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# The Hydrologic Engineering Center Experience in Nonstructural Planning

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# THE HYDROLOGIC ENGINEERING CENTER EXPERIENCE IN NONSTRUCTURAL PLANNING[1]

*William K. Johnson and Darryl W. Davis*[2]

ABSTRACT: The Hydrologic Engineering Center, Corps of Engineers, has been engaged in research, training, and project assistance in nonstructural flood control planning for Corps offices across the United States since 1975. Lessons learned from this experience deal with the role of nonstructural measures in flood plain management, the role of creativity in analysis, the role of analysis, and tools for analysis. The role of nonstructural measures in flood control planning depends upon the scale of the problem, the nature of the measure, the degree of protection desired, and whether damage is to existing or future property. An earnest seeking for nonstructural opportunities, a field presence for their formulation, and compatbility with local infrastructure plans are prerequisite to creative use of nonstructural measures. Analysis is a necessary complement of creativity. Several tools for nonstructural analysis have been developed and applied to flood problems involving several hundred and several thousand structures.
(KEY TERMS: flood control planning; nonstructural measures; hydrology; economics.)

## INTRODUCTION

Since 1975 the Hydrologic Engineering Center (HEC), Corps of Engineers, has been engaged in research, training, and project assistance in nonstructural flood control planning for Corps offices across the United States. Eighteen documents covering a wide-range of nonstructural topics have been published and are available from the Center (U.S. Army Corps of Engineers, 1982d). Included are research documents which report on investigations into technical aspects of nonstructural measures; user manuals for computer programs developed for analysis of nonstructural measures; and project reports which describe studies in which nonstructural alternatives were formulated.

Training in nonstructural planning has also been conducted. Since 1975 four training courses and one seminar have been held by the Center. Another training course is cheduled during 1984. These group activities have provided the opportunity for exchange of insights, information, counsel and advice on the planning of nonstructural measures in Corps field offices.

The experience gained by the Hydrologic Engineering Center through research, analysis, project investigations, and training and seminars is the subject of this paper. Much has been learned. The paper will focus on four subject areas: 1) lessons in the role of nonstructural measures, 2) lessons in creativity, 3) lessons in analysis, and 4) tools for analysis. Lessons in the role of nonstructural measures presents observations related to the role nonstructural plays in the larger context of flood plain management. As part of the solution, what have we learned about these measures as a group or category? Lessons in creativity addresses those activities in nonstructural planning which are nonquantitative in character. They are more intuitive, more social, more cultural. Lessons in analysis summarizes experience gained in the use of computer programs in nonstructural planning. It is not the programs themselves, but their use which is the subject. Lastly, tools for analysis describe various computer programs and their application in nonstructural planning studies.

In discussing flood probability in this paper the term exceedance probability is used. A 0.01 exceedance probability, for example, is often referred to in the literature as the "100-year flood." It is felt that terms such as exceedance probability, or alternately, percent chance or exceedance frequency are technically superior and less likely to be misunderstood than the more common literature terminology of exceedance interval expressed in years (U.S. Army Corps of Engineers, 1982e).

## LESSONS IN THE ROLE OF NONSTRUCTURAL MEASURES

### *Large Scale Solutions*

Large scale nonstructural solutions to problems of flooding to existing property have not been found in studies conducted at the HEC nor in Corps District offices. There are several reasons for this. First, formulation of plans to protect against the 0.01 exceedance probability or Standard Project Flood event in a populated flood plain creates a need which nonstructural measures alone cannot practically nor economically

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meet. The number of structures, the variety of types of property, their location, the severity of hazard, ownership . . . all these factors and others make nonstructural solutions on a large scale improbable. Second, there are a limited number of measures which can be effective in reducing damage to existing structures. Conditions which make these measures attractive are unique. For example, structures in frequently flooded areas where damage is high enough for relocation to become a viable option; or structures built of materials such that they may be easily floodproofed or raised; or communities where the flood warning time is sufficient to allow emergency action.

While nonstructural solutions to flooding of existing structures may not generally be found attractive on a large scale, there are opportunities for their use. Often nonstructural measures can be combined with structural measures to provide a composite plan. Such a plan should always be sought. It should look to the strengths of each type of measure and utilize them in a way which produces the most effective response to the hazard.

