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This document provides an annotated and illustrated summary of analytical aids, developed by the HEC, that have utility in formulating and evaluating nonstructural flood loss reduction measures in the planning setting. Twelve documents and computer programs are presented.

15. SUBJECT TERMS
nonstructural, flood loss reduction, flood proofing, raising, relocation, regulations, flood preparedness, stage-damage, expected annual damage, benefits, costs

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PREFACE

Federal legislative actions of the past decade have dictated that water resources planning investigations be conducted in a comprehensive manner to include not only broader scoped economic evaluations but also inline considerations to environmental needs and social values. Among the legislative actions were the Unified Policy Program (H.D. 11296) of 1966, the National Environmental Policy Act (NEPA) of 1970, and the establishment of Principles and Standards for water resources planning of 1973. These actions emphasized the need for formulation and evaluation of flood loss reduction measures that provide local protection, are generally of a smaller scale, and less environmentally disruptive than traditional flood control alternatives of reservoirs, channels, flood walls, levees. For expedient referencing purposes the former type of measures have become known as "nonstructural" as opposed to the latter group which are referred to as "structural" measures. Congress, in Section 73 of the 1974 Water Resources Development Act, required nonstructural measures be given equal consideration as structural measures. The President's message of 6 June 1978, again emphasized the need to evaluate nonstructural measures with the same intensity as structural measures.

The Corps of Engineers has followed each of these actions with institutional regulations and guidelines designed to assist field planning personnel with their interpretation. While these regulations are explicit as far as general planning procedures and outputs for documentation, they purposefully are limited in defining applied analytical procedures required in the formulation and evaluation aspects of planning, leaving these considerations to the study participants. This is especially true of the area of nonstructural measures.

The objective of this document is to provide an annotated and illustrated summary of analytical instruments developed by the U.S. Army Corps of Engineers' Hydrologic Engineering Center (HEC) that have utility in formulating and evaluating nonstructural alternative plans. The purpose is to provide the reader with a basic understanding of the capabilities of each instrument while conveying its usefulness in perspective of overall planning requirements and formulation strategy. The instruments are primarily comprised of computer programs which have been developed from a need established by Corps field offices. Also, each has been or is currently being applied in an actual project evaluation mode. The tools were developed consistent with traditional Corps methods, are designed to enhance and broaden the analysis capability, and to reduce the tedium in data manipulation and computational aspects of planning. Two general data processing and analysis philosophies presently being used by Corps field offices are discussed: (1) conventional data management procedures; and (2) management and processing of geographic information using the Spatial Analysis Methods (SAM). The instruments used to prosecute the study are dependent upon which of these two philolophically different procedures are adopted.

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INTRODUCTION

Objective and Scope

The objective of this document is to provide an annotated and illustrated summary of analytical aids, developed by the U.S. Army Corps of Engineers Hydrologic Engineering Center (HEC), that have utility in formulating and evaluating nonstructural flood loss reduction measures in the planning setting. The purpose is to provide the reader with a basic understanding of the analysis capabilities of each instrument while conveying its usefulness in the perspective of the overall planning requirements and formulation strategy. The material presented consists of:

- A general overview of study considerations and processes which impact on selection of analytical procedures;

- Descriptions and comparisons of the analysis capabilities of the selected instruments; and

- A discussion of the utilization of selected instruments in the plan formulation and evaluation aspects of three case studies.

Categorization of Nonstructural Measures

The complexities, varing nature, and scope of nonstructural measures make it desirable for the measures to be classified into three categories (James, 1973; Davis, 1975) for analysis and presentation purposes. The three categories of nonstructural measures used herein for presentation purposes include: (a) measures designed to permanently modify the damage susceptability of existing structures; (b) measures designed to manage future development and activities impacting on the flood plain; and (c) preparedness planning procedures. Following paragraphs describe in general terms measures associated with each of these three categories.

Measures Which Permanently Modify Damage Susceptability of Existing Structures. Several types of nonstructural measures are designed to permanently modify damage potential of existing structures. They include: flood proofing (seals, earthen dikes, walls, etc.); raising existing structures; and relocation of people and/or people and structures from the specified threatened area. The measures are designed to modify the damage potential of an area. They are typically implemented on a localized scale (such as neighborhood) as opposed to structural and other types of nonstructural measures which often are designed to function for larger areas.

Flood proofing and raising of structures to target elevations protect structures and contents until design limits are exceeded. The measures, applied to individual or small groups of structures, are generally less environmentally disruptive than structural alternatives. The measures do not reduce damage to vital services (i.e., water, gas, power), streets, bridges, landscaping, etc., and only slightly (in most cases) reduce the social impact and disruption associated with flood events. Also, seals, walls and dikes are often significantly less reliable than other permanent measures.

Permanent relocation is defined as the removal of inhabitants and damage potential from the identified hazard area. Included are the physical moving of a structure and contents from the flood plain or demolition of the structure and moving inhabitants and contents to a new structure off the flood plain. If a compatible flood plain use of the structure can be identified, demolition of the structure may not be required.

Measures Which Manage Future Development. Management of future development reduces losses by requiring flood plain development and activities be operated or located in a specified manner. Land use development can be controlled by regulations such as: zoning ordinances; building codes and restrictions; taxation; or purchase of land in fee or for a flood easement. Structures not precluded from flood plain locations by these measures may locate on the flood plain if constructed and maintained to be compalible with the recognized flood hazard.

Regulatory actions and land acquisition can also bring about new use of the flood plain. The measures are attractive from the perspective of managing development to reduce the future damage potential of the area and utilization of the flood plain for compatible purposes.

Typical measures included in regulatory actions are:

o Land use development situations (both in flood plain and off flood plain);

o Sanitary land fills; and

o Gravel mining operations or similiar flood plain activities.

Flood Preparedness Plans. Flood preparedness plans are comprised of flood threat recognition, dissemination of warnings; emergency response actions; post flood recovery and reoccupation of flooded areas, and continued plan management elements to mitigate flood losses and social disruption. The measures should not be considered in lieu of other feasible permanent structural or nonstructural alternatives due to their temporary nature and uncertain reliability during flood episodes. Preparedness plans, however, should be considered as interim measures until other flood mitigation measures are implemented, as enhancements to other measures, and as a means of providing management of loss of life, flood damage and social disruption if other methods are not feasible.

Summary of Instruments Presented

Analytical aids selected for presentation are those developed by the HEC which have direct applicability for formulating and evaluating nonstructural flood mitigation measures, within the framework of the Corps planning process. Other evaluation and formulation tools may be more readily applicable for a given investigation, if so, their use is encouraged. For clarity, ease of understanding, and utility, the nonstructural assessment instruments have been categorized according to data processing and application procedures. The categories include: (1) generalized procedural evaluation documents; (2) measure formulation tools; (3) system analysis programs; and (4) site attractiveness assessment programs. The general categories and specific instruments presented are defined in subsequent paragraphs.

<u>Generalized Procedural Evaluation Documents</u>. This category consists of procedural documents which either describe nonstructural assessment considerations and procedures or present abbreviated evaluation methods for preliminary assessments. Documents classified include:

(1) "Physical and Economic Feasibility of Nonstructural Measures" (Hydrologic Engineer Center, 1978a);

(2) "Estimating Costs and Benefits for Nonstructural Measures" (Hydrologic Engineer Center, 1975a);

(3) "Costs of Placing Fill in a Flood Plain" (Hydrologic Engineering Center, 1975b);

(4) "Annotations of Selected Literature on Nonstructural Flood Plain Management Measures" (Hydrologic Engineering Center, 1977a) and

(5) "National Economic Development Benefits for Nonstructural Measures" (Hydrologic Engineering Center, 1980b).

<u>Measure Formulation Tools</u>. These instruments comprise of computer programs which have analytical capabilities to formulate and evaluate specified nonstructural measures. Specific programs include:

(1) "Structural Inventory for Damage Analysis (SID) Program" (Hydrologic Center, 1981b);

(2) "Damage Reach Stage-Damage Calculation (DAMCAL) Program" (Hydrologic Engineers Center, 1978b);

(3) "Expected Annual Damage (EAD) Program" (Hydrologic Engineering Center, 1977b); and

(4) "Interactive Nonstructural Analysis (INA) Program" (Hydrologic Engineering Center, 1980a).

System Analysis Programs. The computer programs of this classification are capable of formulating composite sets of nonstructural measures or of "mixed" structural and nonstructural measures throughout a watershed system. They include:

(1) "HEC-1, Flood Hydrograph Package" (Hydrologic Engineering Center, 1981a); and

(2) "HEC-5, Simulation of Flood Control and Conservation Systems" (Hydrologic Engineering Center, 1979).

Site Locational Attractiveness Assessments. The "Resource Information and Analysis Program (RIA)" is included in the array of nonstructural analysis instruments because of its potential utility in determining site attractiveness of various types and components of nonstructural flood mitigation measures (Hydrologic Engineering Center, 1978c).

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Chapter II

OVERVIEW OF NONSTRUCTURAL INSTRUMENTS SELECTION CONSIDERATIONS

Overview

The selection and utilization of procedures and instruments to perform desired analyses of nonstructural measures and plans are significant aspects of a flood mitigation study. This process is often neglected or constrained by other study considerations. As a consequence, improper thought and efforts are given to the selection of appropriate analytical tools to be used in the evaluation process of the study. Following sections define study variables and considerations which impact on the selection process of analytical instruments for evaluating nonstructural measures and plans.

