III

DATA BASES FOR WATERSHED MANAGEMENT

FLOOD DAMAGE ASSESSMENTS USING SPATIAL DATA MANAGEMENT TECHNIQUES

by Darryl W. Davis and R. Pat Webb

INTRODUCTION

Modern damage appraisals estimate existing damage potential and provide the bases for formulation and evaluation of possible management actions under alternative future development patterns and land-use management policies. Spatial data management techniques, in which land use, topographic details, and other natural resource information are catalogued into computerized data files, can help greatly in estimating and analyzing flood damage.

In most floodplains, several unique activities that may collectively involve one or more structures fall outside logically defined land-use or damage potential categories. They may be major industries, unique commercial properties, or religious and service facilities. Cataloguing and managing the damage potential of these structures individually seems appropriate to maintain credibility in the analysis.

The Corps of Engineers Hydrologic Engineering Center has developed techniques that combine the spatial data analysis approach and the individual structure approach, and work is near completion on an integrated analysis package. We will soon be able to write damage appraisals in a manner that encourages a land-use approach to flood prevention (especially by nonstructural measures) while it preserves the ability to analyze individual, unique structures if necessary.

FLOOD DAMAGE ASSESSMENT CONCEPTS

Flood damage assessments tell us the quantitative social cost of flooding. They also provide a sound basis for formulating, evaluating, and implementing remedial management actions. Assessments of potential

Mr. Davis is Chief, Planning Analysis Branch, of the Hydrologic Engineering Center, Davis, CA. Mr. Webb is Environmental Resources Planner, Planning Analysis Branch, HEC.

flood damage to *existing* floodplain development can point out problem areas and aid in the development of actuarial insurance premiums for government and private industry. Damage appraisals made after floods are used to allocate relief funds and other emergency assistance. Damage estimates made for *potential* land-use conditions can encourage local government agencies and private individuals to make wise decisions that consider the flood hazard consequences. Several types of analysis are required.

The two major types of damage appraisals usually performed are 1) "event" analysis (often referred to as *single event damage*), and 2) expected annual damage analysis (often referred to as *average annual damage*). The damage assessments for both types involve technical procedures to develop and make coordinated use of economic, hydrologic, and hydraulic data.

Single event analysis includes development of a damage potential function (elevation-damage curve) and hydrologic data collected during the flood. The amount of damage for the event is then calculated for the flood level reached. The computer can give information on both real and hypothetical floods.

The expected annual damage analysis requires the additional development of "exceedance frequency" information, which is used to weight probabilities. This could include direct application of a stage-exceedance frequency function describing the probabilities with which given flood stages are exceeded in any given year, or more commonly, the development of a flow-exceedance frequency function describing the probabilities with which given flow volumes are exceeded in any given year combined with an elevation flow curve. The flow-exceedance frequency function is commonly referred to as a frequency curve and the elevation flow curve is commonly referred to as a rating curve.

Figure 1, Damage Computation Concepts (Hydrologic Engineering Center, June 1977), summarizes the functional relations discussed above and their use in computing the expected annual damage. The final step in the appraisal, development of the damage-frequency relationship, is illustrated by cross-hatching. Here, the expected value is the probability-weighted value and is shown as the area under the curve. The result is identical to that achieved by computing the mathematical expectation of a cumulative distribution function. As would be expected, current analysis is often computerized so that the integration to compute the expected value is performed numerically.

DAMAGE FUNCTIONS USING SPATIAL DATA APPROACH

Overview

The spatial data management technique for generating elevation-damage functions adapts traditional methods to the grid cell data bank concept. One constructs a unique elevation-damage relationship for each grid