*Local/Individual Nature*

Traditional structural measures often have the important advantage of being back in the mountains or over by the river. Reservoirs, levees, flood walls, and channel modifications are in general, constructed away from or on the fringes of the urban/suburban infrastructure. While relocation of existing property was often necessary, it was a relatively small percentage of what existed in the flood plain. Also, these traditional measures provided protection for large sectors of the community. A reservoir provides protection of developed and undeveloped land downstream. Levees, walls, and channel works protect all property within their area of influence. Another feature of traditional measures is that they protect both existing and future development. Open space occupied later by damageable property is assured of protection because structural measures protect all the land not just that which is occupied at the time. Lastly, reservoirs, levees, walls, and modified channels are physical, concrete and steel, engineering works which we know how to plan, design, construct, and operate. Equally important, they are reliable and certain within the bounds of our knowledge of hydrology, hydraulics, and structures. There is a sense of confidence which structural measures create, by virtue of their history of use.

Nonstructural measures are uniquely different from structural. First, they include a wide range of activities. Flood plain zoning and flood preparedness are significantly different from relocation or raising a structure. Second, some measures are designed for existing structures (relocation, flood proofing) while others only apply to future development (regulation). Still others like flood preparedness and flood insurance are applicable to both existing and future development. With the exception of flood preparedness planning, flood plain regulation, and flood insurance, nonstructural measures when applied to existing flood problems are local and individual. As a consequence, the means of protection is not "over there" as in the case of structural measures, but in the midst of the flood plain infrastructure. Protection is not for a large sector of the community, but for individual properties . . . primarily existing properties. And lastly, there is considerably more uncertainly, perhaps unjustifiably, in the protection provided by nonstructural measures. Part of this uncertainty is because many nonstructural measures require a personal involvement or response.

*Degree of Protection*

A nonstructural plan or a combined structural and nonstructural plan is most likely to provide variable degrees of protection. The concept of a uniform degree of protection is derived from, and more applicable to, structural measures than nonstructural. Relocation, for example, provides complete protection; flood insurance no physical protection, preparedness, unquantifiable protection; and raising, quantifiable protection. For some measures, for example, raising existing structures, it is difficult for a uniform level to be achieved because of variations in topography, type of structures, and personal preference. When mixes of nonstructural measures are formulated, the task of providing uniform protection is near impossible. The difficulty lies in trying to maintain a concept (uniform protection) developed with one type of measure in mind (structural) and apply it to quite a different set of measures (nonstructural).

The question of certainty or confidence in the protection provided has already been raised in comparison with structural measures. Thus, not only will the degree of protection vary with nonstructural measures, but the confidence in that protection may also vary.

*Present and Future*

Flood preparedness planning, flood plain regulation, and flood insurance are measures which should be part of every community's planning to minimize the flood hazard. Flood preparedness is designed to reduce the social disruption and losses caused by flooding to existing property and is an essential component of a community's disaster planning. It can serve in the absence of more permanent measures to reduce the threat to loss of life and property and can be part of both structural and nonstructural plans. In addition, it can include public facilities such as roads, bridges, drainage, and sewer systems which are not part of other nonstructural plans.

Flood plain regulation has been given nationwide impetus through the National Flood Insurance Program. A major contribution of regulation is the prevention of future flood losses. In measuring the overall effectiveness of nonstructural measures, regulation has made a significant contribution in preventing future losses. This is the new America being constructed in the next 50 years. The flood insurance itself does not reduce damage directly but provides indemnification for financial loss and shifts part of the burden to flood plain occupants. Where flood plain regulation does not already exist, it can be encouraged through the development and implementation of flood plain management plans.

## LESSONS IN CREATIVITY

In light of the foregoing, several observations can be made relative to the creative dimension of nonstructural planning. First, nonstructural opportunities must be earnestly sought. The variety of nonstructural measures, the lack of experience with their implementation, and the uncertainty surrounding their use makes a vigorous search to utilize them a necessary prerequisite to any study. We must look for the opportunities. There must be a genuine desire to find nonstructural solutions or partial solutions.