Study and Institutional Factors

Professionals charged with performing analyses of nonstructural flood mitigation measures must understand the study aspects and procedural requirements prior to selection of analytical techniques to be used. The selection of the analytical procedures and instruments should be a well thought though process based on the type of study and other study factors. Study considerations which may impact on the selection of analytical tools used in evaluating nonstructural measures are:

- Study type and purpose
- Time and resources (manpower, monies, etc.)
- The physical study setting
- Data availability
- Institutional policies regulating the studies and methodologies
- Interface requirements with other study disciplines
- Experience, judgement and capability of the professional performing the analysis.

Planning Procedures

Paramount to peforming a successful nonstructural investigation is the understanding of the study framework and process required. The Corps' multi-objective planning regulations (Corps of Engineers, 1975 a and b) specifies the general criteria for Corps investigations. The planning process is conceptually displayed in Figure 1 as successively proceeding through three stage of plan development, several internal iterations, successively increasing the specificity of the plans and corresponding evaluations. Figure 2 illustrates the plan screening, final array and ultimate plan selection for recommendation by the Corps of Engineers. At least one nonstructural plan must be carried through the process and presented in the final array of plans.

Analytical procedures and instruments used in nonstructural measure evaluation vary with the level of detail requirement progression throughout the three planning stages. The following paragraphs briefly describe the level of analytical detail requirement of the three stages.

Reconnaissance Study (Stage I). The purpose of this stage is to conduct reconnaissance level investigations to determine whether further study is warranted, and if so, to develop a detailed work plan for Stage II planning. Emphasis is on identifying the water and related needs of the study area. The efforts will generally involve analyzing a wide range of available data, which may be more qualitative than quantitative. The nonstructural analysis task typically centers on identifying potential measures, eliminating those obviously not feasible or attractive, and to the extent possible conduct rudimentary evaluations of the feasibility of the measures (Corps of Engineers 1975a).

Development of Intermediate Plans (Stage II). Stage II emphasizes development of a full range of alternative plans. It more specifically defines the problems and opportunities of the study area, planning objectives, and more fully outlines and refines alternative plans and measures without concentrating on detailed engineering or design considerations. Nonstructural measures are formulated, evaluated and

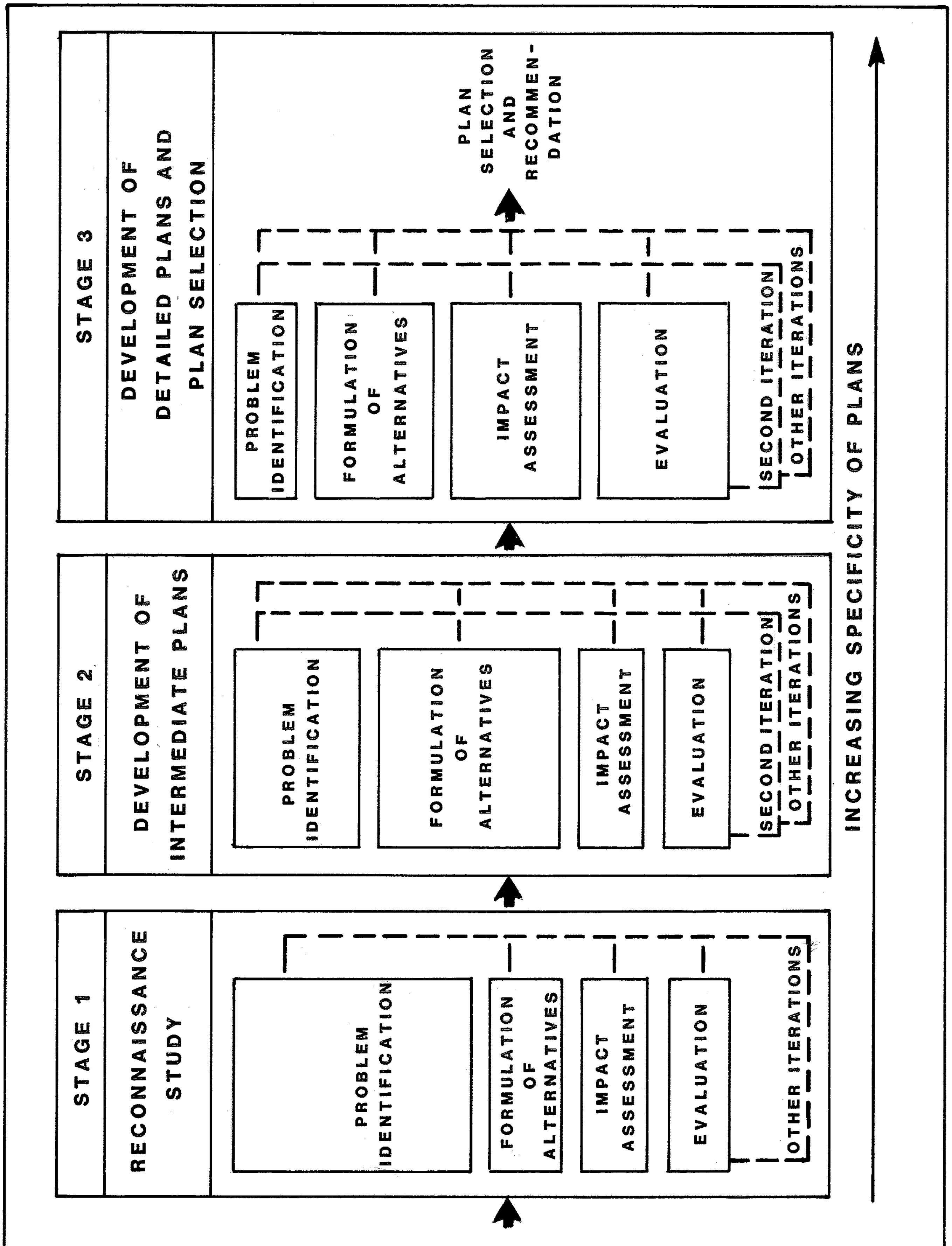


Figure II-1 PLANNING PROCESS

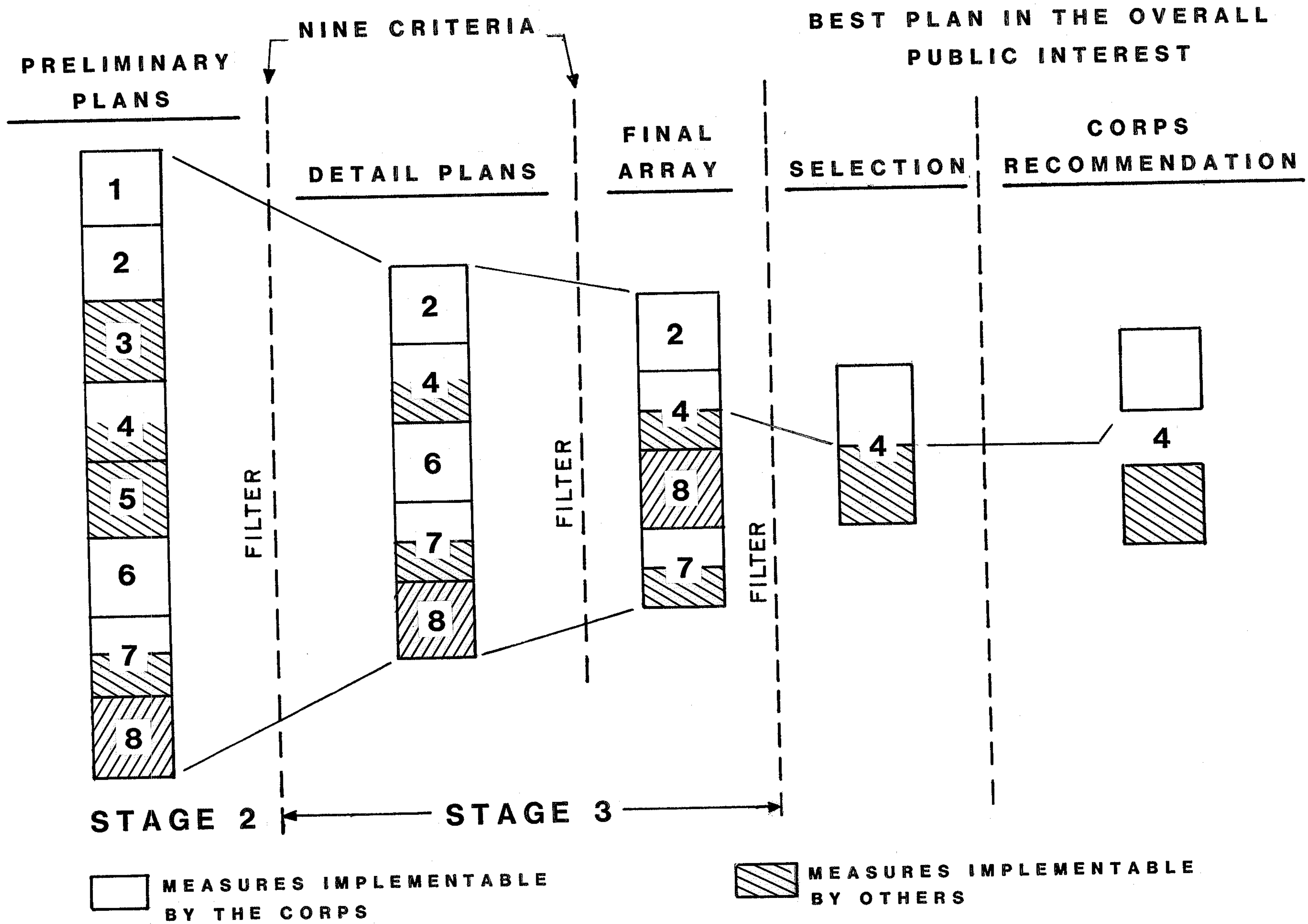


Figure II-2 PLAN SELECTION - CORPS RECOMMENDATION combined into plans with other nonstructural or structural measures. Plans determined to warrant more detailed analyses are carried forward into Stage III; the remainder are eliminated from further consideration. At least one nonstructural plan must be carried forward into Stage III (Water Resources Council 1979).

