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SPATIAL DATA ANALYSIS OF NONSTRUCTURAL MEASURES

by

ROBERT P. WEBB

& MICHAEL W. BURNHAM

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Consistent and expedient evaluations of nonstructural flood loss reduction measures for existing and alternative future land use patterns can be performed using spatial analysis concepts. The techniques developed center about the processing of spatial geographic data into a grid cell data bank and the subsequent accessing and manipulation of pertinent data variables by a computer program. The results are an automatically constructed elevation-damage function at damage reach index locations for selected land use patterns.(Continued)

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The modification of the damage function resulting from specific nonstructural alternatives may be performed by inputting into the computer program a target protection level or a specified stage of protection for selected land use categories. These functions may be analyzed conventionally by damage frequency integration methods or used as input into more complex system models.

SPATIAL DATA ANALYSIS OF NONSTRUCTURAL MEASURES

R. P. Webb,[1] and M. W. Burnham,[1] A.M., ASCE

ABSTRACT

Consistent and expedient evaluations of nonstructural flood loss reduction measures for existing and alternative future land use patterns can be performed using spatial analysis concepts. The techniques developed center about the processing of spatial geographic data into a grid cell data bank and the subsequent accessing and manipulation of pertinent data variables by a computer program. The results are an automatically constructed elevation-damage function at damage reach index locations for selected land use patterns. The modification of the damage function resulting from specific nonstructural alternatives may be performed by inputting into the computer program a target protection level or a specified stage of protection for selected land use categories. These functions may be analyzed conventionally by damage frequency integration methods or used as input into more complex system models.

INTRODUCTION

Water resource planners are charged in the plan formulation process to evaluate a broad range of alternative flood loss management measures that will provide flood damage reduction for existing and alternative future land use conditions. The plan formulation process is comprised of developing alternative means for accomplishing performance targets and selecting from those alternatives the ones which are the most attractive. One criteria of an attractive alternative is the minimization of environmental impact which has resulted in an increased emphasis in the evaluation of nonstructural alternatives. Even with this increased emphasis on less construction intensive measures which are less disruptive to the environment, there continues to be a need for the systematic assessment of the economic value of the proposed alternatives. It is desirable that alternatives be compared quickly, with the comparisons based on a consistent methodology.

Spatial analysis methods can provide the mechanism for expedient and consistent economic evaluation of alternative flood loss management measures. The methods used include the evaluation of geographic information which has been digitized and stored in computer files in digital form. Each geographic data variable is encoded separately and a registered grid cell representation of each data variable is stored in a sequential grid cell record on a computer file which then represents the data bank.

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Technology has been developed and applied by Corps of Engineers, Hydrologic Engineering Center, which accesses geographic information stored in a grid cell data bank for an integrated evaluation of flood hazard potential, flood damage and environmental effects of 1) existing land use condition, 2) alternative future land use conditions and 3) specific land development proposals. A powerful analytical capability in the spatial flood damage analysis is the ability to evaluate the nonstructural alternatives of 1) flood plain management policies, 2) flood proofing alternatives which may include raising structures, ring levees or the addition of flood proofing materials to structures, 3) permanent evacuation of structures in the flood plain 4) temporary structural protection and content removal in response to flood warning disseminations, and 5) combinations of the above. These alternatives may be evaluated in terms of providing a target protection level (such as protection from the 100-year frequency flood) or as providing uniform land use category protection (for instance flood proofing industrial structures four feet above ground elevation).

The geographic data variables that are used to perform the analysis are: 1) topographic elevation, 2) reference flood elevations, 3) damage reach delineations, 4) existing land use classification, and 5) alternative future land use patterns. The output for each spatial flood damage analysis is an aggregated elevation-damage function for each land use category at each damage reach index location. These functions may subsequently be analyzed conventionally by damage frequency integration methods or used as input into more complex system formulation models.

The objective of the nonstructural evaluation procedures developed and presented herein is the systematic and consistent development and modification of elevation-damage relationships corresponding to specific nonstructural flood loss reduction measures. The procedures described include the automatic generation of the damage functions for selected land use patterns by processing selected spatial gridded data variables, and the modification of these damage functions for specified nonstructural alternatives based on uniform structural protection criteria or a prescribed level of protection. These concepts were applied for the Trail Creek watershed located near Athens in northeast Georgia.

DAMAGE FUNCTION DEVELOPMENT

General Approach.--Methods of computing the flood damage potential of a stream reach requires the development of elevation-damage functions at selected damage reach index locations throughout the system. The elevation-damage functions are then integrated with hydrologic flow-frequency and flow-elevation data to compute the expected value of annual damages. Damage reaches are defined to allow capturing economic and hydrologic variation that occur in the reach. Elevation-damage relationships are developed for individual structures and the associated value of the contents. The structure functions are aggregated to an index location and adjusted to account for the slope of water surface profiles throughout the damage reach.

The technique developed for automatically generating elevation-damage functions adapts this traditional method to the grid cell data bank concept. The methodology consists of constructing a unique elevation-damage relationship for each grid cell within the flood plain (based on topographic ground elevation, land use, and composite damage function assigned to the grid cell) and aggregating all the grid cells assigned to a particular damage reach to the appropriate index location, using a reference flood as the mechanism for adjusting for a sloping water surface profile.

Damage Reaches.--Damage reach boundaries are selected based on the traditional procedure that includes determining reaches with consistent parallel water surface profiles for a range of discharges while maintaining the economic detail desired for analysis. The boundaries extend to a reasonable lateral distance from the stream to the flooded area of the largest flood event determined necessary for economic-damage evaluations, plus an arbitrary vertical distance (say 5 feet). Fig. 1 Damage Reach Delineation illustrates a typical damage reach delineation. The damage reaches are encoded and processed into the grid cell data bank with each cell within a reach assigned the reach identification value. The damage reach identification is used to aggregate grid cells to the appropriate damage reach index location.

