCRAT(J)
300   FORMAT (1X,I2,F8.0,5F10.0,F10.3)
400   CONTINUE
      STOP
      END

      SUBROUTINE BIC(IYO,TOTWZ)
      DIMENSION Y(30),P(30),D(30)
      DATA (Y(I),I=1,30)/5.,5.,5.,6.,6.,7.,8.,9.,9.,10.,11.,12.,12.,13.,
     214.,15.,15.,16.,17.,18.,18.,20.,22.,26.,30.,39.,40.,45.,50./
      DATA (P(I),I=1,30)/10.64,8.93,7.41,6.25,5.21,4.35,3.62,3.03,2.50,2
     1.08,1.75,1.45,1.33,1.20,1.00,0.80,0.71,0.67,0.57,0.50,0.44,0.40,0.
     233,0.24,0.17,0.12,0.08,0.06,0.04,0.00/
      DATA (D(I),I=1,30)/0.,6000.,30000.,85000.,104000.,120000.,150000.,
     2173000.,200000.,230000.,260000.,290000.,310000.,330000.,370000.,42
     35000.,450000.,468000.,510000.,545000.,590000.,618000.,738000.,9000
     400.,1100000.,1240000.,1335000.,1450000.,1500000.,1600000./
        I = 1 $ DP=0 $ AD =0 $ DPADI=0  $ DPADK=0
      PRINT 100
100   FORMAT (20X,*DAMAGE PROBABILITY TABLES WITHOUT ZONING * )
      PRINT 200
```

```
200 FORMAT (4X,*I*,1X,*Y(I)*,6X,*P(I)*,8X,*DP*,6X,*D(I)*,8X,*AD*,5X,*D
   1PADI*,5X,*DPADK*)
    PRINT 250,I,Y(I),P(I),DP,D(I),AD,DPADI,DPADK
250 FORMAT (I5,F5.0,2F10.2,4F10.0)
    SUM =0 $ SUMK=0
    DO 400 I=2,30
    DP = P(I-1) - P(I)
    AD = (D(I)+D(I-1))/2.
    IF (I .EQ. IYO) ADIYO=AD
    DPADI =(DP*AD)/100.
    IF (I .LE. IYO) GO TO 300
    DPADI = DP*ADIYO/100.
    DPADK = DP*(AD - ADIYO)/100.
    SUMK = SUMK + DPADK
300 SUM    = SUM+DPADI
    PRINT 250,I,Y(I),P(I),DP,D(I),AD,DPADI,DPADK
400 CONTINUE
    TOTWZ = (SUMK + SUM )
    PRINT 500, SUM, SUMK, TOTWZ
500 FORMAT (50X,3F10.0)
    RETURN
    END

    SUBROUTINE PDZC(IYO,TOTZC)
    DIMENSION Y(30),P(30),D(30)
    I=1 $ DP=0 $ AD=0 $ DPADI=0 $ DPADK=0
    READ (5,220)  J,Y(1),P(1),D(1)
    PRINT 100
100 FORMAT ( 20X,*PROBABILITY DAMAGE TABLE WITH ZONING CHANGES*)
    PRINT 200
200 FORMAT (4X,*I*,1X,*Y(I)*,6X,*P(I)*,8X,*DP*,6X,*D(I)*,8X,*AD*,5X,*D
   1PADI*,5X,*DPADK*)
    PRINT 250,I,Y(1),P(1),D(1)
    SUM=0 $ SUMK=0
    DO 210 I = 2,30
    READ(5,220)  J,Y(I),P(I),D(I)
220 FORMAT (I5,F5.0,2F10.2)
    DP  = P(I-1) - P(I)
    AD  = (D(I) +D(I-1))/2.
    IF (I .EQ. IYO) ADIYO=AD
    DPADI = (DP*AD)/100.
    IF (I .LE. IYO) GO TO 300
    DPADI = DP*ADIYO/100.
    DPADK = DP*(AD- ADIYO)/100.
   'SUMK = SUMK + DPADK
300 SUM = SUM+DPADI
    PRINT 250, I,Y(I),P(I),DP,D(I),AD,DPADI,DPADK
250 FORMAT(I5,F5.0,2F10.2,4F10.0)
210 CONTINUE
    TOTZC = (SUMK + SUM )
    PRINT 450
450 FORMAT (57X,*SUM*,6X,*SUMK*,5X,*TOTZC*)
    PRINT 500, SUM,SUMK,TOTZC
500 FORMAT (50X,3F10.0)
    RETURN
    END


    SUBROUTINE ANCOS(IYO,TAC,ICHECK)
    DIMENSION SUMK(20),SUM(20),TOTZC(20),ACA(20),TNLC(20),TANLIP(20),
   1ANLCIP(20),TAC(20)
    PRINT 100
100 FORMAT(20X,*THE EXPECTED ANNUAL COST OF INSURANCE PROGRAM*)
    PRINT 200
200 FORMAT(1X,*J*,4X,*SUMK*,7X,*SUM*,5X,*TOTZC*,7X,*ACA*,4X,*ANLCIP*,
   17X,*TAC*)
    DO 400  J=1,12
    IF (ICHECK .GE. 2) GO TO 250
    READ(5,220)   SUM(J),SUMK(J),TOTZC(J),TNLC(J),TANLIP(J)
220 FORMAT  (5F10.0)
250 CA = 0.5
    ACA(J) = CA*(TOTZC(J))
    R = 0.07
    LT = 100
    CRF   = (R*((1. +R)**LT))/(((1. + R)**LT) - 1.)
    ANLCIP(J) = (TNLC(J)*CRF) + TANLIP(J)
    TAC(J)   = ACA(J) + ANLCIP(J)
    PRINT 300,J,SUMK(J),SUM(J),TOTZC(J),ACA(J),ANLCIP(J),TAC(J)
300 FORMAT (1H ,I2,6F10.0)
400'CONTINUE
    RETURN
    END
```

SELECTED VARIABLE NAMES IN PROGRAM FOR INTEGRATED ZONING AND FLOOD INSURANCE

Computer Variable Name	Mathematical Term Represented	Computer Variable Name	Mathematical Term Represented
IYOA		DPADK	
BENZC	$[B^Z]_{ijt}$	SUMK	
TOTWZ	$\varepsilon[D]_{ijt}^{NZ}$	SUM	
TOTZC	$\varepsilon[D]_{ijt}^{WZ}$	J	J
BENMD	$B_a^{(In)}$	CA	C_w
BENNET	$[NB^{Z\ In\|J}]_{ijt\lambda}$	R	
BCRAT	B/C	CRF	C_{CRF}
Y(I)		ANLCIP	$[C_a^{Z\|J}]_{ijt\lambda}$
P(I)		TAC	$[C_a^{Z.In\|J}]_{ijt}$
D(I)		TANLIP	C_{TANL}^Z
DP		TNLC	C_{TNLC}^Z
DPADI			

```
                THE NET ANNUAL BENEFIT AND B/C RATIO FOR VARYING
                FLOOD PLAIN STANDARDS IN INSURANCE PROGRAM WITH ZONING
 J     TOTWZ       TOTZC        TAC      BENZC       BENMD     BENNET      BCRAT
                          DAMAGE PROBABILITY TABLES WITHOUT ZONING
   I Y(I)          P(I)          DP       D(I)          AD      DPADI      DPADK
   1   5.         10.64        0.00         0.          0.         0.         0.
   2   5.          8.93        1.71      6000.       3000.        51.         0.
   3   5.          7.41        1.52     30000.      18000.        46.       228.
   4   6.          6.25        1.16     85000.      57500.        35.       632.
   5   6.          5.21        1.04    104000.      94500.        31.       952.
   6   7.          4.35         .86    120000.     112000.        26.       937.
   7   8.          3.62         .73    150000.     135000.        22.       964.
   8   9.          3.03         .59    173000.     161500.        18.       935.
   9   9.          2.50         .53    200000.     186500.        16.       973.
  10  10.          2.08         .42    230000.     215000.        13.       890.
  11  11.          1.75         .33    260000.     245000.        10.       799.
  12  12.          1.45         .30    290000.     275000.         9.       816.
  13  12.          1.33         .12    310000.     300000.         4.       356.
  14  13.          1.20         .13    330000.     320000.         4.       412.
  15  14.          1.00         .20    370000.     350000.         6.       694.
  16  15.           .80         .20    425000.     397500.         6.       789.
  17  15.           .71         .09    450000.     437500.         3.       391.
  18  16.           .67         .04    468000.     459000.         1.       182.
  19  17.           .57         .10    510000.     489000.         3.       486.
  20  18.           .50         .07    545000.     527500.         2.       367.
  21  18.           .44         .06    590000.     567500.         2.       339.
  22  20.           .40         .04    618000.     604000.         1.       240.
  23  22.           .33         .07    738000.     678000.         2.       473.
  24  26.           .24         .09    900000.     819000.         3.       734.
  25  30.           .17         .07   1100000.    1000000.         2.       698.
  26  39.           .12         .05   1240000.    1170000.         1.       583.
  27  40.           .08         .04   1335000.    1287500.         1.       514.
  28  45.           .06         .02   1450000.    1392500.         1.       278.
  29  50.           .04         .02   1500000.    1475000.         1.       294.
  30    I          0.00         .04   1600000.    1550000.         1.       619.
                                                                 319.     16576.
```

