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Interactive Nonstructural Flood-Control Planning

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The goals of nonstructural flood-control planning are formulation, evaluation, selection, and implementation of a practicable management plan that provides optimal protection from the adverse effects of flooding. Many alternative flood-control measures can be dismissed by the water resources planner on the basis of judgment, but a substantial number will require detailed analysis before a suitable plan can be selected. This analysis is an iterative process, requiring input from the planner at each step. Software developed at the Hydrologic Engineering Center (HEC) allows efficient data storage in a structure-oriented data bank and provides for selective retrieval and manipulation of the data from an interactive terminal. Thus the planner is able to propose nonstructural measures and to evaluate rapidly the economic and technical feasibility of those measures in an iterative scheme that allows the required input from the planner.

An application of the interactive plan evaluation software is presented. Steps in creating the data bank are defined, and use of the software for subsequent accessing and manipulating the data for plan evaluation is discussed.

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INTERACTIVE NONSTRUCTURAL FLOOD-CONTROL PLANNING[1]

by David T. Ford,[2] A. M. ASCE

ABSTRACT

The goals of nonstructural flood-control planning are formulation, evaluation, selection, and implementation of a practicable management plan that provides optimal protection from the adverse effects of flooding. Many alternative flood-control measures can be dismissed by the water resources planner on the basis of judgement, but a substantial number will require detailed analysis before a suitable plan can be selected. This analysis is an iterative process, requiring input from the planner at each step. Software developed at the Hydrologic Engineering Center (HEC) allows efficient data storage in a structure-oriented data bank and provides for selective retrieval and manipulation of the data from an interactive terminal. Thus the planner is able to propose nonstructural measures and to evaluate rapidly the economic and technical feasibility of those measures in an iterative scheme that allows the required input from the planner.

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INTRODUCTION

Selection of an acceptable, practicable flood-control plan requires integration of hydrologic, hydraulic, engineering, economic, social suitability, environmental, and community well-being information (5). This task can only be accomplished through an iterative process in which the planner proposes an alternative that seems promising, evaluates the efficiency of the alternative, analyzes the social and environmental acceptability, and repeats the process if the alternative is inefficient or unacceptable. In this process the planner must answer three broad questions:

1. What is the nature of the flood hazard?
2. What measures are available to reduce effectively the adverse effects of flooding?
3. How efficient are these measures in terms of the flood-control goals?

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The first question is answered with the hydrologic and hydraulic information, which is used to delineate areas subject to inundation and to estimate flood flows and the severity of floods of varying frequency. Economic information is required also to quantify the hazard. Identification of effective flood control measures requires analysis of engineering information in addition to the hydrologic, hydraulic, and economic data. To answer the third question within the multiobjective framework, the social suitability, environmental, and community well-being information must be considered also. The social suitability information is necessary to assess public support of alternatives and to evaluate obstacles to implementation, the environmental data are required to assess modifications to the urban ecology, and the community well-being data are required to determine how a proposed plan would affect the quality of life for flood plain residents (5).

Flood damage mitigation may be provided by measures that modify the flood (structural measures) or by measures that modify damage susceptibility or the loss burden (nonstructural measures). Structural measures include reservoirs, detention structures, levees, floodwalls, flood bypasses, and channel improvements. Nonstructural measures include flood proofing structures, raising structures, evacuating and relocating structures, managing future development, forecasting and preparing for floods, and insuring against flood losses (6).

The efficiency of flood-control measures traditionally is quantified for planning in terms of changes to the flood hazard indices and in terms of the economic benefits and costs of the measures. Indices commonly used as measures of flood hazard include the following: (1) depth of flooding due to an historical or hypothetical flood, (2) damage incurred by an historical or hypothetical flood, (3) frequency of flooding to some specified elevation, (4) level of protection, and (5) the expected annual value of flood damages. The first index is determined by finding the discharge associated with the flood of interest and then referring to a discharge-depth function to establish the corresponding depth. The second index is evaluated by carrying the process one additional step to determine the damage associated with the depth. Evaluation of the third index requires development of a elevation-frequency function; the frequency of flooding to a specified elevation can be determined by referring to this function. The fourth index, level of protection, is defined as the recurrence interval (reciprocal of probability) of the minimum elevation at which damages occur. Evaluation of level of protection requires analysis of an elevation-damage function to define the elevation at which damages start, followed by analysis of the elevation-frequency function to determine the corresponding recurrence interval. The final index, the expected annual flood damage, is defined as the average damage which can be expected in a year and is computed by summing the products of the damage caused by each depth of flooding and the probability of each of those depths occurring. Inundation reduction benefits are determined by subtracting expected annual damage incurred with a flood-control measure in-place from expected annual damage incurred with no additional protection. Net benefit and the benefit-cost ratio are determined by comparing the benefits (inundation reduction and others) with the cost of implementing, operating, and maintaining the flood-control measure.