Reference Flood.--Since flood profiles result in different water surface elevations throughout a damage reach, a reference flood is required to properly adjust the elevation for aggregation purposes of each cell within the reach with respect to the index location. Each cell is assigned a reference flood water surface elevation which is used with the reference flood elevation at the index location to adjust the composite damage function for proper aggregation of damages at the index location.

The reference flood should be an event within the range which is critical for flood damage computation, a mid-range flood (say 25 to 50 year) is a better choice than a rare flood such as a 500-year exceedance interval event. If the flow profiles are consistently parallel throughout the potential damage range, the selection of the reference flood is less critical. The reference flood elevations should be determined from detailed water surface profile analysis. If water surface profiles are not available, the slope of the flood profile through a damage reach may be assumed to correspond to the slope of the thalweg of the main stream or the slope of the adjacent flood plain itself. Fig. 2 Reference Flood Concepts illustrates the adjustments performed using the reference flood.

Composite Damage Functions.--The general objective of the analytical methods developed are to provide a consistent and expedient methodology of evaluating a range of nonstructural alternatives for existing and selected alternative future land use patterns. The concept of using generalized composite stage-damage relationships for the land use category assigned to each grid cell was selected as the mechanism to perform the analysis rather than the conventional individual structure approach. The use of these generalized functions provides the capability of expediently evaluating alternative land use patterns that are consistent with the existing (base) condition land use pattern.

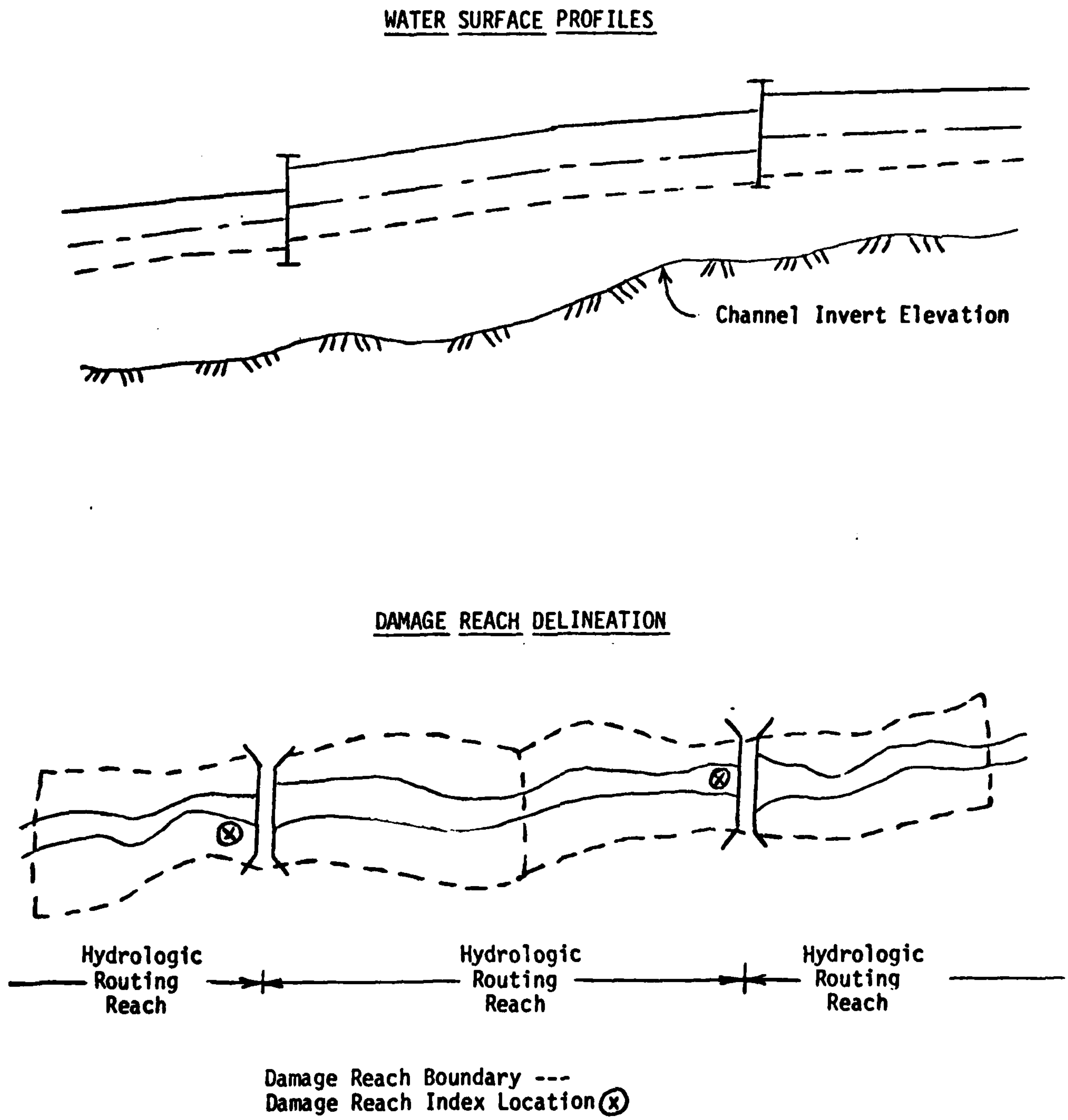
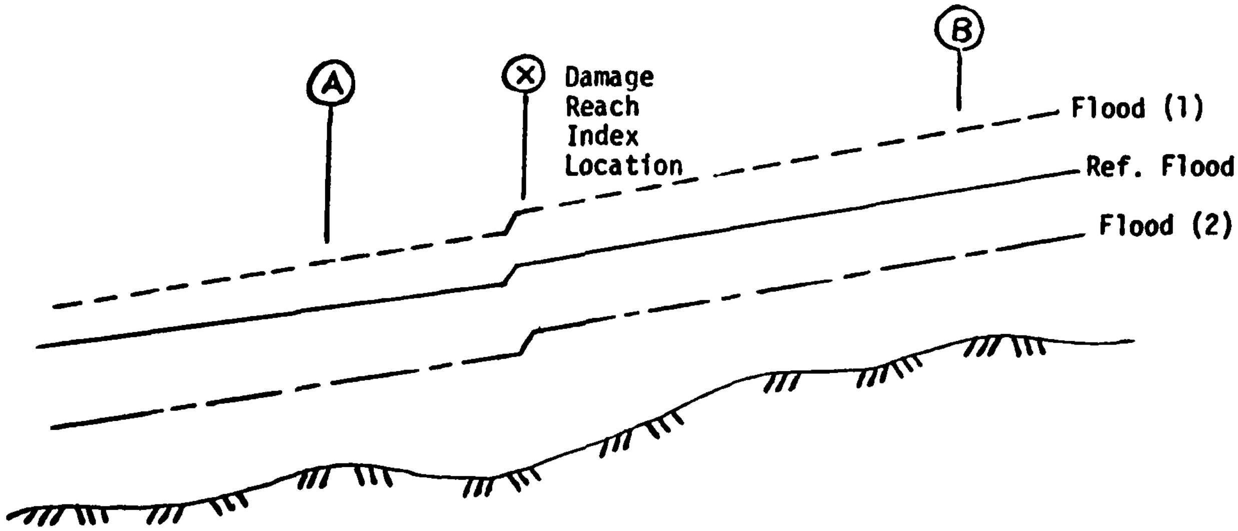
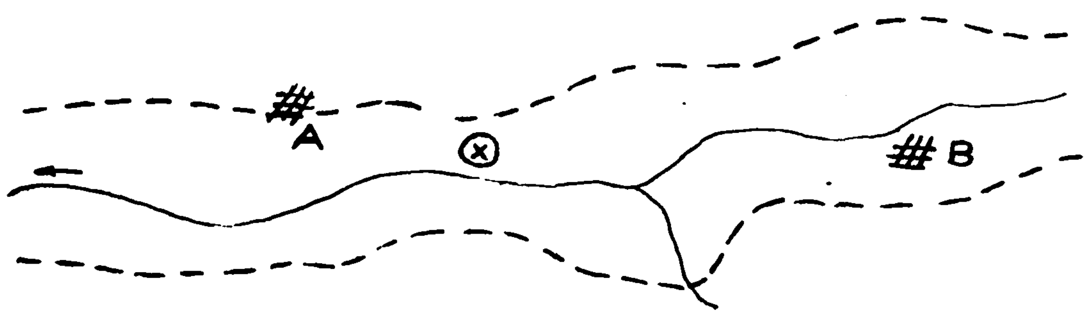