```
                       PROBABILITY DAMAGE TABLE WITH ZONING CHANGES
 I Y(I)          P(I)          DP          D(I)          AD       DPADI       DPADK
 1   5.        10.64         0.00
 2   5.         8.93         1.71            0.           0.          0.          0.
 3   5.         7.41         1.52            0.           0.          0.          0.
 4   6.         6.25         1.16            0.           0.          0.          0.
 5   6.         5.21         1.04            0.           0.          0.          0.
 6   7.         4.35          .86            0.           0.          0.          0.
 7   8.         3.62          .73            0.           0.          0.          0.
 8   8.         3.03          .59            0.           0.          0.          0.
 9   9.         2.50          .53            0.           0.          0.          0.
10   9.         2.08          .42            0.           0.          0.          0.
11  10.         1.70          .38            0.           0.          0.          0.
12  11.         1.45          .25            0.           0.          0.          0.
13  12.         1.33          .12            0.           0.          0.          0.
14  12.         1.20          .13            0.           0.          0.          0.
15  13.         1.00          .20            0.           0.          0.          0.
16  14.          .80          .20            0.           0.          0.          0.
17  15.          .71          .09        55000.       27500.          0.         25.
18  15.          .67          .04       104000.       79500.          0.         32.
19  16.          .57          .10       176000.      140000.          0.        140.
20  17.          .50          .07       241000.      208500.          0.        146.
21  18.          .44          .06       317000.      279000.          0.        167.
22  18.          .40          .04       375000.      346000.          0.        138.
23  20.          .33          .07       525000.      450000.          0.        315.
24  22.          .24          .09       718000.      621500.          0.        559.
25  26.          .17          .07       948000.      833000.          0.        583.
26  30.          .12          .05      1119000.     1033500.          0.        517.
27  39.          .08          .04      1244000.     1181500.          0.        473.
28  40.          .06          .02      1389000.     1316500.          0.        263.
29  45.          .04          .02      1470000.     1429500.          0.        286.
30  50.         0.00          .04      1600000.     1535000.          0.        614.
                                                                     SUM        SUMK
                                                                      0.       4258.
                       THE EXPECTED ANNUAL COST OF INSURANCE PROGRAM
J      SUMK         SUM      TOTZC          ACA     ANLCIP         TAC
 1     16895.         0.     16895.        8447.        792.       9239.
 2     16495.         0.     16895.        8447.       3176.      11623.
 3      9998.         0.      9998.        4999.       7146.      12145.
 4      6822.         0.      6882.        3441.      10321.      13762.
 5      5468.         0.      5468.        2734.      11874.      14608.
 6      4707.         0.      4707.        2353.      13568.      15921.
 7      4258.         0.      4258.        2129.      13894.      16023.
 8      3791.         0.      3791.        1895.      14292.      16187.
 9      3485.         0.      3485.        1742.      14688.      16431.
10      3187.         0.      3187.        1593.      15086.      16679.
11      2939.         0.      2939.        1469.      15284.      16753.
12      2671.         0.      2671.        1335.      15482.      16818.
 7  16895.       4258.      16023.      12637.       3534.        148.        1.009
```

APPENDIX D: COMPUTER PROGRAM FOR COMBINATIONAL SCREENING OF FLOOD CONTROL MEASURES AND COMPLETE RESULTS.

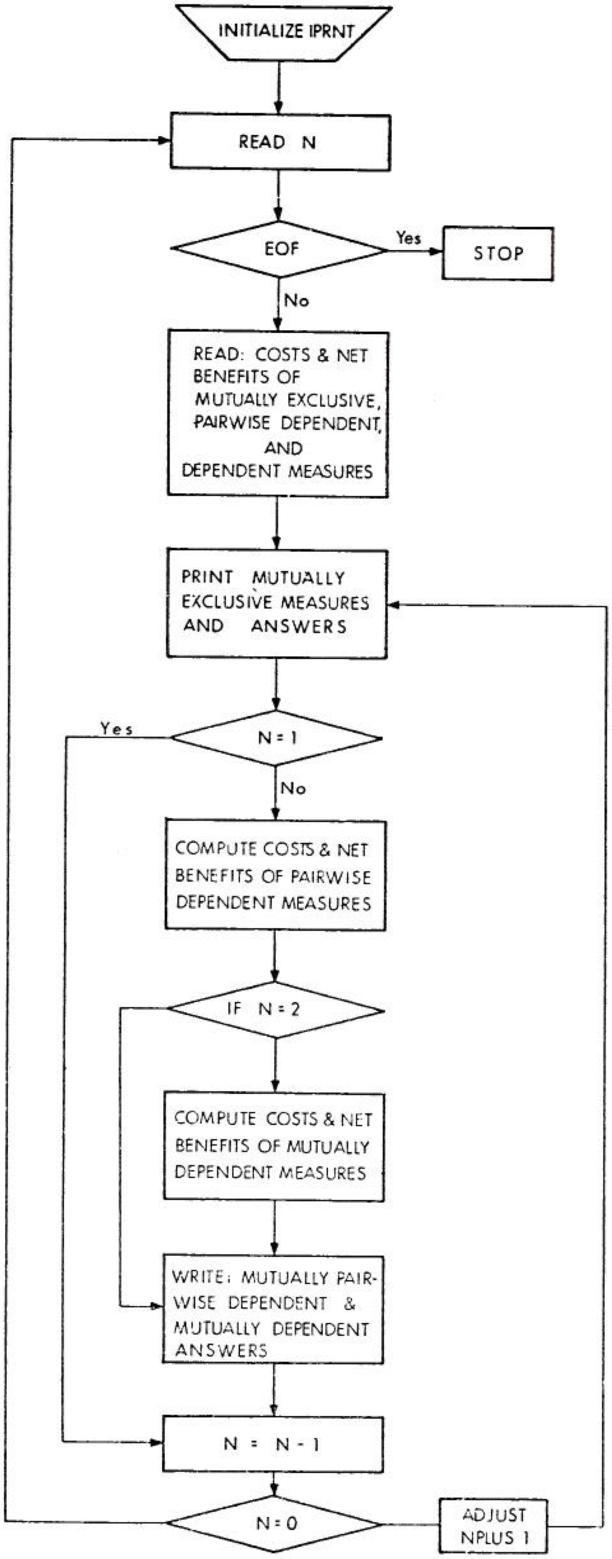

Fig. D-1 Flow Chart for Combinatorial Screening of Flood Control Measures