Development of Detailed Plans and Plan Selection (Stage III). The purpose of Stage III is to perform necessary subsequent iterations of the four planning tasks to produce detailed, implementable, alternative plans so that a final plan may be selected. The level of detail of the nonstructural plans should be commensurated with others presented in the final array prior to plan selection. The recommended plan is identified by the District Engineer upon the completion of Stage III.

Interdisciplinary Evaluation Requirements

The progression of the study through the three stages of the planning process requires the interface of information among the interdisciplinary participants in the study. Evaluation procedures must provide consistent level of detail among the participants, meet study objectives, and interface with the results of other disciplines. Following paragraphs summarizes important considerations of the various disciplines as they relate specifically to nonstructural measures.

Flood Hazard Assessments. Flood hazard can be characterized by timing, velocity, elevation and spatial delineation of specific exceedance interval flood events. Assessment requirements for nonstructural measures are hydrologic and hydraulic analyses to properly define the present and future flood hazard conditions. Specific analytical requirements likely for each of the three categories of nonstructural measures might include:

- Existing Structures. Evaluations involving traditional flood hazard analyses (flood hydrographs, rating functions and discharge-frequency functions). Velocities and bouyancy considerations may also be required. Analyses of effects of future flood hazard conditions on existing structures.

- Future Development. Two major flood hazard aspects related to future development are of interest in nonstructural measures planning. They are: (1) modification in runoff characteristics of off flood plain areas (increased flood levels from urbanization), and (2) modification of the flood plain response and conveyance characteristics as affected by development and management works within the flood plain itself, such as, large scale placement of fill.

- Preparedness Plans. Flood hazard specifications are particularily significant in developing and implementing preparedness planning actions. The plans and arrangements require traditional analyses to formulate viable activities, continuous updating of information, and real-time event forecasts and predictions to implement the plans during flood emergencies.

Flood Damage Evaluations. Analyses required to perform flood damage evaluations of nonstructural measures include assessments of existing and future with and without conditions. Assessments may also include the need to perform spatially oriented analyses of present and future land use activities. Typical damage analyses required for the three categories of nonstructural measures are defined in subsequent paragraphs.

- Existing Structures. Flood damage analyses are required for conditions with and without the nonstructural measures in place. These measures (flood proofing, permanent relocation, etc.) typically modify the depth-damage relationships of existing structures. Traditional flood damage elevation criteria are used.

- Future Development. Flood damage evaluations of future development management measures involve projections (in a spatial location sense) of the future development. Damage assessments of with and without future development management policies in effect are also required.

- Preparedness Plans. Flood damage analyses of implementation of emergency flood loss reduction measures are difficult because of the unique features associated with each event and the unknown reliability of implementing various actions. Temporary barrier installations, flood fight efforts, etc., may be estimated as to their reliability and effect on the depth-damage functions. Locational analyses of emergency measures (travel routes, mass care centers, etc.) may be desirable for some investigations.

Cost Analyses. Cost analyses of the nonstructural measures are conducted in a similar manner as structural measures. Costs are refined in detail throughout the study process on a level commensurate with other disciplines. Design analyses (preliminary in nature) may be required to adequately refine some cost estimates in Stage III planning. Cost estimates for nonstructural measures involving existing structures is relatively straight forward compared to those involved with implementing future regulatory policies and preparedness planning actions.

Environmental Assessments. The present focus on nonstructural measures can be traced to the emphasis on environmental concerns and preservation of riverine areas. Analytical procedures presently concentrate on physical, biological and chemical processes affecting the river areas. A significant amount of research attention in these areas in continuing. Receiving less attention, but potentially important, is the need to provide locational assessments of activities to be performed in flood plain or related areas. Adverse environmental impacts are generally significantly less than for compariable structural measures (Hydrologic Engineering Center 1976).

Social/Institutional Analysis. Most nonstructural measures will require complex social and institutional assessments of areas where the measures will be implemented. Analytical procedures and strategies for performing these analyses are limited and not directly included in the capability of analytical instruments presented herein (Hydrologic Engineering Center 1976).

Data Management

Data management refers to the systematic processing of information and its interface with analytical tools. The processing aspects of data management may include acquisition, formatting, storage and retrieval of information. With the increasing complexities of water resources investigations, it is imperative that data be managed in an efficient and effective manner.

Primarily data management advancements involving conventional study management processes have centered about automation, via computer related devices, of manual procedures performed by the individual disciplines. The methods have significantly enhanced the capabilities to perform more complex and comprehensive evaluations in an expedient manner. However, problems of individual disciplines using common data sets, level of detail and proper integration of information often effect the viability of the overall investigative results.

The Spatial Analysis Methods (SAM) and associated analytical tools are an attempt to resolve the above mentioned problems by using automated traditional evaluation techniques and a more common data management structure among the disciplines. The SAM provides the mechanism for expedient and consistent evaluation of alternative flood loss management measures (Hydrologic Engineering Center 1975d; Davis 1979). The procedures used include the evaluation of geographic information which has been digitized and stored in computer files in a digital (grid cell) form. Each geographic data variable is encoded separately and a registered grid cell record on a computer file which then represents the data bank. Analytical computer programs access designed variables stored in the grid cell data bank for an integrated evaluation of flood hazard, flood damage and environmental assessments. These programs, which are applicable to nonstructural flood mitigation measure evaluations, are included in the nonstructural instruments presented in subsequent chapters (Webb and Burnham 1977).

The data management procedures, study factors, and the type and level of detail of the evaluation being conducted, have a major impact on the evaluation tools selected. Following chapters describe the HEC developed nonstructural evaluation instruments.

Chapter III

GENERALIZED PROCEDURAL DOCUMENTS

Overview

These documents comprise the analytical procedures and means designed to assist study participants in initial aspects of nonstructural investigations. They include material to assist in literature review, benefit evaluation, and simplified equations, tables and charts to screen prospective nonstructural measures in the Stage I and early portions of Stage II flood mitigation planning studies. The material may also be used to verify subsequent more detailed assessments. Much of the material presented was developed or generated from previous investigations of nonstructural measures.

The documents described include:

- "National Economic Development Benefits for Nonstructural Measures";
- "Physical and Economic Feasibility of Nonstructural Flood Plain Management Measures";
- "Annotations of Selected Literature on Nonstructural Flood Mitigation Measures";
- Estimating Costs and Benefits for Nonstructural Flood Control Measures";
- "Costs of Placing Fill in a Flood Plain".

Each document was developed specifically to assist study participants in nonstructural measure evaluation. Following sections summarize the intent and general utility of the documents.

National Economic Development Benefits for Nonstructural Measures

This report is intended to assist planning personnel in evaluation of National Economic Development (NED) benefits for nonstructural measures by use of economic concepts, interpretation of regulatory procedural documents and numeric examples. The applicability of different benefit classifications (inundation, intensification and location) with respect to implementation of various nonstructural measures is presented. Narrative examples and summary tables for quick reference are in the main body of the report. Other numeric examples displaying simplified computations are contained in an appendix.

Emphasis of the report is on nonstructural measure evaluation procedures, not formulation of measures. Methods and procedures suggested in the report are based on economic theory, pertinent Corps of Engineers regulations, and other documents. The information presented is applicable throughout the planning process, with the level of detail of application increasing with the progression of the study (Hydrologic Engineering Center 1980b).

Physical and Economic Feasibility of Nonstructural Flood Plain Management Measures

This document presents findings of an investigation of the physical and economic feasibility of implementing eleven nonstructural flood loss mitigation measures. The objective of the research investigation was to examine the physical and economic feasibility of a number of nonstructural measures and to develop, where possible, specific criteria for their use. Attempts were made to define the conditions, that are appropriate or not appropriate, for implementing each measure. The report contains a brief description of each measure, defines the physical characteristics of the measures, and estimates the costs and damage reduction potential of each measure. The potential damage reduction assessment capability is based on the flood hazard factor (difference in elevation between the 10- and 100-year frequency events), the type of structure, and reduction in contents and structure damage based on the percent of the respective values.

The document provides a means of readily identifying various types of nonstructural measures for investigation, and a screening procedure to eliminate measures not warranting more detailed assessments. It is especially applicable in the Stage I and early Stage II aspects of the planning process and as an expedient verification method for more detailed evaluations (Hydrologic Engineering Center 1978a).