FIG. 1.--Damage Reach Delineation

WATER SURFACE PROFILES



REFERENCE FLOOD BOUNDARIES



Reference Flood Elevations

Index location = 614.5

A = 610.0

B = 617.0

Structure Locations

X Index Location

---- Boundary of Reference Flood

Damage Functions at A must be adjusted by adding 4.5 feet (614.5-610.0) before aggregating to the index location.

Damage Functions at B must be adjusted by subtracting 2.5 feet (614.5-617.0) before aggregating to the index location.

FIG. 2.--Reference Flood Concepts

A composite damage function is defined as a stage-damage function for a unit area for each land use category that has significant damage potential. These functions may be developed for each land use category by averaging the structural and related content values obtained from sampling a range of structure values and types within each land use category by use of field surveys, review of tax records and interviews conducted with regional and local agencies. The composite damage function may include direct and indirect damages that are associated with each particular land use category. Table 1 Composite Damage Function for Low Density Residential Land Use Category illustrates an example of a composite stage-damage function of a land use category. These functions can be developed for other land use categories such as pasture and developed open space although the corresponding damages would probably be small compared to those occurring in the structurally developed areas.

Aggregate Damage Function.--The flood damage associated with each grid cell is determined by matching the land use for each grid cell with the appropriate composite damage function (in effect placement of the function on the elevation assigned to the cell). The individual cell elevation-damage functions are then aggregated to the index location by use of the mechanism of the reference flood. A schematic of this procedure is shown in Fig. 3 Damage Function Development. The computer program that performs the aggregation may also be used in the development of the composite damage functions. To develop the composite stage-damage function for a specific land use category, the following types of information are used.

- *stage vs % damage for structure*
- stage vs % damage for contents
- value of structure
- values of contents (option, % of structure value)
- indirect damage (dollar amount or % structure and contents)
- development density (number of structure per grid cell)
- vacancy allowance (amount of land classified in the particular category that is developed)

The data is prepared by land use category and the program accesses the grid data file and computes elevation-damage relations for all pertinent land use categories and damage reaches. *Table 2 Aggregate Damage Functions* contains an example elevation-damage tabulation for selected land use categories of a typical damage reach index location.

Once the damage function is developed for the land use pattern of interest (base condition) the function can be adjusted to reflect each specified nonstructural measure (with condition) and corresponding performance criteria that are of interest in plan formulation. The capability to automatically adjust these functions is provided by the computer program that is used to develop the aggregated damage functions.