```
PROGRAM TAI IS A COMBINATORIAL SCREENING OF FLOOD CONTROL MEASURES.
********************************************************************
INPUT DATA FOR ANNUAL AMORTISED COSTS AND AVERAGE ANNUAL NET
         BENEFITS ARE REQUIRED FOR THE VARIOUS COMBINATORIAL MIXES.
THE THREE MEASURES SELECTED ARE EARTH DAM, CHANNEL, AND INSURANCE.
IPRNT  = THE FLOOD PROTECTION CODE DATA.
    N  = THE FLOOD PROTECTION CEILING LEVEL SELECTED. 8 MEANS
A FLOOD FREQUENCY OF 400 YEAR RETURN PERIOD.
DCOST  = THE SINGLE ANNUAL AMORTISED COST OF AN EARTH DAM AT SIZES
         UP TO N.
CCOST  = THE SINGLE ANNUAL AMORTISED COST OF THE CHANNEL AT SIZES
UP TO N.
TCOST  = THE SINGLE ANNUAL COST OF THE FLOOD INSURANCE PROGRAM.
DNB    = THE ANNUAL NET BENEFIT OF THE EARTH DAM.
CNB    = THE ANNUAL NET BENEFIT OF THE CHANNEL DOWNSTREAM OF THE
         DAM
TNB    = THE ANNUAL NET BENEFIT OF THE FLOOD INSURANCE PROGRAM.
CCCOST = THE ANNUAL COST OF THE CHANNEL SUPPLEMENTARY TO THE DAM.
TTCOST = THE ANNUAL COST OF THE INSURANCE SUPPLEMENTARY TO THE DAM.
T2COST = THE ANNUAL COST OFTHE INSURANCE SUPPLEMENTARY TO THE CHANNEL.
T3COST = THE ANNUAL COST OF THE INSURANCE SUPPLEMENTARY TO DAM AND
AND CHANNEL.
PAIR-WISE DEPENDENCY.
DCCOST = THE ANNUAL COST OF DAM AND CHANNEL.
DTCOST = THE ANNUAL COST OF DAM AND INSURANCE.
CTCOST = THE ANNUAL COST OF CHANNEL AND INSURANCE.
MUTUTUALLY DEPENDENT.
DCT    = THE ANNUAL COST OF DAM, CHANNEL, AND FLOOD INSURANCE.
CORRESPONDING NET BENEFITS *NB* ARE SHOWN AFTER THE RESPECTIVE
         DESIGNATED SYMBOLS FOR DAM, CHANNEL, AND INSURANCE.
COMPUTER PRINTOUT ARE THE EXPECTED ANNUAL NET BENEFITS AND
         ANNUAL COSTS OF MIXES. THESE VALUES NEED TO BE PLOTTED OUT
         TO OBTAIN THE OPTIMAL CHARACTERISTIC FOR EACH Q - DELTAQ.

      PROGRAM TAI (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      DIMENSION DCOST(12),DNB(12),CCOST(12),CNB(12),TCOST(12),TNB(12),
     + CCCOST(11,11),CCNB(11,11),TTCOST(11,11),TTNB(11,11),
     + T2COST(11,11),T2NB(11,11),T3COST(11,11),T3NB(11,11),
     + DCCOST(11),DCNB(11),DTCOST(11),DTNB(11),CTCOST(11),CTNB(11),
     + DCTCOST(10,10),DCTNB(10,10)
      DIMENSION IPRNT(11)
      INTEGER OFF
      DATA IPRNT / 1,2,3,4,5,6,7,8,9,10,11 /
      BLNK=1H

1     READ (5,5) N
5     FORMAT (I5)
      IF (EOF(5)) 999,20
20    NPLUS1=N+1
      NLESS1=N-1
      NLESS2=N-2
      OFF=0
      READ (5,40) (DCOST(I),I=1,N)
      READ (5,40) (CCOST(I),I=1,N)
      READ (5,40) (TCOST(I),I=1,N)
40    FORMAT (8F10.2)
      DO 60 I=1,NLESS1
60    READ (5,40) (CCCOST(I,J),J=1,NLESS1)
      DO 63 I=1,NLESS1
63    READ (5,40) (TTCOST(I,J),J=1,NLESS1)
      DO 65 I=1,NLESS1
65    READ (5,40) (T2COST(I,J),J=1,NLESS1)
      DO 67 I=1,NLESS1
67    READ (5,40) (T3COST(I,J),J=1,NLESS1)
      READ (5,40) (DNB(I),I=1,N)
      READ (5,40) (CNB(I),I=1,N)
      READ (5,40) (TNB(I),I=1,N)
      DO 70 I=1,NLESS1
70    READ (5,40) (CCNB(I,J),J=1,NLESS1)
      DO 73 I=1,NLESS1
73    READ (5,40) (TTNB(I,J),J=1,NLESS1)
      DO 75 I=1,NLESS1
75    READ (5,40) (T2NB(I,J),J=1,NLESS1)
      DO 77 I=1,NLESS1
77    READ (5,40) (T3NB(I,J),J=1,NLESS1)

C     ---  PART 1  ---
105   WRITE (6,115)N,N,N,DNB(N),CNB(N),TNB(N),DCOST(N),CCOST(N),TCOST(N)
115   FORMAT (1H1, 12X *MUTUALLY EXCLUSIVE MEASURES* // 16X *D* I1, 8X
     + *C* I1, 8X *I* I1 /  (8X,3F10.2))

C     ---  PART 2  ---
      IF (N.EQ.1) GO TO 300
      DO 170 I=1,NLESS1
      DCCOST(I)=DCOST(I)+CCCOST(1+OFF,N-I+OFF)
      DTCOST(I)=DCOST(I)+TTCOST(1+OFF,N-I+OFF)
      CTCOST(I)=CCOST(I)+T2COST(1+OFF,N-I+OFF)
      DCNB(I)=DNB(I)+CCNB(1+OFF,N-I+OFF)
      DTNB(I)=DNB(I)+TTNB(1+OFF,N-I+OFF)
170   CTNB(I)=CNB(I)+T2NB(1+OFF,N-I+OFF)
```

```
      DO 240 I=1,NLESS2
      JJ=N-I-1
      DO 230 J=1,JJ
      DCTCOST(I,J)=DCOST(I) + CCCOST(NPLUS1-I-J+OFF,N-I+OFF) + T3COST
     + (1+OFF,N-I-J+OFF)
      DCTNB(I,J)=DNB(I) + CCNB(NPLUS1-I-J+OFF,N-I+OFF) + T3NB(1+OFF,N-I
     + -J+OFF)
230   CONTINUE
240   CONTINUE

250   WRITE (6,260)
260   FORMAT (//// *0  MUTUALLY PAIRWISE DEPENDENT* 20X *MUTUALLY DEPEND
     +ENT* /)
      IF (N.EQ.2) GO TO 292
      DO 290 I=1,NLESS2
      J1=N-I       $  J2=J1-1
      WRITE (6,272) (I,IPRNT(N-I),K=1,3), (BLNK,I,J,IPRNT(J1-J),J=1,J2)
272   FORMAT (// 4X *D* I1 *C* I1,  6X *D* I1 *I* I1,  6X *C* I1 *I* I1,
     +  5X,10(A4 *D* I1 *C* I1 *I* I1) )
      WRITE (6,275) DCNR(I),DTNB(I),CTNB(I), (DCTNB(I,J),J=1,J2)
      WRITE (6,275) DCCOST(I),DTCOST(I),CTCOST(I), (DCTCOST(I,J),J=1,J2)
275   FORMAT (1X,F10.0,2F10.0,5X,9F10.0)
290   CONTINUE
292   I=NLESS1
      WRITE (6,272) (I,IPRNT(N-I),K=1,3)
      WRITE (6,275) DCNB(I),DTNB(I),CTNB(I)
      WRITE (6,275) DCCOST(I),DTCOST(I),CTCOST(I,
300   N=N-1
      IF (N.EQ.0) GO TO 1
330   NPLUS1=N+1       $  NLESS1=N-1       $  NLESS2=N-2
      OFF=OFF+1
      GO TO 105
999   STOP
      END
```

```
              MUTUALLY EXCLUSIVE MEASURES

                   D8          C8          I8
          386056.00-646000.00  42825.00
         1747028.001671000.00 464983.00



MUTUALLY PAIRWISE DEPENDENT                    MUTUALLY DEPENDENT


 D1C7      D1I7      C1I7           D1C1I6    D1C2I5    D1C3I4    D1C4I3    D1C5I2    D1C6I1
 476857,   446145.   176774.          488071.   565655.   481193.   480702.   483640.   482849.
1540742.  1368553.   421657.         1178875.  1254635.  1490395.  1564913.  1586432.  1595586.


 D2C6      D2I6      C2I6           D2C1I5    D2C2I4    D2C3I3    D2C4I2    D2C5I1
 478675.   447209.    85695.          497503.   541941.   489550.   479488.   479697.
1569436.  1514597.   581946.         1353329.  1460089.  1586607.  1621126.  1629280.


 D3C5      D3I5      C3I5           D3C1I4    D3C2I3    D3C3I2    D3C4I1
 544087.   451528.    82254.          501353.   540962.   557835.   555109.
1431746.  1607015.   740529.         1428399.  1462917.  1461436.  1481590.


 D4C4      D4I4      C4I4           D4C1I3    D4C2I2    D4C3I1
 425252.   404452.    52645.          416127.   431065.   446274.
1481941.  1752317.   921390.         1519112.  1528631.  1521785.


 D5C3      D5I3      C5I3           D5C1I2    D5C2I1
 429035.   433142.   -53420.          429131.   435340.
1517271.  1809199.  1104584.         1529961.  1532115.


 D6C2      D6I2      C6I2           D5C1I1
 426467.   439101.  -210050.          406343.
1582833.  1883312.  1287030.         1604677.