Second, there is a necessity for a field presence during the planning study. The infrastructure, in which nonstructural measures are applicable, is a living community of people whose personality can best be captured through field work. Information on the types of structures, their use, their location in proximity to other property, and their ownership can best be assessed in the field. Community development: parks, bridges, recreation, historic features can be observed in the field. Access roads, terrain, vegetation, and wildlife are also important to observe. Discussions with people in the community can provide valuable insight to both the local flood problem and appropriate means of solution.

A third observation is that every effort should be made to make any nonstructural plan compatible with and appropriate for the community; its infrastructure, its values, its plans. Nonstructural alternatives directly touch the lives of people and communities more than structural measures. As a consequence the appropriateness of proposed actions must be carefully considered.

Also, it should be recognized that a variety of federal, state, and local agencies have responsibility for urban infrastructure including the flood plain. These agencies modify this infrastructure on a regular basis: inadequate bridges are replaced, land use is changed, new development is added, parks are planned, and structures removed. Many such actions by local government are nonstructural in character and should be taken into account in the planning study and encouraged by a spirit of mutual cooperation.

In the search for appropriate nonstructural opportunities . . . the earnest and vigorous search . . . it must be recognized that none may be found; at least, none of significance; or none which are appropriate. Often investigators feel they have failed unless they develop a nonstructural plan. When the task is forced, it could lead to recommendations which are not appropriate for the community and are later rejected by the community. Flood insurance, flood plain regulation, and flood preparedness are exceptions. These are opportunities which should be seriously put forth and considered by all communities. They are nonstructural measures which have the potential for doing much good and may be confidently recommended. Other more local and individual measures must be examined in the context of each community and flood hazard.

## LESSONS IN ANALYSIS

In addition to the creative activities of nonstructural formulation there is also an analysis or analytical side. This is equally important. Analysis is generally of two types: flood hazard assessment and flood damage assessment. Hazard assessment includes hydrologic and hydraulic computations which describe where the flood waters go; how frequent flooding occurs; and their depth, velocity, and other characteristics. The level of protection provided by nonstructural measures can be determined as part of this analysis. Damage assessment includes estimating the economic damage to property at different levels of flooding, estimating the frequency of occurrence at each level, and computing the expected annual damage. Damage prevented by nonstructural measures is the damage to the structures without implementation minus the damage with implementation. Both hazard and damage assessments provide quantitative information to the investigator on the severity of the hazard and its economic consequences.

To provide the Corps with hazard and damage assessment capability for nonstructural planning, the Hydrologic Engineering Center developed several new computer programs as tools for analysis and has extended the capability of several existing programs. The basic hydrologic analysis programs HEC-1 "Flood Hydrograph Package" and HEC-2 "Water Surface Profiles" are well known to flood plain investigators. The new programs are discussed in a following section on "Tools for Analysis." These programs have been invaluable to the task of nonstructural formulation. They have been used on projects ranging from several hundred structures to several thousand. In all applications they provide a very necessary tool for organizing, analyzing, and displaying large amounts of hazard and damage information. Coupled with the creative side of formulation they provide the investigator with the necessary tools for formulation.

### *Level of Detail*

An important question in nonstructural formulation is the level of detail at which the hazard and damage analysis should be performed. The options range from considering each structure individually (structure-by-structure analysis) to considering all structures within a river reach as a single damageable property (reach-by-reach analysis). The latter approach is common in damage assessment for structural measures. The structure-by-structure analysis has the advantage of being able to analyze and consider alternatives for each structure in the flood plain, and the disadvantage of having to analyze and consider individually large numbers of structures if the number of structures is large. Reach-by-reach analysis aggregates all structures within a reach to one location which makes analysis more tractable, but in the process of aggregation the individual characteristics (hazard, damage, and structure) are not readily accessible to formulation. Experience has shown that either handling the damageable property individually or in groups of homogeneous units is best for nonstructural formulation unless a single measure is being applied to all structures in the same way. To ensure accuracy when grouping structures it is necessary that they have similar damage potential (depth-damage relationship) and are subject to similar severity of hazard (frequency and depth of flooding). Such an approach (individual or groups of structures) preserves the individual characteristics of the property while at the same time providing the opportunity to reduce data handling. The tools for analysis described later handle both types of conditions.