THE NONSTRUCTURAL ANALYSIS PACKAGE

The Nonstructural Analysis Package was developed to manage the large amount of data necessary for nonstructural planning and to perform the calculations necessary to assess the efficiency of alternative measures, thereby freeing the planner to think. The practical success of a flood-control plan is dependent on the ability of the planner to analyze the available data, considering systematically the many possible alternative solutions to formulate a feasible plan. As the number of structures to be considered increases, the complexity of the data management problem increases substantially, and a search through the data to identify viable alternatives consumes resources that are better allocated to analysis of social acceptability, environmental impacts, and other factors that govern plan feasibility. Furthermore the arithmetic required to evaluate a multitude of alternatives is time-consuming, so that the number of alternatives that are actually considered for each structure is likely to be reduced as the number of structures increases. The Nonstructural Analysis Package programs obviate these problems by providing for efficient storage and manipulation of the data and rapid performance of the arithmetic evaluation of alternatives.

The Nonstructural Analysis Package programs focus on individual structures or on user-defined groups of structures as the elements of analysis. Alternative nonstructural flood control measures are evaluated on a structure-by-structure basis, just as these measures would actually be implemented. In addition to allowing a detailed and practically-useful analysis, this approach yields more accurate resolution of the elevation-frequency and damage-frequency functions than is possible with the alternative grid-cell approach proposed by Webb and Burnham (8) and by Robillard, Walter, and Allee (7).

The Nonstructural Analysis Package includes computer programs that accomplish the following tasks: (1) read data describing the hydrologic, hydraulic, and physical characteristics of a river channel and of the surrounding flood plain, (2) read data describing structures within the flood plain, (3) merge the data to develop information on the flood hazard at each structure, (4) prepare a computer file containing the data collected and the resulting information on the flood hazard, (5) selectively access and display the basic data and the indices of flood hazard, and (6) modify the data and recompute the hazard indices to reflect the effects of proposed nonstructural flood-control measures. Tasks 1 through 4 are accomplished by a computer program designated the Preprocessor; tasks 5 and 6 are accomplished by a program designated the Interactive Analysis Program.

THE PREPROCESSOR PROGRAM

The Preprocessor Program is designed to accomplish all "once-through" data manipulation and computation, and to create a data bank in a special format for later access with the Interactive Program. The program is written in FORTRAN IV and requires random access software for preparation of the data bank. The program is intended to be executed in batch mode.

The Preprocessor Program manipulates basic hydrologic, hydraulic, economic, and engineering data to derive the indices that quantify the existing flood hazard at each structure (or group of structures) and to arrange the information so the efficiency of alternative measures can be evaluated. This manipulation is shown schematically in Figure 1. The objective of the manipulation is derivation of the elevation-frequency and damage-frequency curves for each structure or group of structures. Typically frequency information is developed only at a stream gage location, so the information must be "transferred" to each structure. This is accomplished by first combining the discharge-frequency function with an elevation-discharge relationship to derive an elevation-frequency function. Then using information on the hydraulic characteristics of the stream and the surrounding flood plain, elevations at a point on the stream can be related to elevations at a structure, and an elevation-frequency function for that structure can be derived. If this function is combined with the elevation-damage relationship for the structure, the damage-frequency relationship can be determined.