 D7C1      D7I1      C7I1
 396449.   416919.  -403117.
1672930.  1977342.  1468409.
```

APPENDIX E: COMPUTER PROGRAM FOR RESOURCE ALLOCATION AND TYPICAL RESULTS

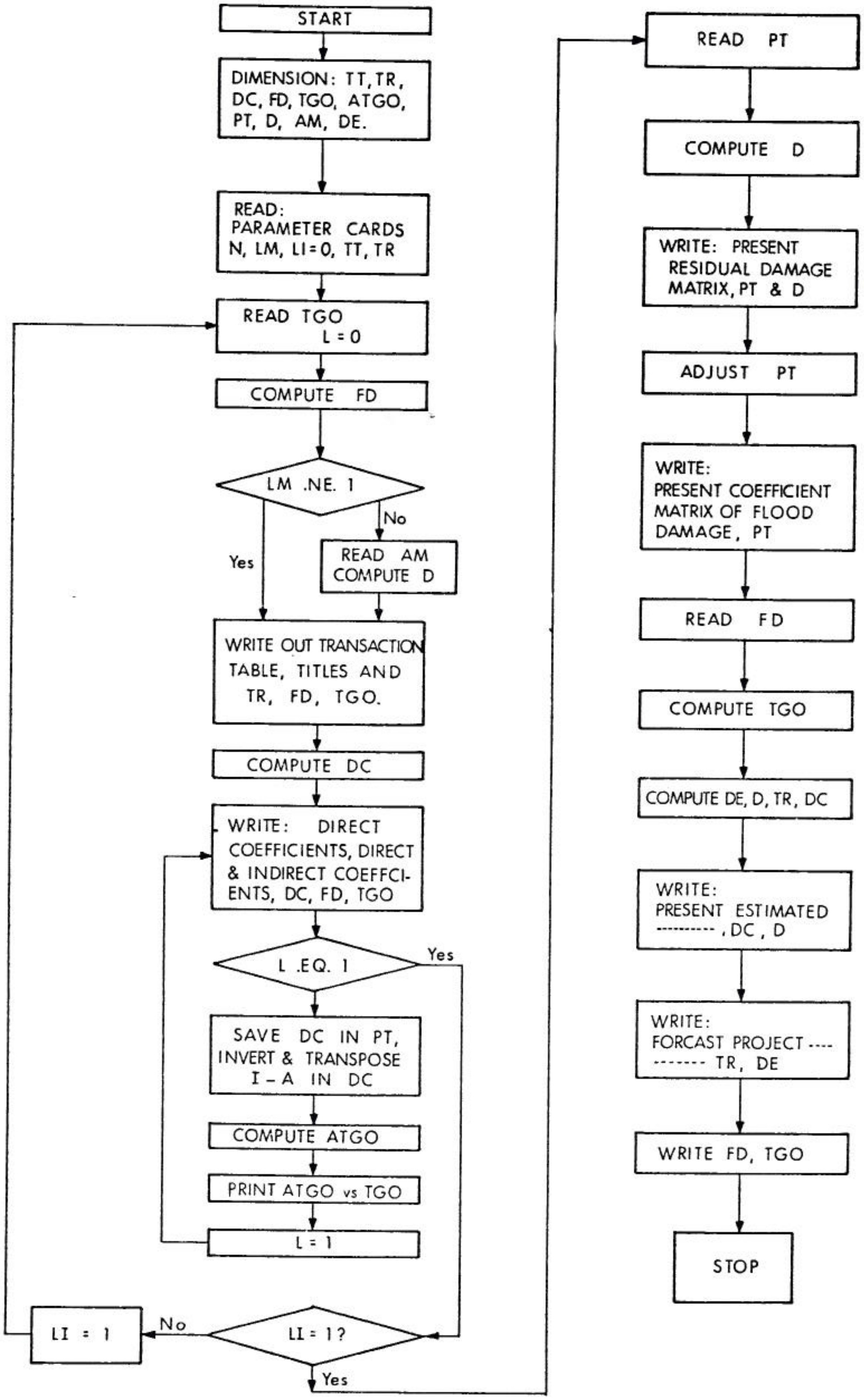

Fig. E-1 Flow Chart for One-Dimensional Resource Allocation for the Three Branches by Dynamic Programming

```
BASIC FORTRAN PROGRAM FOR 1-DIMENSIONAL RESOURCE ALLOCATION
BY DYNAMIC PROGRAMMING.
R(I,J) = TOTAL NET RETURN FROM ALLOCATING J-1 UNITS OF $ TO ACTIVITY
I.
N      = TOTAL NO. OF ACTIVITIES OR STAGES OR SUBSYSTEMS.
M-1    = TOTAL AMOUNT OF CAPITAL AVAILABLE.
           UNITS $ TO STAGES I THROUGH N.
G(J)   = GIVEN STAGE I, THE MAXIMUM RETURN FROM ALLOCATING J-1
           UNITS TO STAGES I+1 THROUGH N. G(J) IS STORED VALUE.
```

```
COMPOSITE 2-DIMENSIONAL RESOURCE ALLOCATION PROGRAM FOR THREE RIVER
BRANCHES, COUNTY OF PUEBLO.
R(I,J) = TOTAL NET BENEFIT FROM ALLOCATING J-1 UNITS OF $ TO
          SUBSYSTEM  I.
N      = TOTAL NO. OF STAGES OR SUBSYSTEMS.
F(J)   = GIVEN STAGE I, THE MAXIMUM NET RETURN FROM ALLOCATING
       ' J-1 UNITS $ TO STAGES I THROUGH N.
G(J)   = GIVEN STAGE I, THE MAXIMUM NET RETURN FROM ALLOCATING
       . J-1 UNITS $ TO STAGES I+1 THROUGH N.
M      = NO. OF DISCRETISED VALUES AT EACH GIVEN STAGE I.
ICONT(J)=ALLOCATION CODE IN UNITS OF $. CODE 8 MEANS 8*$10000.=
          $80,000.


COMPOSITE PROGRAM FOR 2-DIMENSIONAL STATE RESOURCE ALLOCATION
IS BUILT UP OF BASIC 1-DIMENSIONAL PROGRAM OBTAINED FROM DR. JOHN
W. LABADIE.

      PROGRAM BASIC DP (INPUT, OUTPUT)
      DIMENSION IR(I,J),ICONT(J),F(J),G(J)
      READ 501,M,N
 501  FORMAT  (I3,I10)
      READ 502, ((IR(I,J),I=1,N), J=1,M)
 502  FORMAT  (33I5)
      DO 1  J=1,M
    1 G(J)=0.
      DO 2 II=1,N
      I=N-II+1
C     I = N-II+1 IS THE LAST STAGE.                                 ****
      PRINT 602,I
  602 FORMAT (1X,*ACTIVITY*,I4)
      PRINT 603,I
  603 FORMAT(5X,*RESOURCE AVAILABLE*,5X,*ALLOCATION TO*,I4)
      DO 5 J=1,M
C     SOLVE FOR ALL J.                                              ****
      A=0.
      DO 4 L=1,J
      JJ=J-L+1
C     JJ = J-L+1 IS THE AMOUNT OF CAPITAL LEFT OVER AFTER ALLOC. L TO
C     TO STAGE'I.                                                   ****
      B = IR(I,L) + G(JJ)
      IF(B-A)4,3,3
    3 A=B
      LL = L-1
    4 CONTINUE
      F(J)=A
 5    ICONT(J) = LL
      DO 6 J=1,M
    6 G(J)=F(J)
      DO 7 J=1,M
      PRINT 604, J,CONT(J),G(J)
  604 FORMAT (5X,I10,15X,F10.0,15X,F10.2)
    7 CONTINUE
    2 CONTINUE
      STOP
      END

      PROGRAM TEST (INPUT,OUTPUT, TAPE5=INPUT,TAPE6=OUTPUT)
      DIMENSION  IR(20,600),F(600),G(600),ICONT(600),LAB(3),SAVE(600,2)
      REAL IR
      LAB(1) = 10HBOTTOM
      LAB(2) = 10HTOP
      LAB(3) = 10HDOWNSTREAM
      DO 1000 KNT=1,3
      WRITE(6,100) LAB(KNT)
  100 FORMAT(*1*20X,A10,//)
      READ 501, M, N
  501 FORMAT (2I10)
      READ 502, ((IR(I,J), I=1,N), J=1,M)
  502 FORMAT(10F8.2)

      IF (KNT.EQ.3) GO TO 30
      DO 1 J=1,M
    1 G(J)=0.
      GO TO 90
```

```
30     DO 45 L1=1,M
       TEMP=0.
       DO 43 L2=1,L1
       TTT=SAVE(L2,1) + SAVE(L1-L2+1,2)
43     TEMP=AMAX1(TEMP,TTT)
45     G(L1)=TEMP