*Preliminary Estimate of Damage*

One of the research findings from analysis of flood damage of individual residential structures is that expected annual damage decreases rapidly (exponentially) as structures are located further out of a flood plain (Johnson, 1978). For example, a residential structure located at the 0.5 exceedance probability (2-year) flood event has significantly more damage potential than the same structure located at the 0.05 exceedance probability (20-year) flood line. This is illustrated in Figure 1. Total expected annual damage expressed as a percentage of the value of a structure is plotted against the frequency of the flood event at the first floor. The curve shown is for a one-story, no basement structure; however, other types of structures show a similar relationship. The analysis uses 1974 FIA damage and frequency data. Figure 2 illustrates the significance of this relationship in another way. Expected annual damage is 13.2 percent of the structure value when the first floor is located at the 0.5 exceedance probability (2-year) flood level. The same structure located with the 0.5 exceedance probability (20-year) event at the first floor has only 1.2 percent expected annual damage, and at the 0.2 exceedance probability event, 0.5 percent. This relationship between expected annual damage and location in the flood plain is significant when it comes to understanding the economic feasibility of nonstructural measures.

*Limits of Analysis*

There are some nonstructural measures for which factual data and empirical relationships on performance is sparse or nonexistent. This is true of flood preparedness (forecast, warning, emergency action, and temporary evacuation) and individual actions such as rearranging damageable property. As a consequence analysis is limited. Analytical tools will be of less value for estimating level of protection and damage reduced for these measures. The way to make them more valuable and obtain better estimates of their performance is to conduct research and collect information on their nature and application. To be effective in plan formulation there must be a better understanding of what some of themore complex human response measures, in fact, do. Better data and better understanding will most likely result in better analysis and plans.

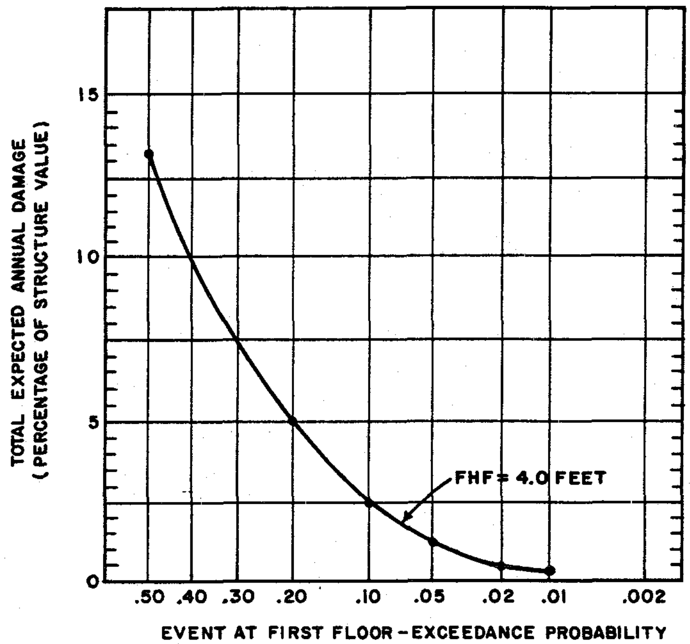


Figure 1. Expected Annual Damage for Different Location of Structures in Flood Plain (one story, no basement structure; flood hazard factor (FHF) = 4.0 feet).