TABLE 1

COMPOSITE DAMAGE FUNCTION
FOR LOW DENSITY RESIDENTIAL
LAND USE CATEGORY (1)

DEPTH OF WATER	PER CENT DAMAGE STRUCTURE	PER CENT DAMAGE CONTENTS	AMOUNT OF DAMAGE PER GRID CELL IN THOUSAND DOLLARS
-2.00	1.00	0.00	.12
-1.00	1.00	0.00	.12
0.00	10.00	2.00	1.21
1.00	13.00	33.00	3.08
2.00	20.00	54.00	4.90
3.00	27.00	66.00	6.27
4.00	30.00	73.00	6.95
5.00	33.00	77.00	7.48
6.00	35.00	80.00	7.85
7.00	36.00	81.00	8.01
9.00	40.00	81.00	8.45
-0.00	41.00	81.00	8.57
10.00	41.00	81.00	8.57
11.00	45.00	81.00	9.01
12.00	45.00	81.00	9.01

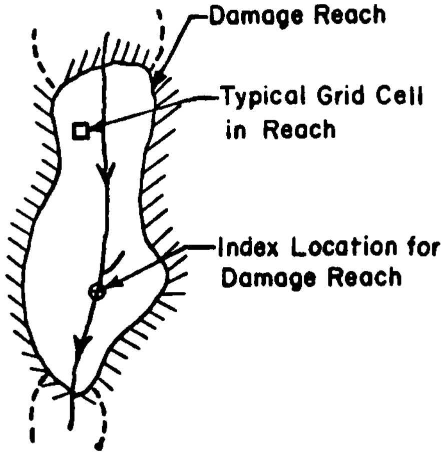
DENSITY OF THE LAND USE UNITS PER GRID CELL = 1.00

BASE VALUE OF THE STRUCTURE = 18500.00

BASE VALUE OF THE CONTENTS = 8250.00

VACANCY FACTOR (PER CENT DEVELOPED) = 60.00

INDIRECT DAMAGES = 5.00



DATA REQUIRED

- **5** — Grid representation of land use (exhaustive for study area).
- **321.6** — Grid representation of topography (elevations).
- **325.0** — Grid representation of reference flood (water surface elevation at reference flood) for each grid cell.
- **12A** — Grid representation of Damage Reach Boundary.
- **A** — Composite stage-damage functions for each significant land use.

INDEX LOCATION DAMAGE FUNCTION CONSTRUCTION

STEP 1, *Develop Elevation - damage Function at Each Cell*

a. Determine land use from grid file
b. Retrieve appropriate composite stage damage function
c. Determine grid elevation of cell from grid file
d. Tabulate elevation-damage for cell from above

STEP 2, Aggregate Cells to Index Location

a. Determine cell damage reach assignment
b. Determine index location reference flood elevation (X_1)
c. Determine cell reference flood elevation (X_2)
d. Adjust cell elevation-damage function by (X_2-X_1)
e. Aggregate cell adjusted elevation-damage function at index station
f. Repeat for all grid cells

FIG. 3.--Damage Function Development (1).

TABLE 2

AGGREGATE DAMAGE FUNCTIONS (1)
(1000's of Dollars)

Elev.	Exist. Land Use [1]				
	1	6	7	9	Total
640.0	0.0	0.0	0.0	0.0	0.0
645.0	0.5	0.1	0.0	0.0	0.6
650.0	1.2	0.4	0.0	0.0	1.6
651.0	1.4	0.4	0.0	0.1	1.9
652.0	1.5	0.4	0.0	0.1	1.9
653.0	1.6	0.4	0.0	0.1	2.1
654.0	1.9	0.4	0.0	0.1	2.4
655.0	2.4	0.4	0.0	0.1	2.9
656.0	2.8	0.4	1.2	0.2	4.6
657.0	3.1	0.4	1.2	0.2	4.9
658.0	3.2	0.4	20.4	0.2	24.2
659.0	3.4	0.4	86.1	0.2	90.1
660.0	3.7	0.4	175.9	0.3	180.3
661.0	4.0	0.4	267.5	0.3	272.2
662.0	4.2	0.4	325.1	0.4	330.1
663.0	4.4	0.4	372.2	0.4	377.4
664.0	4.5	0.5	410.6	0.4	416.0
665.0	4.6	0.5	442.8	0.5	448.3

[1] Land Use Categories Are:

1 = Natural vegetation
6 = Agricultural
7 = Industrial
9 = Pasture

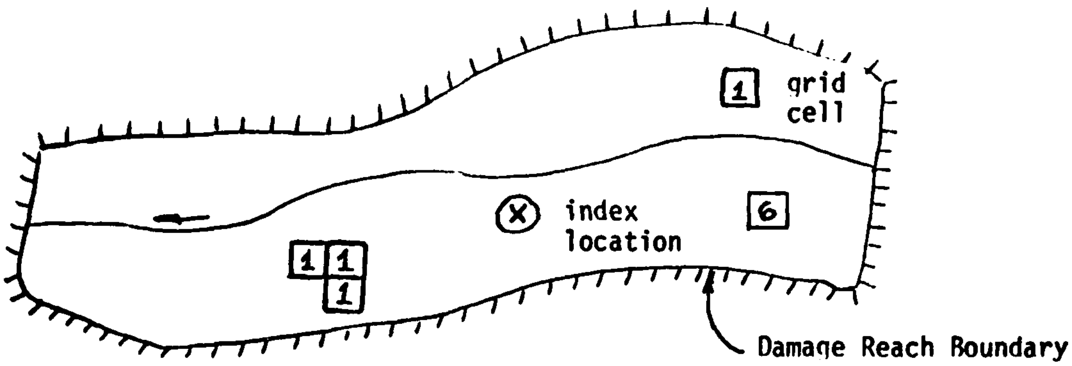
EVALUATION OF NONSTRUCTURAL MEASURES

General Approach.--The evaluation of the flood damage potential of a stream reach for existing (or base) conditions and with the assumed implementation of proposed flood loss reduction measures is an integral part of the plan formulation process. The general procedure used to perform these analyses is the computation of "expected" annual damages of the system for the with and without condition of each alternative to obtain the average annual benefits associated with each plan. The benefits are the "expected" annual damage for the base (without) condition less the "expected" annual damage associated with the alternative (with) condition. The hydrologic information of flow rating curves (discharge vs. elevation) and flow-frequency relationships are combined with the elevation-damage function to yield a damage-frequency curve for the condition analyzed. The damage-frequency function is then integrated to compute the "expected" annual damage of the condition or alternative evaluated.