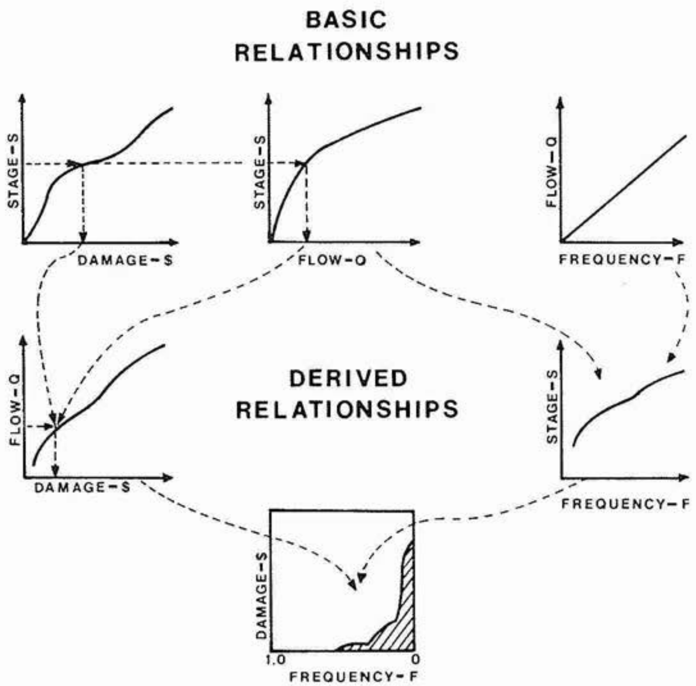


FIG. 1. DAMAGE COMPUTATION CONCEPTS. The basic functional evaluation relationships and the derived relationships are shown above.

Stage-Flow Relationship: This is a basic hydraulic function that expresses, for a specific location, the relationship between flow rate and stage. It is frequently referred to as a "rating curve." It is usually derived from water surface profile computations.

Stage-Damage Relationship: This is the economic counterpart to the stage-flow function; it represents, at a specific location, the damages that will occur in a river reach at various river stages. Usually the damage represents an aggregate of damage that occurs some distance upstream and downstream from the specified location. It is usually developed from field damage surveys.

Flow-Frequency Relationship: This defines the relationship between exceedance frequency and annual peak flow at a location. It is the basic function describing the probability of given stream flows and is commonly determined either from statistical analysis of gauged flow data or through watershed model calculations.

Damage-Frequency Relationship: This relationship is derived by combining the previously discussed basic relationships using the common parameters stage and flow. For example, the damage for a specific exceedance frequency is determined by ascertaining the corresponding flow rate from the flow-frequency function, the corresponding stage from the stage-flow function, and finally the corresponding damage from the stage-damage relationship. Any changes that occur in the stage-damage, stage-flow, or flow-frequency function because of watershed development or floodplain management measures will be reflected in the damage-frequency function. Therefore the magnitude of the expected annual damage is computed as the integral of (the area underneath) the function.

Other Functional Relationships: The flow-damage relationship is developed by combining the stage-damage with the stage-flow relationship using stage as the common parameter. The stage-frequency relationship is developed by combining the stage-flow with the flow-frequency relationship, using flow as the common parameter. The damage-frequency relationship could then be developed as a further combination of these derived relationships.

cell within the floodplain (based on topographic ground elevation, land use, and the composite damage function assigned to the cell) and groups all of the grid cells assigned to a particular damage reach at an appropriate index location. A reference flood is used to adjust for a sloping water surface profile (Hydrologic Engineering Center, 1975).

Grid cell data bank

A grid cell data bank is a stored computer file of spatial data (from maps) that can be used in a variety of analyses. *Guide Manual for the Creation of Grid Cell Data Banks* (Hydrologic Engineering Center, June 1978) contains detailed guidance on the creation of data banks. The stored data bank is the central feature of damage appraisals using spatial data management techniques.

Spatial data occur both as discrete forms that can be bounded by definite lines (e.g., land use, damage reaches, etc.) and as continuously changing data (e.g., topographic elevation). Discrete types of data may be classified into groups, while continuous data can be assigned a representative value for each specific grid cell (e.g., topographic elevation for each cell).

The location of each cell and the value ("legend") for each variable must be recorded. This is accomplished by cataloguing each grid cell with a specific location (row and column) as the first two values for a grid cell record. All data associated with a particular grid cell are then stored sequentially at the address specified for that grid cell. The stored data bank exists as a matrix of numbers identifying data values and location.

Part *a* of figure 2, Grid Cell Data Bank Concepts, illustrates how a single data variable may be visualized as a numerical matrix with the three dimensions of row, column, and data value for each grid cell. Figure 2*b* represents a portion of a grid cell data bank containing several data variables. Grid data stored to represent several variables are referred to as a multivariable file.