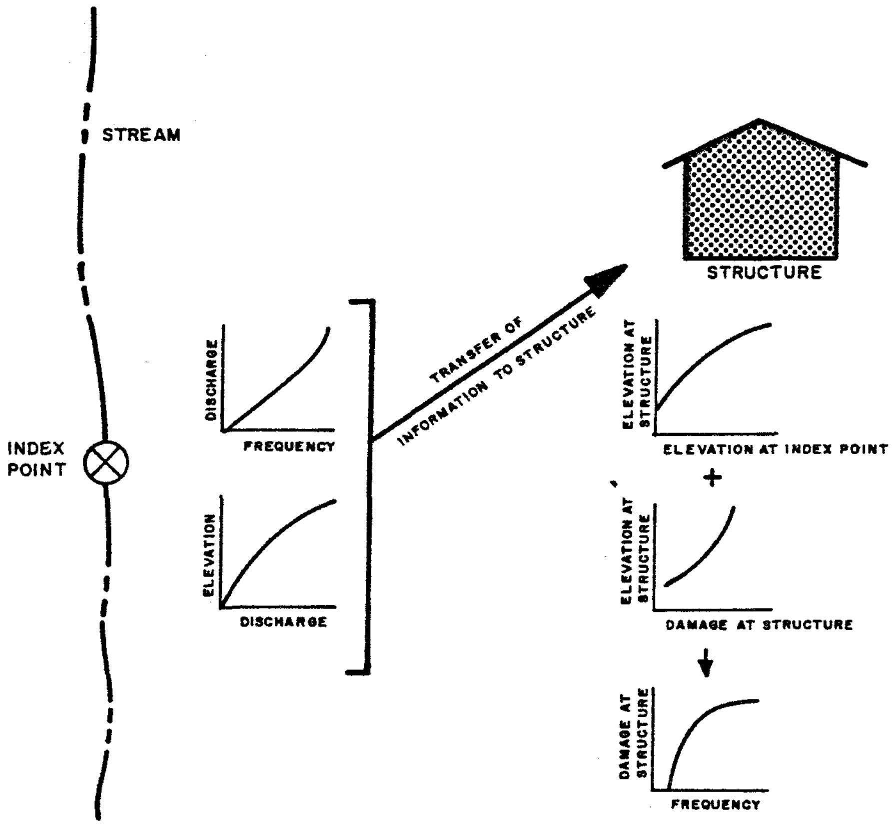

Figure 1. Schematic of Data Manipulation for Nonstructural Analysis

The standard output from the Preprocessor Program includes a printed record of the basic economic and engineering data for each structure, of the computed hydrologic and hydraulic information for the structure, and of the flood hazard indices for existing conditions (with no flood-control measures) at the structure, and a file that may be used as input to an alternative analysis program, the HEC's Expected Annual Flood Damage Computation Program (EAD) (2). This program was developed to assist in economic evaluation of flood plain management plans and has become a familiar tool to many planners and economists.

DATA BANK

The data bank created by the Preprocessor Program contains basic and computed data for each structure or group of structures in the flood plain, along with data bank "directories" that permit rapid retrieval of these data. The data are organized by stream reaches, a convention often employed by planners when managing and analyzing data by conventional means. The extent of these reaches is defined for the Nonstructural Analysis Package programs by the user on the basis of study needs and available data; the only requirement is that a discharge-frequency function and an elevation-discharge function be provided at an index point on the stream in each reach. Hydrologic, hydraulic, and economic characteristics of the flood plain generally dictate the boundaries of stream reaches.

For each structure in the flood plain, approximately 150 elements of basic and computed information are stored in the data bank. This information includes 32 so-called structure "attributes" that characterize the structure and the nature of the flood problem at the structure. Included as attributes are the previously described indices of flood hazard, data describing the location of the structure, engineering data describing the construction techniques and materials employed, and "flags" to indicate environmental or historical significance. These attributes are the foundation of subsequent sorting and screening of the data. In addition to the attributes, other structure-related data are stored, including the elevation-frequency function and the elevation-damage function for the structure.

The data bank for the Nonstructural Analysis Package is written to a permanent storage medium as a random access file. Random access is a data input-output technique that provides for determining and storing an index of the location at which data are initially written to the medium and for reading from and rewriting to the medium at a location specified by an index (1). Thus, a specific block of data can be located and read without reading unnecessary preceding data simply by specifying the appropriate index of the first element of the block. Values that are to be read first can be written last and vice versa if the indices are stored and used to locate those values when they are written and read.