The implementation of nonstructural flood loss reduction measures typically modify the elevation-damage function of the damage reach and have little effect on the hydrologic response of the system (2). The computer program used to construct elevation-damage functions at damage reach index locations for existing or alternative future land use patterns is also used in developing these functions for modified conditions. The types of nonstructural alternatives for which elevation-damage functions may be constructed by the automatic spatial analysis method are: 1) flood proofing specified land use categories a desired number of feet above or below the ground floor level, 2) flood proofing specified land use categories within a damage reach to a uniform flood protection level, 3) temporary protection of structures and evacuation of contents for damage reaches in response to a flood warning dissemination, 4) permanent relocation of structures from flood prone areas, and 5) regulatory policies restricting development in the flood plain. Each of these nonstructural alternatives are evaluated by modifying either the appropriate land use category composite stage-damage function and/or the elevation-damage function of the grid cells which are to be aggregated to a specified damage index location.

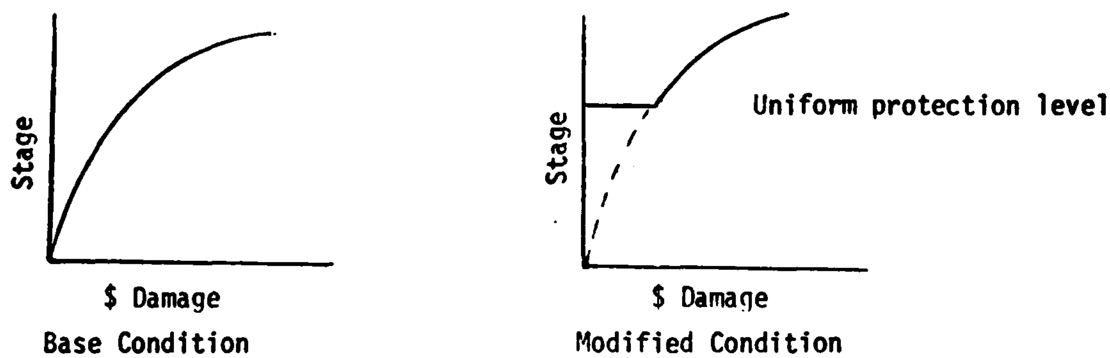
Flood Proofing Land Uses to a Specified Stage.--The flood proofing of selected land use categories to a specified stage results in all grid cells of the land use category being protected to a designated non-damage stage. The assessment of the potential flood damage reduction resulting from uniform flood proofing of specified land use categories is accomplished either by directly modifying the inputted composite stage-damage function or by automatically truncating the composite stage-damage function at the appropriate stage. Fig. 4 Flood Proofing Land Uses to a Specified Stage schematically illustrates and describes the method used to perform the analysis. The evaluation of existing and alternative future land use patterns for the without condition requires that the nonmodified composite damage function be used to construct the elevation-damage relationship for each cell. When the with condition is analyzed, all of the grid cells of land uses categories that are to be flood proofed use the modified composite damage function to construct the elevation-damage function. To illustrate the evaluation of flood proofing only future development, the grid cell in Fig. 4 that is classified as land use 6 is converted to land use 1. In the aggregation process, the base condition composite damage function would be used for the four original grid cells and the modified composite damage function would be used for the converted grid cell. It is possible in a single computer run to uniformly flood proof as many land use categories as desired and each land use category may have its own unique flood proofing level.

Flood Proofing to Selected Protection Levels.--Flood proofing specified land uses to a selected protection level within a damage reach requires the computation of the depth of flooding resulting from the protection level event for each grid cell and if a cell is flooded, it is flood proofed to that elevation. As an example, flood proofing a damage reach to a 50-year frequency protection level may require some grid cells of a



NOTE: Only selected grid cells are shown for clarity but in application the grid cells are exhausite for the entire damage reach.

COMPOSITE DAMAGE FUNCTIONS (Land Use Category 1)



GENERAL PROCEDURE

1. The composite damage functions of all grid cells assigned land use category 1 are truncated to the specified protection level. The process is repeated for other flood proofed land use categories using their modified composite damage functions.

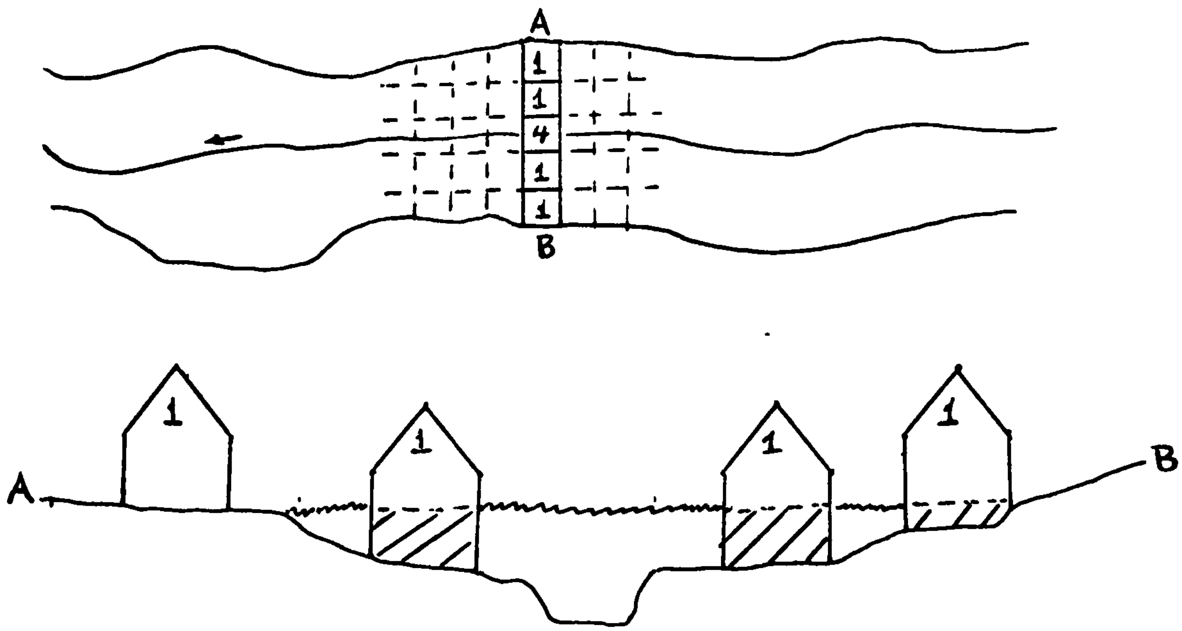
2. An elevation-damage curve is developed for each grid cell (composite damage function plus assigned topo elevation) in the damage reach.