Nonstructural measures presented in the document include:

- Temporary and permanent closures for openings in existing structures
- Raising existing structures
- Small walls or levees around new or existing structures
- Rearranging or protecting damageable property within an existing structure
- Removal of existing structures and or contents from a flood hazard area
- Flood forecast, warning and evacuation
- Elevating new structures
- Construction materials and practices for new or existing structures
- Zoning ordinances, subdivision regulations, and building and housing codes
- Public acquisition of flood plain land
- Flood insurance

Annotations of Selected Literature on Nonstructural Flood Mitigation Measures

This document is designed to assist Corps of Engineers and other planners by providing annotations of selected literature about nonstructural flood mitigation measures. The material was compiled from an exhaustive literature search and review. Summaries of 18 publications, determined to be among the most valuable to Corps planning personnel, are presented. The publications cover policy, and technical and procedural issues for evaluating nonstructural measures.

The intent of the document is to: (a) reduce the literature search and review time required by planning personnel; and (b) present technical material of the state-of-the-art description of analytical procedures developed to date. The summaries describe, to the extent possible, the key contents, findings and recommendations of the annotated publications. The primary utility of this document is for the Stage I portion of the planning process but it may be used as an important reference throughout the investigation (Hydrologic Engineer Center 1977a).

Estimating Costs and Benefits for Nonstructural Flood Control Measures

This document is a predecessor to the previously described "Physical and Economic Feasibility of Nonstructural Flood Plain Management Measures." It describes investigative results that identify and develop expedient procedures for estimating benefits and costs associated with nonstructural measures. The material is focused on estimating costs and benefits of flood proofing, permanent relocation and implementation of land use regulatory policies. Data obtained from several nonstructural investigations are presented as are previously published equations, tables and graphs. The material offers the capability to expediously determine benefit and cost estimates for Stage I planning detail and for vertification of other assessments. The primary utility of the document is as a preliminary screening tool for nonstructural measures (Hydrologic Engineering Center 1975a).

Costs of Placing Fill in a Flood Plain

The document presents information on costs associated with placing fill in a flood plain for residential development. The data were developed by three engineering firms located in different regions of the country. The data approximating costs of obtaining, placing and compacting fill are relatively complete. The material for clearing and grubbing, stripping top soil, and compensatory storage is limited to experiences in Illinois. Other engineering, environmental and legal aspects of placing fill in the flood plain are beyond the purpose of the document and are only briefly addressed. The information presented is intended for making approximate or order of magnitude estimates. The information of the document is considered commensurate with Stage I or early Stage II planning (Hydrologic Engineering Center 1975b).

Chapter IV

MEASURE FORMULATION TOOLS

Overview

This category of nonstructural instruments is comprised of computer programs which have utility in formulation and evalution of nonstructural flood loss mitigation measure. Most have broader scale applicability and were not specifically developed for nonstructural measure analyses. The programs can be grouped into: (a) stage-damage inventory and manipulation programs; and (b) expected annual damage calculation programs.

Programs specifically designed to aggregate and manipulate elevation-damage functions are the "Structure Inventory for Damage Analysis (SID)" program and the "Damage Reach Stage-Damage Calculation (DAMCAL)" program. The programs aggregate elevation-damage functions by damage category and damage reach and are similiar in analytical capability. The aggregation capabilities of the SID program are derived from inventory data of individual or small groups of structures. The aggregation procedures of the DAMCAL program are derived from Spatial Analysis Methods (SAM) using area-based concepts of damage potential.

Four HEC programs have direct capability to calculate expected annual damage values associated with nonstructural flood mitigation measures. The two programs presented in this chapter are the "Interactive Nonstructural Analysis Package (INA)" and the "Expected Annual Damage Computation (EAD)" program. The "HEC-1, Flood Hydrograph Package" and "HEC-5, Simulation of Flood Control and Conservation Systems" are described in the following chapter. The INA was specifically designed to assess damage reduction associated with implementing nonstructural measures for individual structures. The EAD program is a general purpose program with inherent capabilities to determine economic inundation reduction benefits associated with implementing nonstructural measures.

Structure Inventory for Damage Analysis (SID)

This program is designed to aid in the systematic and expeditious collection and management of data related to structures subject to flooding. Its basic function is to process structure inventory data to develop aggregate elevation-damage functions by damage categories and location. Because of the capability to develop and manipulate elevation-damage relationships the program can evaluate the modifications to those functions for nonstructural measures such as flood proofing, relocation and raising. The evaluations are based on individual structural data and user specifications.

Damage reach evaluations may be performed for all structures, only those associated with future development, or on an individual structure basis. Raising of structures may be performed to specific heights (say 2 feet) above natural ground for each structure or for uniform levels of protection for a designated damage category by damage reaches. Flood proofing may be performed for specified heights or a uniform level of protection. Relocation analyses may be performed based target levels of first floor elevation (zero damage elevations) or for all structures within a specified flood plain area regardless of elevation.

The primary output of the SID program consists of elevation-damage functions by damage category and damage reach. Evaluations may be performed for "with" or "without" conditions for structural, nonstructural or mixed measures. Additional analysis capabilities include computation of single event damage by category and reach, and flood zone summaries of the number of structures in each zone. Structure and damage function data may be stored on computer files and automatically retrieved by the program. Input data obtained as a sample of an area or reach may be scaled based on user specifications. The program may be automatically linked to the Expected Annual Damage Computation program (Hydrologic Engineering Center 1977b) along with hydrologic/hydraulic data to yield expected annual damage computations.

The SID program has utility in the Stage II and Stage III portions of the planning process (Corps of Engineers 1975a). Table IV-1 summarizes the general capabilities of the SID program.

TABLE IV-1

SID ANALYSIS CAPABILITIES

(Elevation-Damage Functions by Category and Damage Reach)

Alternatives/Measures	Land Use Pattern: Existing	Land Use Pattern: Alternative Future	Land Use Pattern: Alternative Future — New Development Only
Without Condition	X	X	
Structural Flood Control Measures	X	X	X
Uniform Flood Proofing of a Specified Damage Category (for each structure)	x	X	X
Unform Flood Protection of a Damage Reach	X	X	X
Flood Preparedness (damage reduction)	X	X	X
Permanent Relocation/Temporary Exacuation*	X	X	X
Flood Plain Regulations*	X	X	X

X Indices analytical capability
* Evaluations may be made for structures in the flood plain and for structures which have their zero damage elevation in the flood plain.

Damage Reach Stage-Damage Calculation (DAMCAL)

The DAMCAL computer program performs similiar evaluations as the Structure Inventory for Damage Analysis (SID) program except the analyses procedures are based on area based concepts (grid cells) of damage potential instead of individual structures. The program accesses geographic information stored in a grid cell data bank for the evaluation (elevation-damage functions by category and damage reach) of existing and future land use patterns for with and without conditions. The nonstructural analytical capabilities include: flood plain regulation policies; flood proofing; permanent relocation; and temporary measures (flood fight, etc.); and removal of contents in response to flood warnings. The measures may be evaluated in terms of providing a uniform level of protection say (100-year) or to specific heights above ground on first floor elevations. The resulting elevation-damage functions are interfaced with other evaluation tool results to perform desired analyses. The DAMCAL program has primary utility in Stage II and early phases of the Stage III planning process (Hydrologic Engineering Center, 1979). Table IV-2 summarizes the functional capabilities of the DAMCAL program.

The principle output of DAMCAL program consists of elevation-damage functions by damage categories and damage reaches. Area (acres)-elevation functions by category and reach may also be output. Evaluations may be for "without" or "with" conditions (structural, nonstructural or mixed measures). Other output options include computation of single event damage by category and reach and summaries of the number of structures in specified flood zone. The program may be automatically linked to the Expected Annual Damage Computation program (Hydrologic Engineering Center 1977b), along with hydrologic/hydraulic data to yield expected annual damage computations.

The DAMCAL program has utility in the Stage II and III segments of the planning process (Corps of Engineers 1975a). Table IV-2 summaries the general SID capabilities.

TABLE IV-2

DAMCAL ANALYSIS CAPABILITIES

(Elevation-Damage Functions by Category and Damage Reach)

	Land Use Pattern		
Alternatives/Measures	Existing	Alternative Future	Alternative Future — New Development Only
Without Condition	X	X	
Structural Flood Control Measures	X	X	
Uniform Flood Proofing of a Specified Damage Category (for each structure)	x	X	X
Unform Flood Protection of a Damage Reach	X	X	X
Flood Preparedness (damage reduction)	X	X	X
Permanent Relocation/Temporary Exacuation*	X	X	X
Flood Plain Regulations*	X	X	X

X Indices analytical capability

* Evaluations may be made for structures in the flood plain and for structures which have their zero damage elevation in the flood plain.

Expected Annual Flood Damage Computation

The Expected Annual Flood Damage Computation (EAD) program was developed to assist in economic evaluation of flood plain management plans. Particular attention was given to requirements and guidelines in ER 1105-2-351, "Evaluation of Beneficial Contributions to National Economic Development for Flood Plain Management Plans". Only inundation reduction benefits (not intensification and location) are evaluated in the program. Damage may be computed by: (1) evaluation of damage associated with a specific event; (2) expected annual damage values associated with a specific set of conditions (say 1980); and (3) the equivalent annual flood damage associated with a specific discount rate and period of analysis. Computations are based on inputs of hydrologic (discharge-frequency), hydraulic (rating functions) and flood damage (elevation-damage) data associated with each damage category and reach.