90     DO 2 II=1,N
       I=N-II+1
       PRINT 602,I
  602 FORMAT (1X,*ACTIVITY*, I4)
      PRINT 603,I
  603 FORMAT (5X,*RESOURCE AVAILABLE*,5X*ALLOCATION TO*,I4,10X,*F(J)*)
      DO 5 J=1,M
      A=0.
      DO 4 L=1,J
      JJ=J-L+1
      B=IR(I,L)+G(JJ)
      IF (B-A) 4,3,3
    3 A=B
      LL=L-1
    4 CONTINUE
      F(J)=A
    5 ICONT(J)=LL
      DO 6 J=1,M
    6 G(J) =F(J)
      DO 7 J=1,M
      PRINT 604,J,ICONT(J),F(J)
  604 FORMAT (5X,I10,15X,I10,10X,F10.2)
    7 CONTINUE
    2 CONTINUE

      IF (KNT.EQ.3) GO TO 1000
      DO 990 LOOP=1,M
  990 SAVE(LOOP,KNT)=F(LOOP)
 1000 CONTINUE
      STOP
      END
```

SELECTED VARIABLE NAMES IN PROGRAM FOR RESOURCE ALLOCATION

Computer Variable Name	Mathematical Term Represented
R(I,J)	$r_N(X_N)$
I	n
N	N
G(J)	$f_n(X_n) = \max_{D_n} Q_n(X_n,D_n)$ n=2,...,N.

```
                              DOWNSTREAM

ACTIVITY   4

          RESOURCE AVAILABLE        ALLOCATION TO 4         F(J)
                  1                       0                 0.00
                  2                       1                 5.92
                  3                       2                11.84
                  4                       2                11.84
                  5                       2                11.84
                  6                       2                11.84
                  7                       2                11.84
                  8                       2                11.84
                  9                       2                11.84
                 10                       2                11.84
                 11                       2                11.84
                 12                       2                11.84
                 13                       2                11.84
                 14                       2                11.84
                 15                       2                11.84
                 16                       2                11.84
                 17                       2                11.84
                 18                       2                11.84
                 19                       2                11.84
                 20                       2                11.84
                 21                       2                11.84
                 22                       2                11.84
                 23                       2                11.84
                 24                       2                11.84
                 25                       2                11.84
                 26                       2                11.84
                 27                       2                11.84
                 28                       2                11.84
                 29                       2                11.84
                 30                       2                11.84
                 31                       2                11.84
                 32                       2                11.84
                 33                       2                11.84
                 34                       2                11.84
                 35                       2                11.84
                 36                       2                11.84
                 37                       2                11.84
                 38                       2                11.84
                 39                       2                11.84
                 40                       2                11.84
                 41                       2                11.84
                 42                       2                11.84
                 43                       2                11.84
                 44                       2                11.84
                 45                       2                11.84
                 46                       2                11.84
                 47                       2                11.84
                 48                       2                11.84
                 49                       2                11.84
                 50                       2                11.84
                 51                       2                11.84
                 52                       2                11.84
                 53                       2                11.84
                 54                       2                11.84
                 55                       2                11.84
                 56                       2                11.84
                 57                       2                11.84
                 58                       2                11.84
                 59                       2                11.84
                 60                       2                11.84
                 61                       2                11.84
                 62                       2                11.84
                 63                       2                11.84
                 64                       2                11.84
                 65                       2                11.84
                 66                       2                11.84
                 67                       2                11.84
                 68                       2                11.84
                 69                       2                11.84
                 70                       2                11.84
                 71                       2                11.84
                 72                       2                11.84
                 73                       2                11.84
                 74                       2                11.84
                 75                       2                11.84
                 76                       2                11.84
                 77                       2                11.84
                 78                       2                11.84
                 79                       2                11.84
                 80                       2                11.84
```

APPENDIX F: COMPUTER PROGRAM FOR INPUT-OUTPUT MODEL AND TYPICAL RESULTS OF IMPACT STUDIES OF FLOOD CONTROL MEASURES

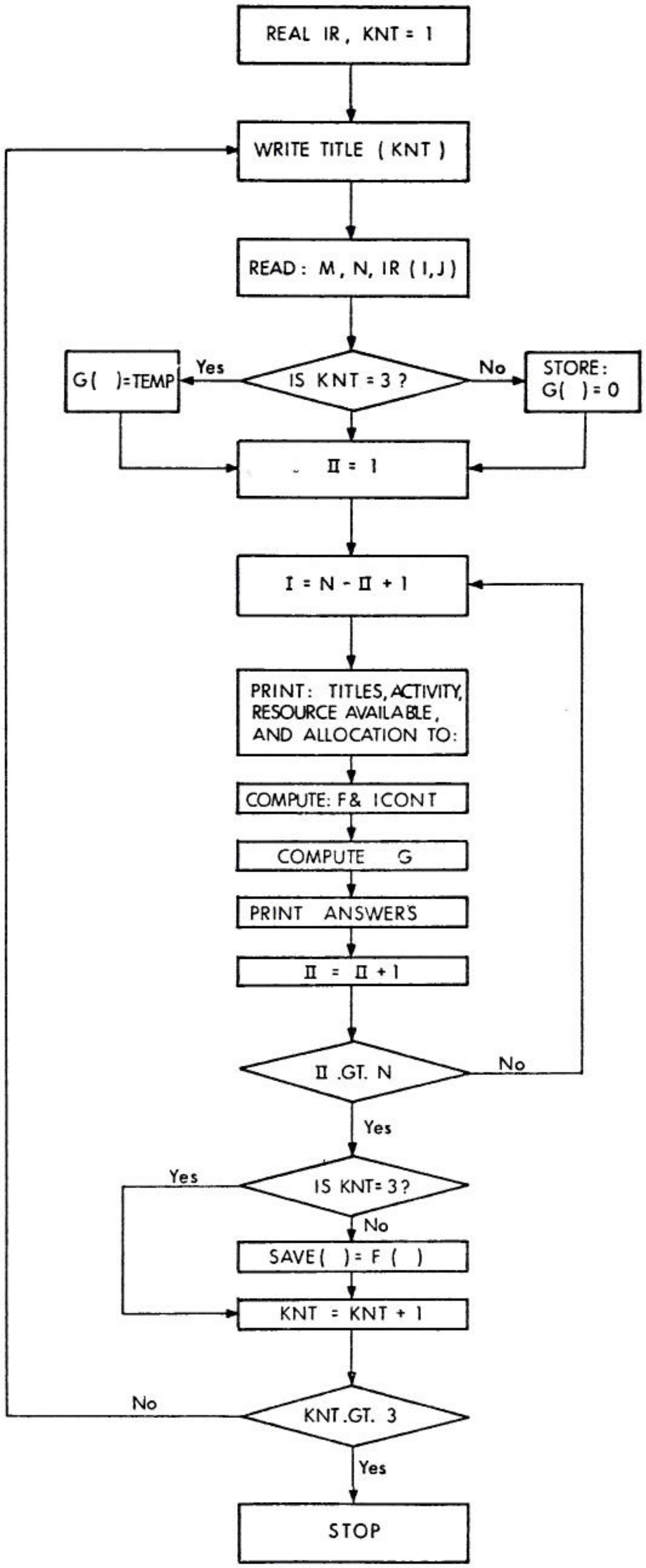

Fig. F-1 Flow Chart for Regional Input-Output Model Adapted for Flood-Control Impact Studies