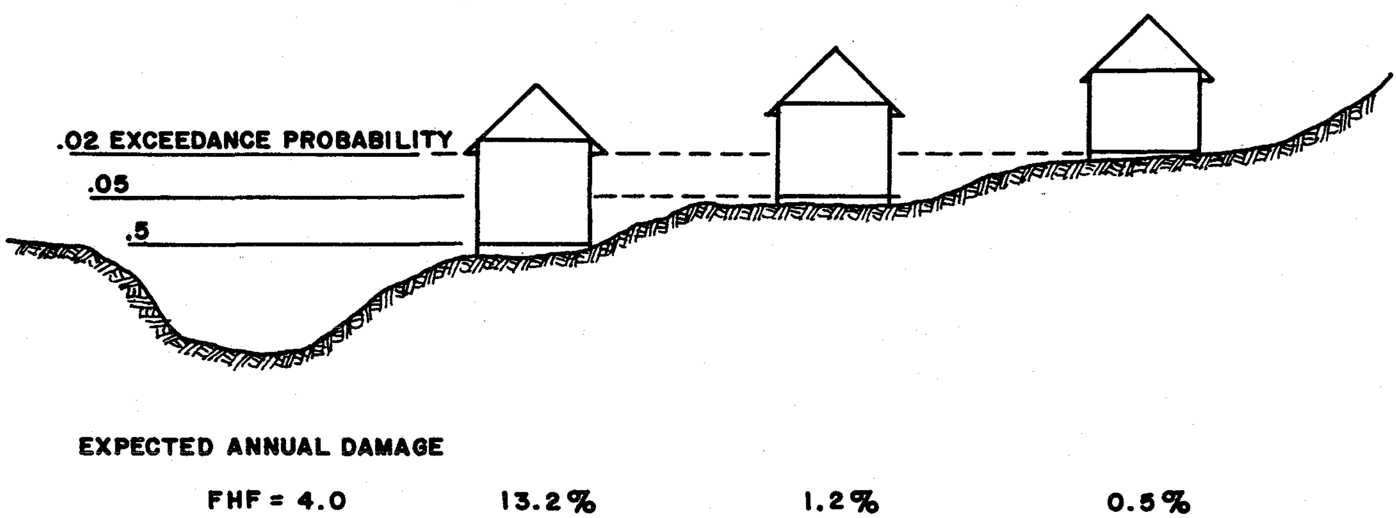


Figure 2. Expected Annual Damage for Alternate Flood Plain Locations (one story, no basement structure; flood hazard factor (FHF) = 4.0 feet).

## TOOLS FOR ANALYSIS

Each of the tools described below is designed to assist in analysis of the hazard and damage related to nonstructural plans. For details on each tool refer to the references cited (U.S. Army Corps of Engineers, 1982a).

### *Interactive Nonstructural Analysis Package*

This analytical tool was first developed for, and used on, a study of nonstructural measures for the Santa Fe River, New Mexico. Since that time it has been used by other Corps offices on a variety of nonstructural studies (Ford, 1981; U.S. Army Corps of Engineers, 1981). The program allows the user to assess the hazard and damage potential of individual or groups of structures interactively, that is, by sitting at a CRT or teletype computer terminal accessing a hazard/damage base and giving commands which request various analysis. A teletype about the size of a briefcase was taken to the field in the Santa Fe Study where it was connected to a previously developed data base at Boeing Computer System, Seattle, via a telephone line. This allowed immediate access to important hazard and damage information while in the field. For each structure, or group of structures, some of the information which may be requested via commands to the generalized program includes:

- Depth of flooding for a range of flood events
- Frequency of the flood event at the first floor
- Level of protection
- Elevation of the ground, first floor, level of protection
- Value of the property
- Expected annual damage of structure and contents
- X, Y coordinates of the structure or group

In addition, the user may give commands to raise or protect a structure or group of structures. The program raises or protects the distance specified and all of the above information then becomes accessible, for example, new level of protection, new expected annual damage. The immediate, interactive access to a data base with a variety of hazard and damage data, and the ability to select certain types of data for analysis make the interactive program a powerful tool in nonstructural formulation.

In the Santa Fe Study nearly 500 structures were analyzed using the interactive program. The program was accessed both at the HEC and from a motel room in the field. This allowed the most effective use of both locations. Results from the program which were used in the final report included a table of the number of structures in the flood plain for different levels of hazard, level of protection for different measures, and expected annual flood damage.

### *DAMCAL – Spatial Data Management System*

This family of tools has evolved from the Corps of Engineers experimental Expanded Flood Plain Information Program (Davis and Webb, 1978). The series of programs comprising the spatial data management technology, referred to as HEC-SAM, was specifically designed to enable comprehensive, flood plain oriented studies to be undertaken in a systematic, land use focused style. The damage reach Stage-Damage Program (DAMCAL) is the central feature of the SAM system which focuses on nonstructural measure formulation and particularly examination of the quantitative consequences of alternative flood plain management policies (U.S. Army Corps of Engineers, 1979).

DAMCAL has the capability to evaluate the following:

- Flood proofing of existing and/or future development – selective by land use categories and damage reaches.
- Relocation of existing development – selective as above.
- Managing future development to a target management flood level – selective as above.
- Temporary adjustments to contents during emergencies – selective as above.