Several damage categories urban, agricultural, industrial, residential, etc., - may be analyzed at the same time and are totalled for each plan and reach. Expected annual damage may be computed for existing conditions during a specified previous year (historic conditions). Equivalent annual flood damage will be computed when the discount rate and period of analysis are specified.

Nonstructural analysis capabilities of the EAD program include flood proofing, relocation, flood warning based actions, and land use regulatory policies. A maximum of nine alternatives may be evaluated with each computer execution. Output results are expected annual damage by plan, damage reach, and damage category. Other output options include determination of single event damage values and equivalent annual flood damage with estimated damage values for the study year, base year, and by decade intervals.

The EAD program is the major program used in calculating expected annual damage values. The SID, DAMCAL, and the "Interactive Nonstructural Analysis Package" programs interface directly with the EAD for expected annual damage analyses. Table IV-3 summarizes the general capabilities of the EAD program.

TABLE IV-3

EAD ANALYSIS CAPABILITIES

(Elevation-Damage Functions by Category and Damage Reach)

		Land Use Pattern	
Alternatives/Measures	Existing	Alternative Future	Alternative Future New Development Only
Without Condition	X	X	X
Structural Flood Control Measures	X	X	X
Uniform Flood Proofing of a Specified Damage Category (for each structure)	x	X	X
Unform Flood Protection of a Damage Reach	X	X	X
Flood Preparedness (damage reduction)	X	X	X
Permanent Relocation/Temporary Exacuation*	X	X	X
Flood Plain Regulations*	X	X	X

X Indices analytical capability
* Evaluations may be made for structures in the flood plain and for structures which have their zero damage elevation in the flood plain.

Interactive Nonstructural Analysis Package (INA)

The INA computer program package was specifically developed to aid in the analysis and formulation of nonstructural flood plain management measures. The package is comprised of two parts: a program (Preprocessor) that creates a data file containing information useful and necessary in the nonstructural analysis, and a program (Interactive Analysis) that allows the user to access selectively data for evaluation of nonstructural measures. Data used include: structure related data; flood hazard data; damage potential data; and environmental data.

The Preprocessor program reads the encoded structure data and writes a specially formatted data file for access by the Interactive Analysis program. The Preprocessor also outputs summaries of the input data and writes a file to the Expected Annual Damage Computation Program (Hydrologic Engineering Center 1977b) for analysis of base conditions expected annual damage values. The Interactive Analysis program is designed to be executed from an interactive terminal, such as a cathode ray tube (CRT). The program accesses the data file written by the Preprocessor and subsequently searches the files to obtain data to evaluate the efficiency of nonstructural flood loss reduction measures. The Interactive program creates the file for the Expected Annual Damage Computation program to allow detailed evaluation of the economic efficiency of those measures.

The INA package has primary utility in the Stage II and III segments of the planning process (Corps of Engineers 1975a). Table IV-4 lists the general capabilities of the Interactive Nonstructural Analysis Package.

TABLE IV-4

INA ANALYSIS CAPABILITIES

(Elevation-Damage Functions by Category and Damage Reach)

Alternatives/Measures	Land Use Pattern: Existing	Alternative Future	Alternative Future: New Development Only
Without Condition	X	X	X
Structural Flood Control Measures	X	X	X
Uniform Flood Proofing of a Specified Damage Category (for each structure)	x	X	X
Unform Flood Protection of a Damage Reach	X	X	X
Flood Preparedness (damage reduction)	X	X	X
Permanent Relocation/Temporary Exacuation*	X	X	X
Flood Plain Regulations*	X	X	X

X Indices analytical capability

* Evaluations may be made for structures in the flood plain and for structures which have their zero damage elevation in the flood plain.

Chapter V

SYSTEM FORMULATION AND ANALYSIS TOOLS

Overview

This category relates to computer programs that are capable of analyzing a system of structural and nonstructural mixes of components. The programs are "HEC-1, Flood Hydrograph Package" and "HEC-5, Simulation of Flood Control and Conservation Systems". They may be used to evaluate hydrologic responses, "with" and "without" project conditions, and to automatically determine the economic benefits of the measure analyzed. The programs have broader scoped analysis potential than other tools previously described and require the interface of information from more than one discipline (such as hydrology and economics) if used as a system flood loss mitigation evaluation tool. Following sections describe the general capabilities of the two programs in evaluating nonstructural measures.

HEC-1, Flood Hydrograph Package

The program has several modules which may be used in the analysis of nonstructural measures. Foremost in recognized utility is the hydrologic capability to define the flood hazard and in the more comprehensive planning assessment modes, to estimate effects of structural projects. An additional program capability is the multiplan option, which incorporates inundation damage analyses by reaches, for up to five alternative plans in a single program execution. The revised damage function (either structure or nonstructure related) is automatically integrated along with existing condition functions to yield expected annual inundation damage for each alternative by damage category and damage reach. The alternative plans may be comprised of mixes of structural and nonstructural measures (Hydrologic Engineering Center 1981a).

The most applicable module of the HEC program for nonstructural and mixed measure analyses is the capability to automatically optimize the size of flood mitigation system components (Davis 1974). The capability uses much of that previously described, but includes enhancements to describe component characteristics and costs, and procedures to enable the size of components which maximizes the system net benefits to be determined. Evaluations for determining flood mitigation measures sizes which maximizes system net benefits may be performed with or without specified target protection levels. The HEC Training Document No. 9 (Hydrologic Engineering Center 1977c) describes the general application capability of the program.

Nonstructural measures are evaluated by input of damage functions (elevation-discharge) into the program. Any type of measure may be evaluated as long as the corresponding damage functions can be defined. Typical nonstructural measures evaluated may be: flood proofing, relocation, raising existing structures; regulatory policies of future development; and preparedness planning actions. The program is applicable for Stages II and III level of analysis.

HEC-5 Simulation of Flood Control and Conservation Systems

The HEC-5 computer program was developed as a generalized system analysis program primarily for reservoir simulation. However, the capabilities of the program enable structural and nonstructural mixed measures to be evaluated in a consistent and straight forward manner. The program can be used to route hydrographs and calculate expected annual damage values by category and reach for the system. Flood reduction benefits may be determined by comparing conditions with alternative measures in place with that of without conditions.

HEC Training Document No. 7 (Hydrologic Engineering Center 1975c) provides examples of methods which may be used to formulate components for flood mitigation. The training document presents procedures for formulating flood mitigation systems using the first and last added concepts. Nonstructural measures may be analyzed in mixed measure systems by input of associated elevation-discharge-damage relationships for the desired measure.

Any nonstructural measure that can be defined by the damage function may be analyzed. Typical measures of a system might be flood proofing, raising structures, relocation, and effects of flood forecasting and warning aspects of preparedness plans (Hydrologic Engineering Center 1979).

General Analysis Capability

The HEC-1 and HEC-5 computer programs are applicable for analyzing the feasibility of implementing nonstructural flood mitigation measures either as individual measures or as a mixed system (including structure measures). Table V-1 lists the general system analysis capabilities of the HEC-1 and HEC-5 computer programs.

TABLE V-1

GENERAL SYSTEM ANALYSIS
CAPABILITIES OF HEC-1 AND HEC-5

	HEC-1	HEC-5
Rainfall-Runoff Analysis	X	
Hydrologic Routing	X	X
Flood Damage Analyses	X	X
o Complex Reservoir Systems*		X
o Simple Reservoir Systems*	X	X
o Levees/Flood Walls	X	X
o Channels	X	X
o Flood Proofing Structures	X	X
o Raising Structures	X	X
o Emergency Damage Mitigation Actions	X	X
Automatic Sizing of System Components (Benefits & Costs)	X	
Analysis of Mixed Structural/Nonstructural Measures	X	X

*Complex reservoir systems refer to capability to control downstream discharge to meet specified targets, whereas, simple reservoir systems are defined as having no control of releases due to the outlet configuration.

Chapter VI

Land Use/Cultural Feature
Site Evaluations

Overview

The increased emphasis on broader scoped planning studies has necessitated the development of more sophisticated and expedient analytical procedures. One example is the site location evaluations associated with Spatial Analysis Methods (SAM) developed in part by the Hydrologic Engineering Center. The procedures modified those developed by Harvard University (Institute for Water Resources 1972) which automated the original overlay system of McHarg (McHarg 1969). The techniques emphasize identifying combinations of locational characteristics that would be attractive for particular activities. The program which performs the locational evaluations is the "Resource Information and Analysis" (RIA) program.

Resource Information and Analysis (RIA) Program

The RIA program is designed to perform selected geographic/locational analysis using a grid cell data bank. The data bank must have been previously developed and accessible by the RIA program in order to perform the locational evaluations. The RIA program can perform five major types of analysis results. These options are: distance determination package; impact assessment package; locational attractiveness package; coincident tabulation package; and mapping package. Following paragraphs define these capabilities:

The Distance Determination Package calculates the linear distance of each grid cell from the nearest cell containing a data variable category of interest, such as the distance of each grid cell from the adjacent cells that are categorized as industrial land use. Nonstructural analyses might include distance to mass care centers, supplies, etc.