When the basic encoded data for each structure in a reach are initially read and additional information is computed by the Preprocessor Program, these are written to the storage medium, and a location index is stored in a "directory" array. When data for all structures within a reach are written, the array of the structure data location indices for that reach also is written to the medium, and the location index of the array is stored in a "master index" array. When all data for all structures in all reaches is written, this "master index" array is written to the medium. When the data are read later by the Interactive Analysis Program, the master index is read first, and additional data are read on demand using the location indices.

THE INTERACTIVE ANALYSIS PROGRAM

The Interactive Analysis Program is designed to retrieve on demand the basic and computed data for any structure in the flood plain, to display the information in a convenient format for the water resources planner, and to manipulate the data and recompute the various flood hazard indices to demonstrate the efficiency of any proposed alternative-flood-control measure. The program is written in FORTRAN IV and requires random access software. The program is designed to be executed in interactive mode, but can be executed in batch mode if an appropriate terminal is not available.

Execution of the Interactive Analysis Program is controlled by the user with simple, English-like commands that define the task to be accomplished and the structures that will be affected. This problem-oriented language allows even the inexperienced user to move around in the program, going ahead when satisfied and reiterating when other alternatives are to be evaluated. Thus, the planner's judgement makes decisions, not the programmer's judgement.

The basic syntax of the commands for the Interactive Analysis Program is

command *constraint*

where *command* specifies the task and *constraint* defines the affected structures. Table 1 lists the currently operative commands and describes each briefly. The constraints are defined much like the constraints of a mathematical programming problem: the left-hand-side of the constraint may be any of the 32 basic structure attributes, the operator may be either LE (less than or equal), EQ (equal), or GE (greater than or equal), and the right-hand-side of the constraint may be alphabetic or numeric as appropriate for the specified attribute. Constraints may be combined with the operators AND and OR.

TABLE 1

DESCRIPTION OF INTERACTIVE ANALYSIS PROGRAM COMMANDS

Command	Action Taken
REACH	Reads data for specified reach
LIST	Lists identification number and name of all structures that satisfy constraints
PRINT	Prints specified summary or specified attribute for all structures that satisfy constraints
NUMBER	Reports number of structures that satisfy constraints
REVISE	Allows data modification to reflect effects of nonstructural alternative
SAVE	Rewrites random access file with changes for nonstructural measures
TERMINATE	Terminates program execution

All user input to the Interactive Analysis Program is read by a scanner routine that allows for entry of the commands in free form, with commands and constraints placed anywhere on a line of input. The only requirement is that items be separated by at least one blank. If the user enters an unrecognizable command or an invalid constraint set or employs unacceptable syntax, an appropriate error message is issued, and program execution continues.

The Interactive Analysis Program was developed as an "open-ended" program to allow easy implementation of additional commands and alternative analysis techniques to satisfy the needs of water resources planners. The program consists of an executive routine that compares each user-specified command with a dictionary of valid commands and transfers control to appropriate subroutines to carry out the specified task. To add commands or to expand the analysis capabilities, the dictionary can be expanded, and additional subroutines can be added.

ILLUSTRATION OF INTERACTIVE PROGRAM USE

When execution of the Interactive Analysis Program begins, a banner identifying the program is printed as shown below, and a title block is read from the user's data bank and is printed to avoid possible confusion of data banks.

```
*****************************************************
*                                                   *
* PROGRAM FOR INTERACTIVE NONSTRUCTURAL ANALYSIS    *
*                                                   *
*****************************************************


SANTE FE NONSTRUCTURAL FLOOD CONTROL STUDY
HYDROLOGIC ENGINEERING CENTER
21 SEPT 1979
```

To proceed with the analysis, the user then identifies the reaches that are to be read from the data bank as shown below, and the program responds with a count of the structures in each reach or with an appropriate message if the requested reach is not in the data bank. (User input in this and all examples that follow is in lower case.)

```
reach 4 5
REACH          4 READ.        58 STRUCTURES.
REACH          5 READ.        18 STRUCTURES.

REACHES READ      2
```

To obtain a list of identification numbers and names for all structures that satisfy specified conditions, the LIST command may be used. For example, the command

```
list eadt ge 2
```

will direct the program to search the data for all structures in reaches 4 and 5 and to display the number and name of all with total expected annual damage (abbreviated EADT) greater than or equal to $2000. (Damages are expressed in thousands of dollars in this data bank.) The program responds with a list of identification numbers and names of all structures that satisfy the constraints, as follows:

```
11128. 653 CANYON RD (ALSO 11129-30) THE COMPOUND CONDOS
11502. 1A PEQUENO (ALSO 11503)
```