```
    INTERREGIONAL INPUT-OUTPUT MODEL ADAPTED FOR IMPACT STUDIES OF
    FLOOD CONTROL MEASURES.
    ASSISTANCE OF MR. CHARLES PALMER, ECONOMIC RESEARCH UNIT,
    IS ACKNOWLEDGED, IN DEVELOPING THE SPECIAL REQUIREMENT OF THIS
    ECONOMIC MODEL.
******************************************************************
    THE INTERREGIONAL INPUT-OUTPUT PROGRAM COMPUTES THE SEVEN
    FEATURES AS REQUIRED.
  (1)  TRANSACTION TABLE, DIRECT COEFFICIENTS, FINAL DEMAND, AND
       TOTAL OUTPUT.
  (2)  DIRECT AND INDIRECT COEFFICIENTS.
  (3)  PRESENT RESIDUAL DAMAGE MATRIX (FLOOD PROTECTION) OR
       PRESENT    TOTAL DAMAGE MATRIX ( NO   PROTECTION).
  (4)  PRESENT COEFFICIENT MATRIX OF FLOOD DAMAGE (WITH OR
       WITHOUT PROTECTION.
  (5)  PRESENT ESTIMATED DAMAGE-RELATED OUTPUT MATRIX.
  (6)  FORECAST PROJECTION DAMAGE-RELATED OUTPUT MATRIX.
  (7)  FORECAST FINAL DEMAND AND TOTAL OUTPUT.
******************************************************************
    N       = THE NO. OF COUNTIES.
    TT      = TITLE (INPUT-OUTPUT TEST DATA)
    TR(I,J)= TRANSACTION MATRIX OF THE SECTORS.
    TGO(I,N)= TOTAL OUTPUT X, VECTOR.
    FD(I)   = PRESENT FINAL DEMAND VECTOR Y.
    DC(I,J)= DIRECT TRANSACTION COEFFICIENT MATRIX.
    ATGO(I)= CHECK OF INVERSION (I-A). IT SHOULD EQUAL IF
             INVERSION IS CORRECT.
    **************************************************************


       PROGRAM IO(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
       DATA INPUT
       FIRST CARD N= NUMBER OF COUNTIES
       SECOND READ  TT TITLE ( INPUT-OUTPUT TEST DATA)
       THIRD READ   FORMAT OF TRANSACTIONS MATRIX
       FOURTH READ  TRANSACTION MATRIX
       FIFTH READ   FORMAT OF TOTAL OUTPUT VECTOR (X)
       SIXTH READ   TOTAL OUTPUT VECTOR (X) WITHOUT PROTECTION
       SEVEN READ   TOTAL OUTPUT VECTOR(X) WITH PROTECTION
       EIGTH READ   FORMAT FOR PRESENT RESIDUAL DAMAGE MATRIX
       NINTH READ   PRESENT RESIDUAL DAMAGE MATRIX
       TENTH READ   FORMAT FOR PROJECTED FINAL DEMANDS VECTOR(Y)
       ELEVENTH READ FINAL DEMANDS PROJECTED VECTOR(Y)
       DIMENSION TT(10),TR(40,40),DC(40,40),FD(40),TGO(40),ATGO(40),
      1PT(40,40),D(40),AM(40),DE(40)
     5 READ(5,11)N,LM
       LI=0
    11 FORMAT(3I2)
       READ(5,12)(TT(I),I=1,10)
    12 FORMAT(10A8)
       READ(5,12)FMT
       READ (5,FMT) ((TR(I,J), J=1,N), I=1,N)
       READ(5,12)FMT
    85 READ(5,FMT)(TGO(I),I=1,N)
       L=0
       CALCULATE TOTAL FINAL DEMANDS
       DO 15 I=1,N
       TGO IS PRESENT TOTAL OUTPUT
       FD(I)=TGO(I)
       DO 15 J=1,N
       FD IS PRESENT FINAL DEMANDS
    15 FD(I)=FD(I)-TR(I,J)
       IF(LM.NE.1) GO TO 81
       READ(5,FMT)(AM(I),I=1,N)
       DO 82 I=1,N
    82 D(I)=TGO(I)-AM(I)
    81 IN=N/10
       IF((10*IN).EQ.IN) GO TO 112
       WRITE OUT TRANSACTIONS TABLE
       IN=IN+1
   112 IM=1
       IF(IN.LT.1)IN=1
       DO 150 KK=1,IN
       WRITE(6,130)(TT(I),I=1,10)
   130 FORMAT(1H1,///,10X,10A8)
       WRITE(6,131)
   131 FORMAT(10X,*TRANSACTIONS TABLE*)
       WRITF(6,121) KK,IN
   121 FORMAT(100X,*PAGE*I2,1X*OF*I2)
       WRITE(6,126)
   126 FORMAT(10X,123(*-*))
       KC=KK*10
       IF(KC.GT.N) KC=N
       WRITE(6,122)(I,I=IM,KC)
   122 FORMAT(10X,*SECTOR*,4X,I2,9I10)
       DO 108 I=1,N
   108 WRITE(6,145)I,(TR(I,J),J=IM,KC)
       WRITE(6,126)
   145 FORMAT(10X,I2,3X,10F10.3)
       IM=KC+1
```

```
  150 CONTINUE
      WRITE(6,102)
      DO 101 I=1,N
  101 WRITE(6,100)I,FD(I),TGO(I)
  100 FORMAT(6X,I8,2F15.3)
  102 FORMAT(1H1,///,10X,*SECTOR*,3X,*FINAL DEMAND*,3X,*TOTAL OUTPUT*)
      DO 30 J=1,N
      DO 30 I=1,N
   30 DC(I,J)=TR(I,J)/TGO(J)
      WRITE DIRECT COEFFICIENTS
   41 IN=N/10
      IF((10*IN).EQ.IN) GO TO 115
      IN=IN+1
  115 IM=1
      IF(IN.LT.1)IN=1
      DO 160 KK=1,IN
      IF(L.EQ.1) GO TO 42
      WRITE(6,130)(TT(I),I=1,10)
      WRITE(6,132)
  132 FORMAT(10X,*DIRECT COEFFICIENTS*)
      GO TO 43
   42 WRITE(6,130)(TT(I),I=1,10)
      WRITE(6,44)
   44 FORMAT(10X,*4IRECT AND INDIRECT COEFICIENTS*)
   43 WRITE(6,121) KK,IN
      WRITE(6,126)
      KC=KK*10
      IF(KC.GT.N) KC=N
      WRITE(6,122)(I,I=IM,KC)
      DO 62 I=1,N
   62 WRITE(6,144)I,(DC(I,J),J=IM,KC)
      WRITE(6,126)
  144 FORMAT(10X,I2,3X,10F10.6)
      IM=KC+1
  160 CONTINUE
      WRITE(6,102)
      DO 201 I=1,N
  201 WRITE(6,100)I,FD(I),TGO(I)
      IF(L.EQ.1) GO TO 245
      COMPUTE I-A
  777 DO 70 I=1,N
      DO 70 J=1,N
      PT(I,J)=DC(I,J)
   70 DC(I,J)=-DC(I,J)
      DO 71 I=1,N
   71 DC(I,I)=1.0+DC(I,I)
      INVERT I-A
      DC(1,N+1)=1.0
      DO 73 I=1,N
   73 DC(I+1,N+1)=0.0
      DO 74 KK=1,N
      DO 75 J=1,N
   75 DC(N+1,J)=DC(1,J+1)/DC(1,1)
      DO 76 I=2,N
      DO 76 J=1,N
   76 DC(I-1,J)=DC(I,J+1)-DC(I,1)*DC(N+1,J)
    4 DO 74 J=1,N
   74 DC(N,J)=DC(N+1,J)
      DC NOW CONTAINS I-A INVERTED AND TRANSPOSED
      DO 80 I=1,N
      ATGO IS CHECK OF INVERSION. IT SHOULD EQUAL TGO IF INVERSION IS CORRECT
      ATGO(I)=0.0
      DO 80 J=1,N
   80 ATGO(I)=ATGO(I)+DC(I,J)*FD(J)
      WRITE(6,90)
   90 FORMAT(1H1,///,10X,*CHECK, BOTH COLUMNS SHOULD BE THE SAME*)
      DO 91 I=1,N
   91 WRITE(6,92) ATGO(I),TGO(I)
   92 FORMAT(10X,2F12.3)
      L=1
      GO TO 41
  245 IF(LI.EQ.1) GO TO 45
      LI=1
      GO TO 85

   45 READ(5,12)FMT
C     PT IS PRESENT RESIDUAL DAMAGE MATRIX HERE
  210 READ (5,FMT)((PT(I,J),J=1,N), I=1,6)
C     D IS ROW TOTAL OF PRESENT RESIDUAL DAMAGE MATRIX
      DO 211 I=1,6
      D(I)=0.0
      DO 211 J=1,N
```