The Impact Assessment Package is designed to determine locations of high environmental impact potential resulting from an activity of interest. The analysis is based on the combination of the effects of specific groupings of categories of two or three data variables which will be impacted upon or will reflect impact potential. Nonstructural applications might include impacts of various effects on flood forecasting, warning and emergency actions.

Locational Attractiveness modeling is an environmental land use analysis technique that emphasizes identifying the combination of locational characteristics that would be attractive for a particular activity. The computational procedure develope numerical attractiveness index values for each grid cell for the desired activity, based on subjective judgements as to attractive locational characteristics for a particular use of interest. The results are printer graphic displayed by the Mapping Package. The attractiveness capabilities enable projection of future development, location of flood fighting areas, evacuation routes, etc.

The Coincident Tabulation Package accounts for coincidence of categories between two data variables within the categories of a third data variable. The third variable is usually one which denotes a geographic boundary for the tabulation such as political subdivisions (town, county, etc.), census tracts, watershed subbasins, etc. An example of the coincident analysis would be the coincident tabulation of land use categories between existing and an alternative land use pattern for a particular census tract. The tabulation would display the quantitative changes in land use between the two patterns. The nonstructural applications include calculating the change in land use area for future development scenarios over existing conditions.

The Mapping Package provides computer line printer graphic displays of the variables from the BASE DATA FILE, Locational Distance Determination, Impact Assessment and Attractiveness Modeling results. The Mapping Package includes several user options such as text description of the results, levels of displays and selection of display symbolism. The graphics are produced by controlled overprinting of line printer characters.

The utility of the RIA program in evaluating nonstructural flood loss reduction measures is in recognized potential and has not been applied to actual studies to date. The potential lies in types of investigations where assessments of spatial locations are desired. The RIA program appears to be most attractive for Stage II and early Stage III planning involving evaluation of nonstructural measures (Hydrologic Engineering Center 1978c).

Chapter VII

NONSTRUCTURAL ANALYSIS FORMULATION STRATEGIES

Overview

The nonstructural tools described in previous chapters provide a variety of analytical capabilities in evaluating nonstructural flood mitigation measures during the federal water resources planning process. These tools were designed by the Hydrologic Engineering Center to assist study management, and other disciplines involved in nonstructural planning, in formulating viable nonstructural and structural/nonstructural mixed plans. Several instruments provide procedural guidance and simplified techniques typically used in assessments during the Stage I protion of the planning process. These documents are primarily used as preliminary screening tools or as means of verifying the reasonableness of detailed evaluations. The remaining tools are computer programs which provide specified evaluation capabilities for the more detailed planning assessments of the Stage II and Stage III portions of the study. The latter are designed to function either with conventional methods or spatial analysis methods of processing and managing information.

Among the problems facing the personnel involved in a planning study is selection of the appropriate mix of analytical instruments required to perform the formulation and evaluation of potential measures. The process is primarily dependent on the various aspects of the study, the experience of the personnel performing the study and institutional considerations. A summary of the general nonstructural capabilities of the instruments within the framework is provided in Table VII-1. Table VII-2 depicts the typical utility of the general nonstructural instruments in the progression through the planning process. The tables are provided to assist study participants in selecting the analytical tools, data requirements and formulation strategies.

TABLE VII-1

SUMMARY OF NONSTRUCTURAL ANALYTICAL
PROCEDURES AND REQUIREMENTS

ANALYTICAL PROCEDURES	NONSTRUCTURAL ANALYSIS INSTRUMENT											
	CPF (1)	PEF (2)	ECB (3)	SID (4)	DAM (5)	INA (6)	EAD (7)	HEC-1 (8)	HEC-5 (9)	RIA (10)	ANL (11)	NED (12)
o Manage Structure Inventory Data		D	D	D		D						
o Area Inventory of Damage (Grid)				L	D		L	L				
o Expected Annual Damage for Individual Structures		D		L		D	D					
o Expected Annual Damage by Reach				L	L	L	D	D	D			
o Cost Data	D	D	D									
o Hydrologic System Analysis							D	D	D			
o Hydrologic System Analysis	D	D	D									
o Traditional Data Processing (No Grid Cell Data Bank)				D		D	D	D	D			
o Geographic Spatial Data (Grid Cell Data Bank)				L	D		L	L		D		
o Land Use/Cultural Feature Site Evaluation										D		

NONSTRUCTURAL ANALYSIS INSTRUMENT IDENTIFICATION CODE

(1) CPF = Costs of Placing Fill in a flood Plain
(2) PEF = Physical and Economic Feasibility of Nonstructural Measures
(3) ECB = Estimating Costs and Benefits for Nonstructural Measures
(4) SID = Structure Inventory of Damages Program
(5) DAM = DAMCAL Program
(6) INA = Interactive Nonstructural Analysis Program
(7) EAD = Expected Annual Damage Computation Program
(8) HEC-1 = Flood Hydrograph Package
(9) HEC-5 = Simulation of Flood Control and Conservation Systems
(10) RIA = Resource Information Analysis Program
(11) ANL = Annotations of Selected Literature on Nonstructural Flood Plain Management Measures
(12) NED = National Economic Development Benefits for Nonstructural Measures

Legend

D - Direct Capability Exists

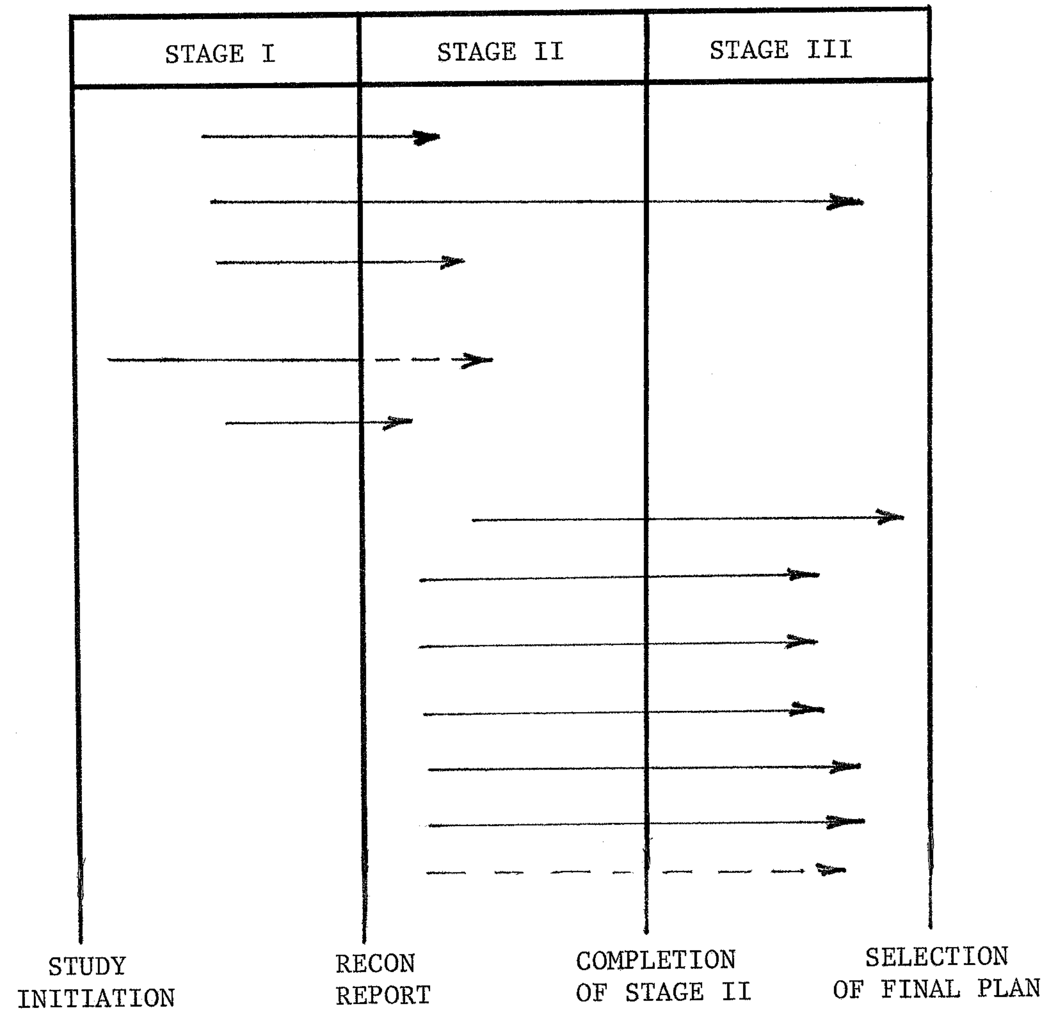
L - Capability Exists with Linkage to Other Programs

TABLE VII-2

TYPICAL UTILITY OF NONSTRUCTURAL

ANALYSIS INSTRUMENTS IN PLANNING PROCESS

- Costs of Placing Fill in a Flood Plain
- NED Benefits for Nonstructural Measures
- Phys. and Econ. Feasibility of Nonstructural F.P.M. Measures
- Annotations of Nonstructural Literature
- Est. Costs and Benefits for Nonstructural Measures
- EAD Program
- DAMCAL Program
- SID Program
- INA Program
- HEC-1 Program
- HEC-5 Program
- RIA Program



LEGEND

Likely Utility ⟶

Possible Utility - - ➤

Three case studies are subsequently included to assist in understanding the general applicability of selected nonstructural aids previously described. The initial case study involves a nonstructural investigation of the metropolitan Phoenix area performed by the Hydrologic Engineering Center for Los Angeles District Corps of Engineers. It involves a large flood plain area with 6-7000 existing structures. The second case study depicts the nonstructural investigation of flood loss mitigation actions for the City of Santa Fe conducted by the Hydrologic Engineering Center for the Alburquerque District Corps of Engineers. The study is of a smaller scale than the Phoenix investigation, with less than 500 structures located in the 500-year flood plain. The third case study summarizes the proposed and on-going procedures of the New York District Corps of Engineers in the Passaic River Basin. It is a comprehensive investigation with over 40,000 structures individually inventoried as part of the investigation.