If the user desires only a count of the structures that satisfy the constraint, the NUMBER command can be used instead, and the response would be

```
2 FEASIBLE STRUCTURES
```

Various data summaries can be produced using the PRINT command. For example to display economic information for structure 11502, the user would enter the following command:

```
print economic idno eq 11502
```

where IDNO is the abbreviation for identification number. The program would produce the following summary:

```
ECONOMIC SUMMARY - STRUCTURE    11502.
1A PEQUENO (ALSO 11503)
VALUE STRUCTUR     40.00
VALUE CONTENTS     20.00
  CATEGORY CURNT EAD  BASE EAD
  STRUCTUR      1.07      1.07
  CONTENTS       .91       .91
  LAWN           .05       .05
     TOTAL      2.02      2.02
```

Nonstructural flood control measures are "implemented" by using the REVISE command and by specifying the effects of the measure. For example to evaluate the effects of providing nonstructural measures for all structures with level of protection (abbreviated LEVEL) less than or equal 15 years, the user will enter the command

```
revise level le 15
```

When the user enters the appropriate information to indicate the types of and dimensions of the measures, data in memory for the structures is altered to reflect the modifications. Also, a file is created for subsequent input to the EAD Program if desired. The data bank is modified permanently only if the SAVE command is used.

Additional examples of program use and additional description of the commands are presented in Reference 4.

APPLICATION OF NONSTRUCTURAL ANALYSIS PACKAGE

The Nonstructural Analysis Package has been used recently by the staff of the Hydrologic Engineering Center in development of a proposed flood-control plan for Santa Fe, New Mexico. In this study, a 15-mile section of the Santa Fe River containing a total of 457 structures was divided into five reaches. A structure-by-structure field survey was conducted and data were collected on coding forms. These data were later checked, encoded, and rechecked, and the Preprocessor Program was executed to create a random access data bank that was stored at a readily accessible commercial computer service site. This data bank was accessed repeatedly with the Interactive Analysis Program during this study.

In this study, the Nonstructural Analysis Package proved most useful as a tool for data organization and display, both in the office and in the field. To formulate effective solutions to flooding problems, the planner must visit the site to develop an understanding of information critical to plan formulation that is not quantitative and thus cannot be captured in a data bank. However the quantitative information must be readily available for integration with this nonquantitative data. This integration is possible with the Interactive Analysis Program. Once the data bank is established and stored, it can be accessed with an interactive terminal via telephone. During this study, the data bank was accessed from the HEC's office in Davis, California, from a Corps of Engineers office in Albuquerque, New Mexico, and from a motel room in Santa Fe. In the last case, planners were able to identify structures for which nonstructural measures appeared to be economically and physically feasible and to inspect these structures on-site to verify this. If the inspection indicated that the measure was not truly appropriate, the effects of an alternative measure could be easily analyzed. Often, this on-site inspection revealed errors in field data that lead initially to formulation of unacceptable flood-control plans. These errors otherwise might not have been discovered and corrected, or might have been discovered when the flood-control plan was presented for public inspection, thereby reducing the credibility of the entire study.

Using the Nonstructural Analysis Package as the primary analytical tool, planners developed a flood-control plan for Santa Fe that recommends removal of certain structures and construction of small walls for reduction of damage susceptibility. Additional measures that modify the characteristics of the flooding were recommended for further study on the basis of the analysis accomplished with the program. Finally flood insurance was recommended for those structures for which the risk of flooding is low or for which no other measures are appropriate, as identified with the Interactive Analysis Program. Additional details of this study are reported in Reference 3.

SUMMARY

The Nonstructural Analysis Package provides the water resources planner with the capability to manage conveniently the large quantity of data necessary for formulation of a viable nonstructural flood-control plan. The package consists of two programs: (1) the Preprocessor Program that digests hydraulic, hydrologic, economic, and engineering information for each structure or group of structures in a flood plain and prepares a random access data bank, and (2) the

Interactive Analysis Program that accesses, displays, and manipulates the data from the data bank. The Package has been employed successfully in development of a proposed nonstructural flood-control plan for Santa Fe, New Mexico.

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