3. The elevation-damage curves are adjusted by the reference flood elevation of the grid cell and index location and aggregated to the index location to generate the total elevation-damage relationship for the damage reach.

FIG. 4.--Flood Proofing Selected Land Use Categories to a Specified Stage

given land use to be protected 5.3 feet, while others may only need the basements flood proofed or no protection. The reason for the difference in flood proofing depths is because of varying ground topography as illustrated in Fig. 5, Example Cross Section.

The construction of the elevation-damage functions for this alternative can be performed only after flow and rating curve data are available for each index location of interest. From the rating curve the elevation of the water surface at the index location which corresponds to the desired protection level is determined and inputted into the computer program. The corresponding elevation of the protection event is then computed for each grid cell by use of the reference flood, since the water surface elevation at the cell changes consistently with the change in water surface elevation at the index location. The designated grid cells are correspondingly flood proofed to protect against the specified flood event.



Denotes Depth of Flood Proofing Required

1 Indicates Low Density Housing Land Use

4 Indicates Water Bodies Land Use

Fig. 5--Example Cross Section (From A to B)

These detailed computations are performed as follows: The reference flood elevation is substracted from the target protection elevation at the index location, and then this difference is added to the reference flood elevation of the grid cell. This elevation then represents the computed protection level water surface elevation. The amount of protection required by the cell is the protection level elevation less the topography elevation. If the grid cell requires flood protection, the program truncates the elevation-damage curve at the protection level elevation. This process is repeated for each grid cell assigned to the damage reach. Fig. 6 Grid Cell Damage Functions illustrates an example of a grid cell which has a reference flood elevation of 424.5 feet and a topographic elevation of 420.0 feet. The damage reach index location has a reference flood water surface elevation of 427.0 feet and the target protection level is 425.5 feet. The difference in water surface elevations at the index location is a minus 1.5 feet (425.5-427.0). This difference is added to the reference flood elevation of the grid cell to compute the corresponding target protection elevation (424.5-1.5 = 423.0 feet) for the cell. The resulting truncated elevation damage curve is then aggregated to the index location in the usual manner. The alternative of the flood proofing land use categories within a damage reach to various frequency flood events may be done for 1) existing conditions, 2) alternative land use conditions, and 3) alternative future land use conditions with only the future development flood proofed.

Response to Flood Warning Dissemination.--The temporary evacuation of facilities within a damage reach is a component of the implementation of a flood warning system in conjunction with the people reacting to the flood warning. This type of alternative is difficult to evaluate, not because of theory, but because it requires the estimation of the effect of the flood warning system on the stage-damage functions for each land use category as temporary protection measures are implemented. To evaluate this alternative, the inputted stage-damage functions are modified for each damageable land use category that will be affected. This modification in the stage-damage functions should include damage reduction to both the contents and the structure.

Since it is difficult to accurately estimate these damage reductions, several runs could be made for a range of percent damage reduction to calculate the break point necessary for this alternative to be cost effective, and then evaluate whether or not the level of damage reduction can be reasonably achieved. Because the evaluation of this alternative flood loss management measure is done by directly modifying the composite stage-damage functions of the affected land use categories prior to the aggregation of the damage potential of a grid cell to the appropriate index location, flood warning may be evaluated as an alternative by itself or as an alternative in combination with any of the other nonstructural alternatives.

Permanent Evacuation of a Flood Plain.--The evaluation of permanent evacuation of the flood plain requires that the spatial location of the flood plain be defined and all specified land uses be removed from that