Case Study 1: Phoenix Investigation

Background. The purpose of the nonstructural investigation for the metropolitan Phoenix area was to formulate a comprehensive array of nonstructural flood loss reduction measures as part of a Stage II feasibility investigation. Recommendations were made for more detailed assessments in Stage III of measures and alternatives identified as potentially feasible and warranting further investigation. Emphasis was placed on performing a balanced investigation based on categories of measures classified as: (a) measures that permanently modify the damage susceptability to existing structures; (b) measures designed to enable management of future development; and (c) flood preparedness plans for temporary emergency actions.

The investigation was performed by the Hydrologic Engineering Center for the Los Angeles District, Corps of Engineers. The study is part of a comprehensive flood loss mitigation investigation being conducted by the Bureau of Reclamation and the Corps of Engineers termed the Central Arizona Water Control Study (CAWCS).

Study Area and Problem Definition. The CAWCS study area includes a major portion of the Great Salt River Valley of central Arizona, lying almost entirely within Maricopa County. The nonstructural investigation was limited to areas potentially impacted by direct flooding from the Salt and Gila Rivers in the metropolitan Phoenix area. Portions of the cities of Mesa, Tempe, and Phoenix are included.

Flooding from the Salt and Gila Rivers in the study area is seasonally related to large regional storms and associated snowmelt that primarily occur in winter and early spring. Major floods result from spillages of upstream reservoirs. The reservoirs are designed and authorized to operate specifically for water supply and hydroelectric power needs, although in the past they have been operated to attenuate flood hydrographs during flood situations within the constraints mentioned.

Direct flooding from the Salt and Gila Rivers in the metropolitan Phoenix area has occurred only periodically, with substantial periods of time often elapsing between major flood events. During the 58-year period from 1920 to 1978, only one significant event (greater than a 10-year flood) occurred. Converse of this relative dry period has been the occurrence of three major events and two lesser events in the past three years. The major events, March of 1978, December 1978 and February 1980 have significantly damaged portions of the study area and resulted in particularly large losses to public facilities (bridges, roads, etc.) private and personal property and disruption of social services.

Analysis Procedures. Analytical evaluation aspects of the investigation were performed using traditional assessment procedures for flood hazard evaluations, and spatial analyses (grid cell data base) data storage, retrieval and processing procedures (Hydrologic Engineering Center 1976c, 1978d; Davis, 1979) for the flood damage evaluation process. Utilization of field reconnaissance, interviews, and flood scenarios for preparedness plans were also significant aspects of the evaluation process. The general analyses procedures used were:

- Preliminary Investigation. Included are review of previous study documents, field reconnaissance of area, development of analytical study strategies. Among the material reviewed were procedural documents "Annotations of Selected Literature on Nonstructural Flood

Plain Management Measures" (Hydrologic Engineering Center, 1977a) and "National Economic Development Benefits for Nonstructural Measures" (Hydrologic Engineering Center, 1980b).

- <u>Analysis of Existing Conditions</u>. Analysis of the existing flood hazard conditions included development of discharge-frequency and discharge-elevation functions. Flood damage assessments were performed using the DAMCAL (Hydrologic Engineering Center 1978b) and EAD (Hydrologic Engineering Center 1977b). The DAMCAL program generated elevation-damage functions by damage reach and categories. The results were calibrated to damage surveyed data of recent historic events and processed to the EAD program along with the flood hazard data to yield existing conditions expected annual damage for without conditions. Under existing conditions 819 structures were estimated at the 50-year level, 2,100 at the 100-year level, and 7,200 at the 500-year flood level. Figure VIII-1 depicts the general process.

- <u>Measure Identification</u>. A list of potential nonstructural measures were adopted for analyses. These included various levels of permanent measures for existing structures (flood proofing, raising, and relocation); management of future development and activities via regulations; and flood preparedness plans. A total of 30 measures including uniform protection levels of 50-, 100-, and 500-year were adopted.

- <u>Measure Evaluation</u>. Evaluations of the feasibility of implementing the various measures were performed via field reconnaissance interviews of local, state and federal agency personnel, interviews with the local populus, and analytical assessments. The evaluation process was performed through an iterative process. Initial screening of measures were based on physical characteristics of the structures, the flood hazard, and estimated damage potential (field reconnaissance and existing conditions). The document "Physical and Economic Feasibility of Nonstructural Flood Plain Management Measures" (Hydrologic Engineering Center 1978a) was used in the

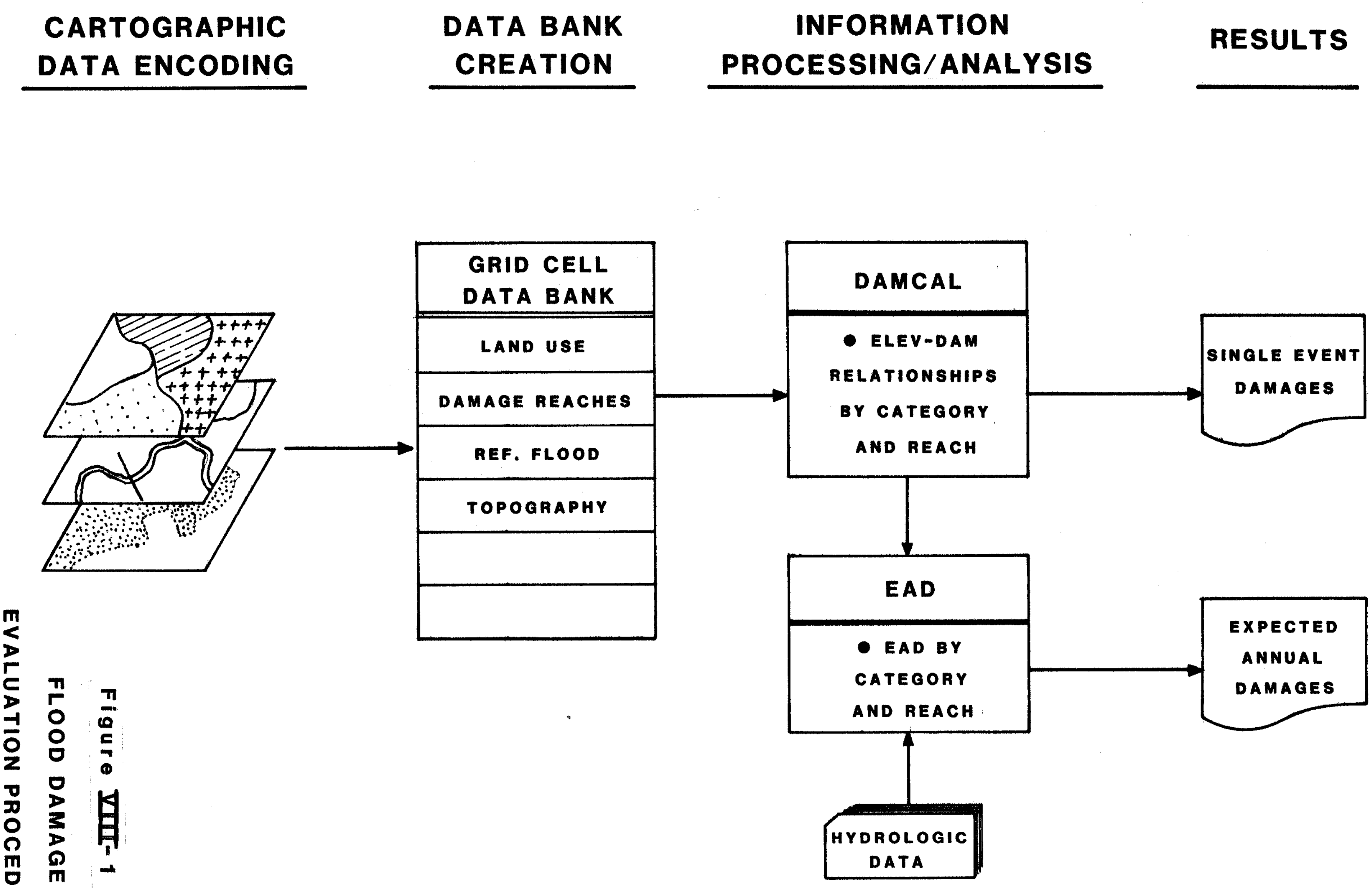


Figure VIII-1

FLOOD DAMAGE EVALUATION PROCEDURES

initial screening. Subsequent assessments were performed on remaining measures using the DAMCAL (elevation-damage adjustments relating to the nonstructural measures) and EAD programs. Cost data were supplied by the Los Angeles District.