Studies of this nature initially create a spatial data bank which contain gridded data on topography, land use, transportation and other infrastructure, hydrologic basins and flood profiles, and any other relevant geographic data. A scale covering not only the flood plain but the entire watershed may be selected. The spatial data file can be accessed by DAMCAL for nonstructural/flood damage studies, by various graphics and boolean operation programs (U.S. Army Corps of Engineers, 1978), and by hydrologic programs as may be appropriate.

About 35 studies have been undertaken by the Corps that make substatial use of all or parts of the SAM system. A recent study performed with the Los Angeles District Corps of Engineers, illustrates the type of utility a spatial/DAMCAL oriented study can contribute to nonstructural planning. The study was for the metropolitan Phoenix area (U.S. Army Corps of Engineers, 1982b) and the particular focus was nonstructural planning. A spatial data bank was constructed of just the flood plain area in the vicinity of Phoenix. The spatial resolution was 1.15 acres and comprised about 50,000 grid cells. Data included were existing and projected future land use, flood profiles and other geographic data. There are about 7,000 structures within the 500-year flood plain. Conventional flood damage analysis was performed using the spatial data by executing DAMCAL without exercising any of the nonstructural options and linking the results (automatically) to the Expected Annual Damage Program (as described in the SID structure-by-structure analysis).

The overall nonstructural evaluation was performed by analyzing the full array of measures for all applicable land use categories and damage reaches. General cost relationships were used to create screened zones of possible candidate structures for further more detailed individual structure analysis. Protection of up to 500 structures by perimeter barriers appeared to be marginally feasible. In addition, nine alternative flood plain management policies, ranging from flood plain fill at selected levels to exclusion of development from the flood plain were quantitatively analyzed. These analyses provided local officials economic data on the likely impacts of management policies which were heretofore unavailable.

An investigation of flood emergency preparedness performed as a component of the nonstructural investigation made valuable use of the spatial data bank and nonstructural analysis features of DAMCAL. The high flood threat areas were graphically displayed by mapping flood depths and expected flood damage by automatic retrieval and mapping from the data bank. Also, flood threat area data were tabulated by area and type by innovative use of the DAMCAL and RIA programs – data such as number and types of structures (thus people and goods) that would be flooded by target flood events, and evacuation routes graphically located. Opportunities for meaningful emergency actions such as flood fighting were located by study of the damage potential map and topographic features . . . which could be automatically superimposed using spatial data management techniques. Lastly, the value of certain emergency actions, such as contents removal, and contents elevation and protection were evaluated and used in an approximate economic analysis of the value of a total flood emergency preparedness plan.

*Structure Inventory for Damage: SID/EAD Package*

This tool was initially developed for a pilot study of Walnut Creek, Texas, conducted by the Ft. Worth District. The package consists of the basic structure inventory, project feature formulation program SID, and the companion Expected Annual Damage computation program EAD (U.S. Army Corps of Engineers, 1982c, 1977). The SID program is an individual structure-by-structure program that yields as an end product elevation damage relationships for each damage reach, flood damage category, and nonstructural measure or flood plain management policy. These data are then linked (automatically) with hydraulic and hydrologic data and input to the EAD program for expected annual damage computations. The SID program, the key nonstructural formulator/evaluator tool of the package, has been used for several large and small studies with nonstructural considerations.

The SID program has the capability of analyzing structure-by structure, then aggregating to an index location for a damage reach. The following array of nonstructural measures can be analyzed:

- Flood proofing existing and future structures by raising and/or ptotecting.
- Relocating existing structures.
- Managing future development to a target management flood level (flood plain regulations).
- Temporary adjustments by emergency action (contents raise, removal, etc.)

Several types of measures may be implemented by reach and/or structure category and a log by structure of all actions taken is filed and may be printed.

The information that may be catalogued into a SID structure file can vary from a minimum of structure elevation, and damage function and reach assignment, to elaborate description for more detailed nonstructural analysis of geographic coordinates, structure construction type, size, number of openings, etc. Thus, SID may be used from preliminary screening studies through to detailed planning level final formulation of plans.