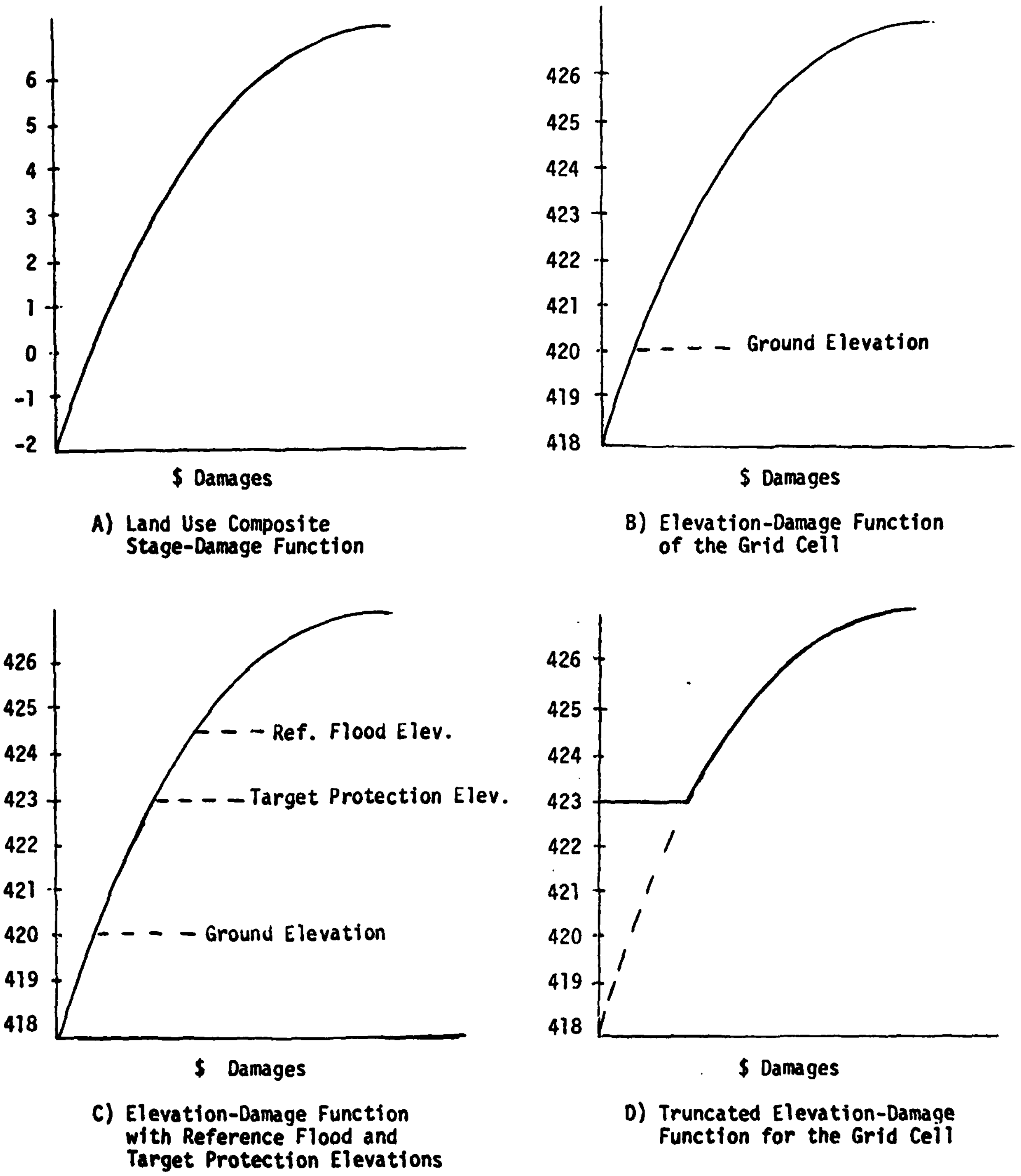


Fig. 6. Grid Cell Damage Functions

flood plain. The reference flood is used as the mechanism for defining the flood plain in the same manner as described in the computation of flood proofing each cell to a uniform protection level. The difference between the flood proofing to a target protection level and permanent evacuation of a flood plain is that instead of a truncated elevation damage function, a no-damage function will be aggregated to the index location.

Fig. 7 Multiple Flood Elevations shows part C of Fig. 6 from the previous section. If the flood plain elevation for the grid cell was 423.0 feet (Flood #1), the land use occupying the grid cell would have to be removed and a no-damage potential would be aggregated to the index location. An interesting point can be made by examining the situation for Flood #2 (water surface elevation of 419.0 feet). The grid cell would be considered outside the flood plain of interest, but if the flood plain event occured the grid cell would incur damages. Therefore, there is an option in the program to permanently evacuate either a specified flood plain or all of the grid cells which have damageable elevations inside the flood plain. If the latter evaluation is made for the grid cell shown in Fig. 7, the flood plain elevation would have to be lower than 418.0 feet in order for the land use to remain.

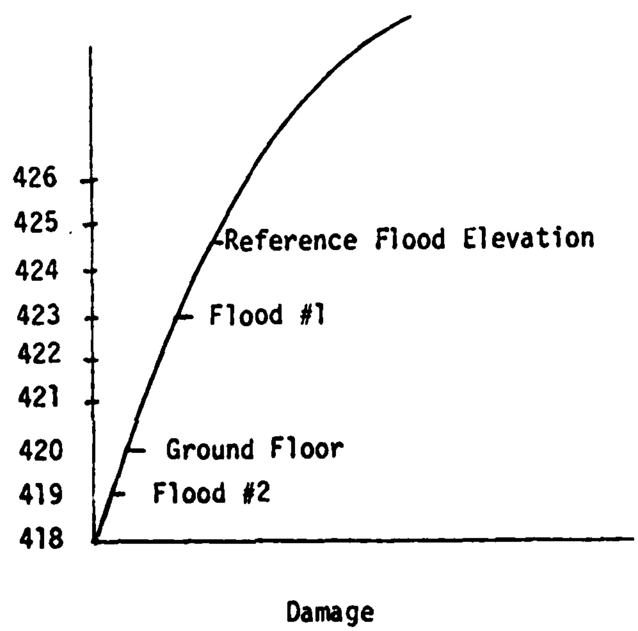
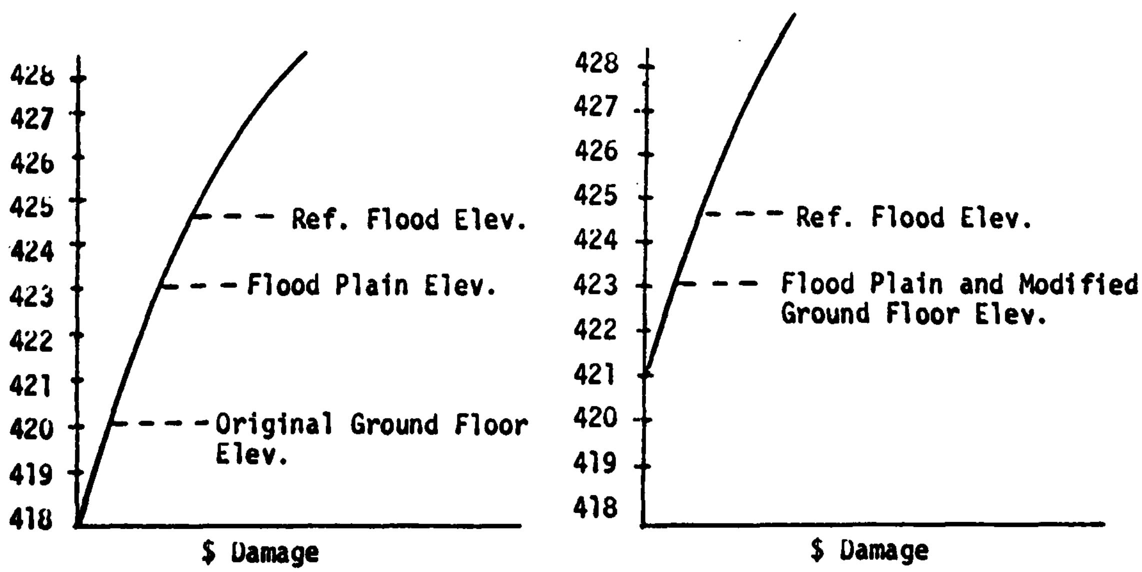