```
211   D(I) = D(I)+PT(I,J)
      WRITE(6,130)(TT(I),I=1,10)
      LOOP = N/13
      IF (LOOP*13  .NE. N)  LOOP=LOOP+1
      I2 = 1
      DO 31 LL= 1,LOOP
      I3 = I2+12
      WRITE (6,214)
 214  FORMAT(10X,*PRES.RESIDUAL DAMAGE MATRIX(FLOOD PROTECTION)*)
      WRITE (6,16)  LL,LOOP
 16   FORMAT(100X,*PART*I2* OF*I2)
      DO 19 I=1,6
      WRITE (6,213) I,(PT(I,J),J=I2,I3)
 213  FORMAT(7X,I2,13F9.0)
 19   CONTINUE
 31   I2=I3+1
      WRITE(6,219) (D(I),I=1,6)
 219  FORMAT (4X*TOTAL* ,/,13F10.0)
      DO 215 I=1,6
      DO 215 J=1,N
C     PT NOW IS PRESENT COEFFICIENT MATRIX OF FLOOD DAMAGE
 215  PT(I,J) = PT(I,J)/D(I)
      WRITE(6,130)(TT(I),I=1,10)
      LOOP = N/13
      IF (LOOP*13  .NE. N)  LOOP=LOOP+1
      I2 = 1
      DO 311  LL=1,LOOP
      I3 = I2+12
      WRITE (6,216)
 216  FORMAT(10X,*PRESENT COEFFICIENT MATRIX OF FLOOD DAMAGE*)
      WRITE(6,161)  LL,LOOP
 161  FORMAT(100X,*PART*I2* OF*I2)
      DO 191 I=1,6
 217  WRITE (6,218)I,(PT(I,J),J=I2,I3)
 218  FORMAT(7X,I2,13F9.6)
 191  CONTINUE
 311  I2=I3+1
      READ(5,12)FMT
C     FD HERE IS THE PROJECTED FINAL DEMANDS
      READ(5,FMT)(FD(I),I=1,N)
      DO 220 I=1,N
      TGO(I)=0.0
      DO 220 J=1,N
C     TGO HERE IS THE PROJECTED TOTAL OUTPUT
  220 TGO(I)=TGO(I)+DC(I,J)*FD(J)
      DO 221 I=1,6
      DE(I)=0.0
      D(I)=0.0
      DO 221 J=1,N
C     DC HERE IS PRESENT ESTIMATED DAMAGE-RELATED OUTPUT MATRIX.
      TR(I,J)=PT(I,J)*TGO(J)
      DC(I,J)=PT(I,J)*ATGO(J)
C     TR HERE IS FORECAST PROJECTED DAMAGE-RELATED OUTPUT MATRIX.
C     D HERE IS TOTAL PRESENT ESTIMATED DAMAGE-RELATED OUTPUT VECTOR.
C     DE HERE IS TOTAL FORECAST PROJECTED DAMAGE-RELATED OUPUT VECTOR.
      D(I)=D(I)+DC(I,J)
  221 DE(I)=DE(I)+TR(I,J)
      WRITE (6,130)  (TT(I),I=1,10)
      LOOP = N/13
      IF (LOOP*13  .NE. N)  LOOP=LOOP+1
      I2 = 1
      DO 312 LL =1,LOOP
      I3 = I2+12
      WRITE (6,240)
 240  FORMAT (10X,*PRESENT ESTIMATED DAMAGE-RELATED OUTPUT MATRIX.*)
      WRITE (6,162) LL,LOOP
 162  FORMAT(100X,*PART*I2* OF*I2)
      DO 192 I=1,6
      WRITE (6,225)I,(DC(I,J),J=I2,I3),D(I)
 192  CONTINUE
 312  I2=I3+1
      WRITE(6,130)(TT(I),I=1,10)
      LOOP = N/13
      IF (LOOP*13  .NE. N)  LOOP=LOOP+1
      I2 = 1
      DO 313 LL=1,LOOP
      I3=I2+12
      WRITE (6,222)
 222  FORMAT (10X,*FORECAST PROJECTION DAMAGE-RELATED OUTPUT MATRIX.*)
      WRITE (6,163) LL,LOOP
 163  FORMAT(100X,*PART*I2* OF*I2)
      DO 193 I=1,6
      WRITE (6,225)I,(TR(I,J),J=I2,I3),DE(I)
 225  FORMAT (1X,I1,13F8.2,F10.2)
 193  CONTINUE
 313  I2=I3+1
      WRITE (6,102)
      DO 231 I=1,N
  231 WRITE (6,100) I,FD(I),TGO(I)
      STOP
      END
```

SELECTED VARIABLE NAMES IN PROGRAM FOR INTER-REGIONAL INPUT-OUTPUT MODEL

Computer Variable Name	Mathematical Term Represented
N	
TR(I,J)	$X_{i,j}$
TGO(I,N)	$\underline{X}$
FD(I)	$\underline{Y}$
DC(I,J)	a_{ij} or b_{ij} (without or with flood protection)
ATGO(I)	$(I-A)^{-1}$ check

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INPUT-OUTPUT TEST DATA. COE.
TRANSACTIONS TABLE
                                                                                          PAGE 1 OF 4
------------------------------------------------------------------------------------------------------
SECTOR       1            2           3            4           5           6           7           8            9          10
  1      228.000      2.000    1633.000       0.000      1.000     225.000      1.000   4262.000       0.000       4.000
  2      251.000      0.000     122.000       0.000      0.000     248.000      0.000    320.000       0.000       1.000
  3      101.000     14.000     176.000     127.000      8.000     100.000     11.000    458.000     573.000      37.000
  4       58.000     49.000     151.000    1089.000     26.000      57.000     37.000    393.000    4929.000     116.000
  5        1.000      0.000       6.000      11.000      2.000       1.000      0.000     16.000      48.000      10.000
  6      766.000      6.000    5485.000       0.000      3.000    3634.000     23.000  68789.000       0.000      61.000
  7      843.000      0.000     411.000       0.000      1.000    3997.000      0.000   5179.000       0.000      17.000
  8      339.000     48.000     590.000     426.000     28.000    1607.000    176.000   7394.000    9255.000     605.000
  9      194.000    166.000     506.000    3659.000     88.000     921.000    604.000   6350.000   79552.000    1866.000
 10        3.000      0.000      20.000      36.000      7.000      14.000      0.000    256.000     777.000     157.000
 11      619.000      5.000    4429.000       0.000      2.000    1387.000      9.000  26260.000       0.000      23.000
 12      681.000      0.000     332.000       0.000      1.000    1526.000      0.000   1969.000       0.000       6.000
 13      274.000     39.000     476.000     344.000     23.000     614.000     67.000   2823.000    3533.000     231.000
 14      157.000    134.000     409.000    2955.000     71.000     352.000    231.000   2424.000   30368.000     712.000
 15        2.000     '0.000      16.000      29.000      6.000       5.000      0.000     98.000     297.000      60.000
 16        8.000      0.000      54.000       0.000      0.000      19.000      0.000    369.000       0.000       0.000
 17        9.000      0.000       4.000       0.000      0.000      21.000      0.000     28.000       0.000       0.000
 18        4.000      1.000       6.000       5.000      0.000       9.000      1.000     40.000      50.000       3.000
 19        2.000      2.000       5.000      40.000      1.000       5.000      3.000     34.000     427.000      10.000
 20        0.000      0.000       0.000       0.000      0.000       7.800      0.000      1.000       4.000       1.000
 21       56.000      0.000     401.000       0.000      0.000     119.000      1.000   2254.000    7473.000       2.000
 22       62.000      0.000      30.000       0.000      0.000     131.000      0.000    169.000     560.000       1.000
 23       25.000      4.000      43.000      31.000      2.000      53.000      6.000    242.000     803.000      20.000
 24       14.000     12.000      37.000     267.000      6.000      30.000     20.000    208.000     690.000      61.000
 25        0.000      0.000       2.000       3.000      1.000       1.000      0.000      8.000      28.000       5.000
 26       14.000      0.000      98.000       0.000      0.000      28.000      0.000    523.000       0.000       0.000
 27       15.000      0.000       7.000       0.000      0.000      30.000      0.000     39.000       0.000       0.000
 28       16.000      1.000      11.000       8.000      1.000      12.000      1.000     56.000      70.000       5.000
 29        3.000      3.000       9.000      65.000      2.000       7.000      3.000     48.000     604.000      14.000
 30        0.000      0.000       0.000       1.000      0.000       0.000      0.000      2.000       6.000       1.000
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INPUT-OUTPUT TEST DATA. COE.
TRANSACTIONS TABLE
                                                                                          PAGE 2 OF 4
------------------------------------------------------------------------------------------------------
SECTOR      11           12          13           14          15          16          17          18          19          20
  1      247.000      6.000 13612.000       0.000      3.000      72.000      2.000     28.000       0.000       0.000
  2      271.000      0.000  1020.000       0.000      1.000      79.000      0.000      2.000       0.000       0.000
  3      109.000     42.000  1463.000     590.000     28.000      32.000     12.000      3.000       4.000       1.000
  4       63.000    144.000  1257.000    5070.000     86.000      18.000     40.000      3.000      38.000       3.000
  5        1.000      0.000    51.000      50.000      7.000       0.000      0.000      0.000       0.000       0.000
  6     1881.000     43.000103878.000       0.000     21.000     573.000     12.000    224.000       0.000       1.000
  7     2069.000      0.000  7788.000       0.000      6.000     631.000      0.000     17.000       0.000       0.000
  8      832.000    320.000 11167.000    4502.000    213.000     254.000     92.000     24.000      35.000       8.000
  9      477.000   1102.000  9590.000   38695.000    658.000     145.000    317.000     21.000     303.000      26.000
 10       72.000      0.000   386.000     378.000     55.000       2.000      0.000      1.000       3.000       2.000
 11     1337.000     30.000 78380.000       0.000     15.000     709.000     15.000    277.000       0.000       1.000
 12     1471.000      0.000  5535.000       0.000      4.000     780.000      0.000     21.000       0.000       0.000