- Future Assessments. Evaluation of future flood damage "with" and "without" conditions were performed using the DAMCAL and EAD computer programs. Only measures identified at the conclusion of Step 4 as warranting further analyses were evaluated for future conditions.

- Determine the final measures and plans that are potentially feasible and warranting further evaluation in the Stage III segment of the study.

Study Findings. The investigation determined that a serious flood threat presently exists throughout the study area. The flood threat is most serious to transportation and public facilities for flood events up to about the 50-year exeedance interval. The consequences of an event of this magnitude are to cause significant traffic disruption and congestions, inflict damage to highways and bridge crossings and to a lesser degree damage commercial businesses and private homes. The flood threat to the area from a quite large event, one exceeding the 100-year exceedance interval, could well be catastrophic. The metropolitan area could be divided with total bridge crossings outages, crises develop in emergency services, catastrophic damage be inflicted upon businesses and communities, and major social disruption generated from the displacement of many thousands of residents from their homes.

Findings of this report include:

- Preparedness Planning. There is a need for immediate implementation of proposed enhancements to flood preparedness planning arrangements and procedures for flood threat recognition, warning dissemination, emergency response actions, post flood recovery and continuous plan management activities. The need for at least one bridge crossing for emergency transportation linking the north and south metropolitan areas during floods greater than a 100-year event, for instance in the order of magnitude of a Standard Project Design.

- Existing Structural. Evaluations of nonstructural measures designed to permanently modify the damage susceptability of existing structures indicate that nonstructural plans to achieve 100-year and 500-year uniform protection levels are not economically feasible. The most promising measures identified are 2-3 feet high earthern dikes implemented on small scale (around several structures for selected locations) for lower frequency protection levels; 20- to 50-year.

- Regulation of Future Flood Plain Activities. Present flood plain regulations need to be broadened in scope and stringently enforced. Regulations should include flood plain activities involving land use development, land fills and gravel mining operations. Analysis of a projected Maricopa County land use plan for year 2000 indicates future damage to structures and contents will increase about 68 percent over present conditions if regulations are relaxed or not enforced. The analysis also indicated an estimated 27 percent increase in future damage even with continued enforcement of present regulations due to probability assessments of damage associated with greater than 100-year events. Explicit regulations are needed for land fills and in particular, gravel mining operations to prevent increased indiced damage from such activities during future floods. Detailed fluvial hydraulic analyses will be required to formulate precise regulatory policies and to determine the feasibility of gravel mining operations enhancing the conveyance capacity of the river.

A composition nonstructural plan consisting of elements of the previously described three categories of nonstructural measures appears to be the best nonstructural plan for mitigating flood losses and minimizing the social disruption, both in the present and future.

Case Study II: Santa Fe (Hydrologic Engineering Center 1979)

Background. The Stage II Santa Fe nonstructural flood mitigation investigation was performed by the Hydrologic Engineering Center for the Alburquerque District, Corps of Engineers. The study examined the nonstructural opportunities for reducing flood losses along the Santa Fe River from Twomile Reservoir to the City of Santa Fe Sewage Treatment Plant west of the airport. The Alburquerque District performed the hydrologic and hydraulic analyses, and the evaluation of structural measures for the study area.

Study Area and Problem Definition. Santa Fe has developed with a park immediately adjacent to the river in much of the flood plain within the city limits. The park area provides a natural floodway, restricting development in the flood conveyance zone. However, some services, such as highways, water supply and waste water conduits cross the river and are subject to damage by flood waters. An estimated 79 structures are located within the 100-year flood zone, with 457 estimated structures within the 500-year flood limits.

Major flood events occurred in the study area in 1957 and 1968. There were no reported injuries or loss of life related to these events. Detailed damage estimates for the events are not available, but damage for each event was estimated to be in the hundreds of thousands of dollars. The historic events could be classified as flash floods, rising and receding in a matter of hours. Several bridges, with small openings, caused increased damage from backwater inundating upstream structures.

Analytical Procedures. The Santa Fe nonstructural investigation made use of intensive interviews of local and state agency personnel, reconnaissance and application of the Interactive Nonstructural Analysis Package (INA) (Hydrologic Engineering Center 1980a). Other evaluation documents were also used in the initial screening of potential nonstructural measures. The INA was developed specifically for the Santa Fe study and was subsequently found applicable to other Corps nonstructural investigations involving a relatively small number of structures.

The information obtained from field reconnaissance and interview of local personnel was important in formulating potential nonstructural flood loss reduction measures. The physical characteristics of the area, and of the structures located in the flood plain were determined. Potential future development conditions and locally compatible measures were identified. Preliminary analysis screenings were performed using the generalized procedural document "Physical and Economic Feasibility of Nonstructural Flood Plain Management Measures" (Hydrologic Engineering Center 1978a). Measures identified as potentially feasible were subsequently evaluated in more detail. The "Interactive Nonstructural Analysis Package" was the principal nonstructural analysis instrument used in the Santa Fe investigation. The remote terminal and interactive capability enabled assessments to be performed in Alburquerque, at HEC and in Santa Fe. The capability of analyzing nonstructural structural measures in Santa Fe (city offices or motel rooms) enabled immediate field inspections as to the overall attractiveness and physical feasibility of the potential measures. The general procedure of the INA was to:

- Read the hydrologic, hydraulic data defining the physical characteristics of the channel and flood plain.
- Read pertinent structure data.
- Develop flood hazard data at each structure and create a computer data file.
- Selectively access and display the hazard and economic data for selected structures for existing "without" conditions.
- Modify the hazard and economic information to reflect the effects of any proposed nonstructural flood control measure.

The nonstructural evaluation of existing structures were performed on an individual structure assessment for each delineated damage reach.

Study Findings. The investigation involved a broad range of nonstructural measures designed to reduce flood losses. Many were found to be inappropriate for a variety of reasons. The following measures are considered appropriate for implementation and together constitute a nonstructural plan for reducing flood losses in the study area.

- o Replacement of selected bridges and relocation of 18 structures in low areas. The land would be converted into the adjacent park.
- o Selected clearing of the river channel.
- o Construction of small walls along the parkway in the downstream area and along property lines of selected neighborhoods.
- o Purchase of flood insurance.
- o Regulation of flood plain land.
- o Disaster assistance planning.

Expected annual damage for "without" conditions was estimated to be $98,500 year. With the nonstructural opportunities identified the expected annual damage would be reduced to $85,200.

Case Study III: Passaic River New Jersey.

Background. The ongoing Stage II level Passaic River basin study is a comprehensive investigation involving analyses of existing and future hydrologic conditions, economic effects of structural and nonstructural alternatives, and water supply yield and related issues of proposed measures. The study is being performed by the New York District Corps of Engineers. Although the study has not been completed it is included because of the analytical procedures that will be applied to evaluate the feasibility of implementing nonstructural measures for over 40,000 structures individually inventoried.

Basin Description and Flood Problems. The watershed has three distinct topographic and hydrologic regions: the highland area, the central basin, and the lower valley. The highland area is 489 square miles, and is of a wooded mountainous terrain. The central basin is broad and flat and consists of about 253 square miles. The lower valley, 193 square miles, is mixed with meadow areas in the center and steeper, narrower flood plains near the mouth in Newark Bay. The Passaic watershed covers about 10 percent of the State's population, but includes approximately 40 percent of the States population.

Floods may result from conventional spring and summer storms or from hurricanes. Portions of the basin have been declared disaster areas in 1968, 1971, 1972, 1973, July 1975, and September 1975. Several significant events have also occurred prior to 1968. The flood problems in the lower valley are due primarily to the relative narrow channels and major urban development along the banks. Eighteen major communities are affected by floods. Flood problems in the central basin and the highland region are less severe.

Analysis Procedures. The "Structure Inventory for Damage Analysis" (SID) (Hydrologic Engineering Center 1981) computer program linked automatically to the "Expected Annual Damage Computation (EAD) (Hydrologic Engineering Center 1977b) via a random access file is the primary analytical tool for evaluating nonstructural measures. The general process of evaluating the nonstructural measures will be:

- Obtain pertinent data for each individual structure. The data is stored on a sequential data file with an edit program written to window out selected structures or reaches for analyses or modify data as needed. Data for over 40,000 structures have been processed and filed.
- Develop stage-damage functions for the various categories of structures. These data, about 500 functions, have been stored on a random access file.
- The SID program is used to generate user designated elevation-damage functions by damage category and damage reach. The required structure and associated stage-damage functions are retrieved from the stored data on the computer files. The SID program is used to generate elevation-damage functions by damage category and reach for "with" and "without" in separate computer executions. The results are output to a random access file, termed the HEC Data Storage System (HECDSS) (Hydrologic Engineering Center 1980).
- The EAD program will access the elevation-damage functions for both "with" and "without" conditions along with hydrologic (discharge-frequency and rating functions) and calculate expected annual damage and benefit values associated with the nonstructural measures.
- The process will be repeated for various types of measures analyzed.

The nonstructural analysis of the Passaic River will represent a major effort with reliance on systematic and rather sophisticated information management and processing procedures.

CHAPTER VII

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