FIG. 7.--Multiple Flood Elevations

Flood Plain Regulation.--Flood plain regulation is the zoning of the flood plain to restrict encroachment by major damageable land uses, hopefully resulting in minimizing future damages. This usually means that if a damageable land use is placed within the flood plain, fill or some other means must be used to raise the ground floor elevation above the flood plain elevation. It is, therefore, desirable to evaluate the effect flood plain regulation has on potential flood damage reduction. The effectiveness of flood plain regulation in reducing potential damage is determined by constructing an aggregate elevation-damage curve for each index location for the future land use pattern, and then reconstructing the aggregate elevation-damage curves again, but with the regulatory policy in effect. These aggregate elevation-damage curves are then used as the basis to make the comparisons.

To subject a land use pattern to flood plain regulation, the analysis makes use of the reference flood to determine the flood plain of interest. The elevation of the regulatory flood at the index location is determined similar to that for flood proofing damage reaches to a uniform protection level. If the computed regulatory flood event water surface elevation is higher than the topography elevation of the grid cell, the elevation damage function for the grid cell is elevated so that the ground floor is the same as the event water surface elevation.

The corresponding change in the elevation damage function is shown in Fig. 8 Grid Cell Elevation-Damage Function Adjustment for Flood Plain Regulation, based on the grid cell example used in Fig. 6. For a regulatory elevation of 423.0 feet, the elevation-damage function must be raised 3 feet to reflect the placement of the ground floor above the regulated flood plain.



A) Elevation-Damage Function Before Flood Plain Regulation

B) Elevation-Damage Function After Flood Plain Regulation

Fig. 8. Grid Cell Elevation - Damage Function Adjustment for Flood Plain Regulation.

Even though a grid cell may have its ground floor moved above a flood plain, it could incur damages from that flood plain event. To accommodate this, the program has the capability to place either the ground floor elevation or the zero-damage elevation above the flood plain elevation. Table 3 Expected Annual Damages shows an example from the Trail Creek data in which a comparison of expected annual damages is made for a 1990 alternative future land use pattern with 1) no flood plain regulation, 2) flood plain regulation in which the new development is required to place the ground floor above the 100-year flood plain, and 3) flood plain regulation in which the new development is required to place the zero-damage elevation above the 100-year flood plain. Results such as those shown in the table may be very helpful in persuading land use planners to be aware of the consequences of taking an inactive role in the regulation of the flood plain.

The evaluation of flood plain regulation is not restricted to the 100-year flood plain, and it may be an alternative evaluated singularly or in combination with other flood proofing alternatives. An example of a combination of these alternatives might be to place the structures above the 75-year flood plain and uniformly flood proof to the 100-year flood frequency event.

TABLE 3

AVERAGE ANNUAL DAMAGES
(1000's of Dollars)

EVALUATION CONDITION	REACH 1	REACH 2	REACH 3
Existing Land Use	1.5	2.5	12.0
1990 Land Use Without policy	1033.3	350.0	32.7
1990 Land Use With policy of Ground Floor	19.3	63.8	23.8
199C Land Use With policy of Zero Damage	9.2	6.7	3.0

SUMMARY

Spatial analysis techniques make it possible to rapidly and consistently evaluate 1) the flood damage potential of existing and alternative future land use conditions and 2) the potential flood damage reduction resulting from various nonstructural measures. The nonstructural measures that may be evaluated individually or in combination by this technology are shown in Table 4 Evaluation of Nonstructural Alternatives by Spatial Analysis Methods.

TABLE 4

EVALUATION OF NONSTRUCTURAL ALTERNATIVES
BY SPATIAL ANALYSIS METHODS

Nonstructural Alternative	Land Use Pattern: Existing	Alternative Future	Altern. Future New Dev. Only
Do Nothing (Without Condition)	X	X	
Uniform Flood Proofing of a Land Use	X	X	X
Uniform Flood Protection of a Damage Reach	X	X	X
Temporary Evacuation	X	X	
*Permanent Evacuation	X	X	X
*Flood Plain Regulation			X

X indicates 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.

The technology described has potential to be helpful in the consistent and rapid evaluation of structural and nonstructural flood damage reduction alternatives for 1) existing land use pattern 2) alternative future land use patterns and 3) specific development proposals. This technology is in the development stage and will be undergoing further testing. The Corp of Engineers is currently making test applications of this technology in the Savannah, St. Louis, and Ft. Worth Districts, with other districts scheduled to make applications in the next fiscal year.

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REFERENCES

1. "Phase 1 Oconee Basin Pilot Study, Trail Creek Test," Hydrologic Engineering Center Corps of Engineers, September 1975.

2. Johnson, W. K., and Davis, D. W., "Analysis of Structural and Nonstructural Flood Control Measures Using Computer Program HEC-5C," Hydrologic Engineering Center Corps of Engineers, November 1975.

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