 13      591.000    228.000  7937.000    3200.000    152.000     314.000    114.000     30.000      44.000      10.000
 14      339.000    783.000  6816.000   27502.000    468.000     180.000    393.000     26.000     375.000      32.000
 15        5.000      0.000   274.000     269.000     39.000       3.000      0.000      1.000       4.000       3.000
 16       33.000      1.000  1801.000       0.000      0.000      71.000      2.000     28.000       0.000       0.000
 17       36.000      0.000    44.000       0.000      0.000      78.000     14.000      2.000       0.000       0.000
 18       14.000      6.000   194.000      78.000      4.000      31.000      6.000      3.000       4.000       1.000
 19        8.000     19.000   166.000     671.000     11.000      18.000      3.000      3.000      38.000       3.000
 20        0.000      0.000     7.000       7.000      1.000       0.000      0.000      0.000       0.000       0.000
 21      172.000      4.000  9518.000       0.000      2.000     346.000      7.000    135.000       0.000       1.000
 22      190.000      0.000   714.000       0.000      1.000     381.000      0.000     10.000       0.000       0.000
 23       76.000     29.000  1023.000     413.000     20.000     153.000     56.000     15.000      21.000       5.000
 24       44.000    101.000   879.000    1354.000     60.000      88.000    192.000     12.000     183.000      16.000
 25        1.000      0.000    35.000     114.000      5.000       1.000      0.000      1.000       2.000       1.000
 26       37.000      1.000  2026.000       0.000      0.000      50.000      1.000     19.000       0.000       0.000
 27       40.000      0.000   152.000       0.000      0.000      55.000      0.000      1.000       0.000       0.000
 28       16.000      0.000   218.000      88.000      4.000      22.000      8.000      2.000       3.000       1.000
 29        9.000     21.000   187.000     755.000     13.000      13.000     28.000      2.000      26.000       2.000
 30        0.000      0.000     8.000       7.000      1.000       0.000      0.000      0.000       0.000       0.000
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INPUT-OUTPUT TEST DATA. COE.
TRANSACTIONS TAPLE
                                                                                                   PAGE 3 OF 4
-----------------------------------------------------------------------------------------------------------------
SECTOR     21         22          23          24         25          26          27         28         29         30
  1      372.000      5.000   1348.000      0.000      1.000     145.000      3.000      3.000      0.000      0.000
  2      410.000      0.000    101.000      0.000      0.000     159.000      0.000      0.000      0.000      0.000
  3      165.000     37.000    145.000     99.000      5.000      64.000     24.000      0.000     10.000      1.000
  4       94.000    128.000    124.000    852.000     16.000      37.000     82.000      0.000     85.000      4.000
  5        1.000      0.000      5.000      8.000      1.000       1.000      0.000      0.000      1.000      0.000
  6     2695.000     36.000   9754.000      0.000      4.000     991.000     22.000     19.000      0.000      1.000
  7     2965.000      0.000   3487.000      0.000      1.000    1090.000      0.000      1.000      0.000      0.000
  8     1192.000    268.000   1402.000    717.000     38.000     438.000    163.000      2.000     67.000      9.000
  9      683.000    922.000    804.000   6163.000    116.000     245.000    559.000      2.000    578.000     28.000
 10       10.000      0.000     12.000     60.000     10.000       4.000      0.000      0.000      6.000      2.000
 11     2876.000     38.000  10409.000      0.000      4.000     983.000     22.000     19.000      0.000      1.000
 12     3164.000      0.000    780.000      0.000      1.000    1082.000      0.000      1.000      0.000      0.000
 13     1272.000    286.000   1119.000    765.000     40.000     435.000    161.000      2.000     67.000      9.000
 14      729.000    985.000    961.000   6576.000    124.000     249.000    555.000      2.000    573.000     27.000
 15       11.000      0.000     39.000     64.000     10.000       4.000      0.000      0.000      6.000      2.000
 16      268.000      4.000    965.000      0.000      0.000      61.000      1.000      1.000      0.000      0.000
 17      294.000      0.000     72.000      0.000      0.000      67.000      0.000      0.000      0.000      0.000
 18      118.000     27.000    104.000     71.000      4.000      27.000     10.000      0.000      4.000      1.000
 19       68.000     92.000     89.000    612.000    122.000      15.000     34.000      0.000     36.000      2.000
 20       10.000      0.000      4.000      6.000      1.000       0.000      0.000      0.000      0.000      0.000
 21     1186.000     16.000   4293.000      0.000      2.000     975.000     21.000     18.000      0.000      1.000
 22     1305.000      0.000    322.000      0.000      1.000     173.000      0.000      1.000      0.000      0.000
 23      525.000    118.000    461.000    316.000     17.000     431.000    160.000      2.000     66.000      9.000
 24      301.000    406.000    396.000   2712.000     51.000     247.000    550.000      2.000    569.000     27.000
 25        5.000      0.000     16.000     26.000      4.000       4.000      0.000      0.000      6.000      2.000
 26      612.000      8.000   2215.000      0.000      1.000    4079.000     10.000      9.000      0.000      0.000
 27      673.000      0.000    165.000      0.000      0.000     527.000      0.000      1.000      0.000      0.000
 28      271.000     61.000    238.000    163.000      9.000     212.000     79.000      1.000     32.000      4.000
 29      155.000    210.000     24.000   1399.000     26.000     121.000    270.000      1.000    279.000     13.000
 30        2.000      0.000      8.000     14.000      2.000       2.000      0.000      0.000      3.000      1.000
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SECTOR   FINAL DEMAND   TOTAL OUTPUT
   1       10836.000      33039.000
   2        1321.000       4306.000
   3       64419.000      68858.000
   4      106207.000     121256.000
   5        5843.000       6064.000
   6           0.000     198922.000
   7           0.000      28503.000
   8      559253.000     631464.000
   9     1054226.000    1209566.000
  10       63503.000      65776.000
  11       32328.000     160178.000
  12        3893.000      21247.000
  13      329087.000     354287.000
  14      579818.000     665326.000
  15       33024.000      34271.000
  16        4318.000       8004.000
  17         581.000       1250.000
  18        9976.000      10804.000
  19       16026.000      18565.000
  20         904.000        953.000
  21       25358.000      52361.000
  22        5568.000       9619.000
  23       50969.000      56114.000
  24       86619.000      96154.000
  25        5148.000       5419.000
  26        7710.000      17441.000
  27        1554.000       3260.000
  28       15044.000      16663.000
  29       27713.000      32025.000
  30        1639.000       1697.000
```

Key Words: Floods, Flood Control Measures, Planning Flood Control.

Abstract: By an approach of analysis and synthesis, flood control planning becomes more meaningful to both the present and future flood control needs. A methodology is developed which incorporates four structural parts: (a) classification of flood control measures, (b) performance analysis of classified measures, (c) subsequent synthesis of various mixes of measures in order to obtain an optimal mix, and (d) impact of proposed measures on regional economy.

Analysis of nonstructural measures, especially land use and insurance, demands a common yardstick in measuring costs and benefits comparable to those of structural measures. The synthesis of measures is in a state of flux,

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with advanced methodology missing to guide the planning process. The methodology presented herein is an attempt to incorporate the difficult problem of interdependence of flood control measures. The methodology of analysis and synthesis of measures is tested on the Arkansas River Drainage Basin, above John Martin Dam in Colorado.

The economic synthesis of this method would enable a planner to examine the adverse effects of project proposal. Sociological, environmental and sediment damages are potential factors in addition to direct flood damage. The Isard-Chenery regional input-output model is applied to planning of flood control measures in a comprehensive and exhaustive manner, by making the hydrology-economics linkage as a synthesis of flood control and regional economic performance.

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