In a study of the Passaic River Basin in the eastern United States, 65,000 structures were catalogued into the SID structure file. A special program named SIDEDT was used to manipulate the file to the subset of structures subjected to detailed analysis. SID (linked to EAD) was run a number of times exploring the range of individual structure measures and flood plain management policies which contribute to alleviating the flood problems in the Passaic. The full range of nonstructural measures analyzed by use of the SID (and other linked programs) were: flood proofing by barriers (structural and perimeter), structure relocation, flood plain management policies, and alternative levels of temporary actions taken as part of a flood emergency preparedness plan. A reference set of lecture notes is available from HEC chronicling the use of the full array of HEC analytical tools in the Passaic Basin investigation.

The SID, EAD, and other hydrologic engineering programs are available from HEC and have HEC standard documentation. At this time, the automatic linking of the programs has been made operational only on Corps computers.

## CONCLUSIONS

It was never intended by the early advocates of nonstructural measures that thesemeasures alone be the answer to our nation's flood problem. White (1945) called for a geographical approach to flooding; Hoyt and Langbein (1955) stressed unified flood management; U.S. Congress House Document 465 (1966) recommended a broad and unified effort. These and other voices were calling for a more comprehensive approach, an approach which seriously considered all possible means to reduce loss of life and damage to property. Subsequent federal legislation and policy guidance were designed to give impetus to these other, so called, nonstructural means which previously had been neglected or nonexistent.

Today, based upon experience in the field and knowledge from research, we can affirm that nonstructural measures have an important role in reducing present and future flood losses. Flood plain regulation, flood preparedness, flood insurance, relocation and other nonstructural measures go hand in hand with structural control works. Formulation of comprehensive plans of this type is a complex and delicate task which requires creativity and analysis. The tools for analysis are available. Do we have the creativity?

## ACKNOWLEDGMENTS

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## LITERATURE CITED


Davis, Darryl W. and R. Pat Webb, 1978. Flood Damage Assessment Using Spatial Data Management. Technical Paper No. 57, Hydrologic Engineering Center, U.S. Army Corps of Engineers.

Ford, David T., 1981. Interactive Nonstructural Flood-Control Planning. Journal of Water Resources Planning and Management Division, American Society of Civil Engineers 107(WR2).

Hoyt, William G. and Walter B. Langbein, 1955. Floods. Princeton University Press.

Johnson, William K., 1978. Physical and Economic Feasibility of Nonstructural Flood Plain Management Measures. Research Report, Hydrologic Engineering Center, U.S. Army Corps of Engineers.

U.S. Army Corps of Engineers, 1977. Expected Annual Flood Damage Computation. Computer Program Users Manual, Hydrologic Engineering Center (June).

U.S. Army Corps of Engineers, 1978. Resource Information and Analysis. Computer Program Users Manual, Hydrologic Engineering Center (September).

U.S. Army Corps of Engineers, 1979. DAMCAL (Damage Reach Stage – Damage Calculation). Computer Program User Manual, Hydrologic Engineering Center (February).

U.S. Army Corps of Engineers, 1981. Interactive Nonstructural Analysis Package. Computer Program Users Manual, Hydrologic Engineering Center (July).

U.S. Army Corps of Engineers, 1982a. Analytical Instruments for Formulating and Evaluating Nonstructural Measures. Training Document No. 16, Hydrologic Engineering Center (January).

U.S. Army Corps of Engineers, 1982b. Flood Preparedness Planning: Metropolitan Phoenix Area. Research Document, Hydrologic Engineering Center (January).

U.S. Army Corps of Engineers, 1982c. SID (Structure Inventory for Damage Analysis). Computer Program Users Manual, Hydrologic Engineering Center (January).

U.S. Army Corps of Engineers, 1982d. Hydrologic Engineering Center Publications Catalog. Hydrologic Engineering Center (June).

U.S. Army Corps of Engineers, 1982e. Flood Risk Analysis. Engineer Technical Letter 1110-2-274 (September).

U.S. Congress, 1966. A Unified National Program for Managing Flood Losses. Report to the 89th Congress by the Task Force on Federal Flood Control Policy, House Document No. 465 (August 10).

White, Gilbert F., 1945. Human Adjustment to Floods: A Geographical Approach to the Flood Problem in the United States. Department of Geography, Research Paper No. 29, University of Chicago, Chicago, Illinois.

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