Damage reaches

Damage reach boundaries are determined by a traditional procedure that identifies areas having consistent parallel water surface profiles. These surface profiles are based on prior determination of the range of discharges that are significant to the calculation of expected annual damages. The damage reach boundaries are encoded and processed into the grid cell data bank. Each cell within a reach is assigned the reach identification value. The damage reach identification code is used to group grid cells at the appropriate damage reach index location.

Reference flood

Since flood profiles result in different water surface elevations

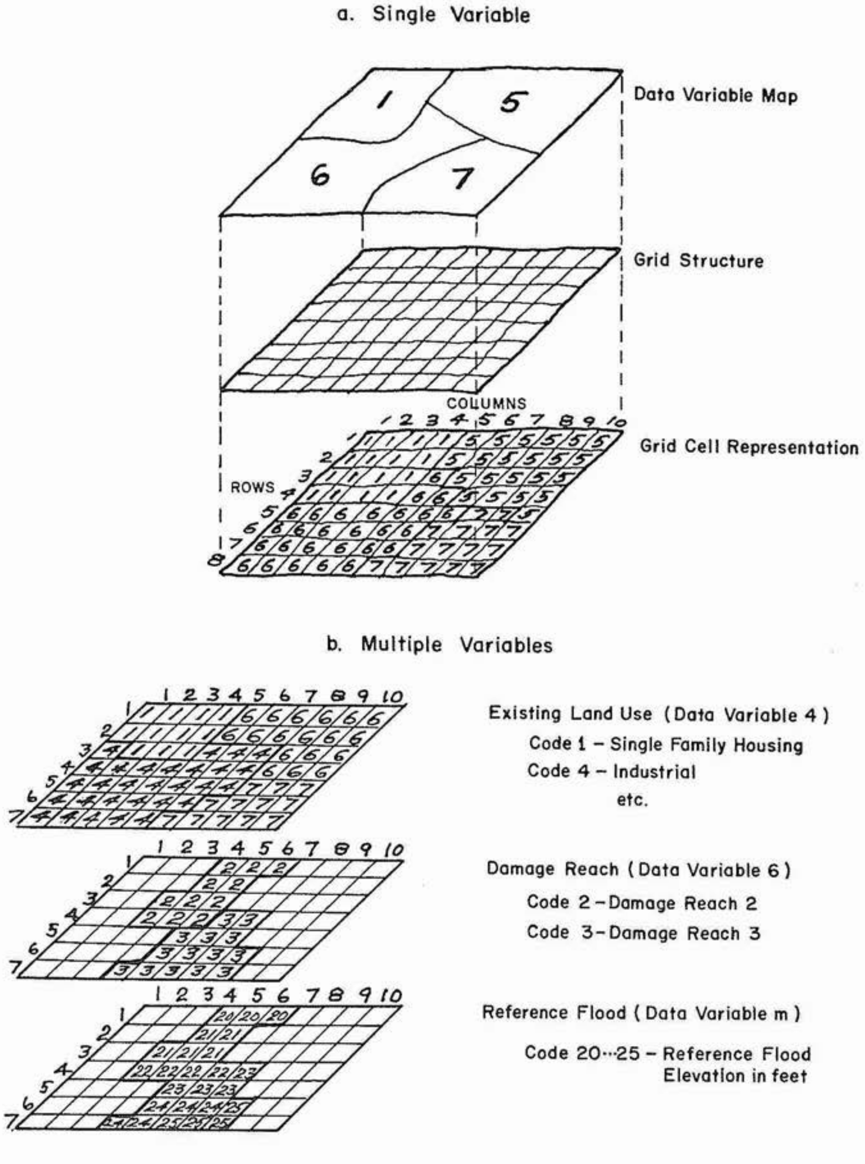


FIG. 2. GRID CELL DATA BANK CONCEPTS

throughout a damage reach, a *reference flood* is used to 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. A schematic drawing of this process is shown in figure 3, Damage Function Development (Hydrologic Engineering Center, 1975).

The reference flood placed in the data bank is a flood within the range that is critical for flood damage computation. Usually a mid-range flood is selected, one that can be expected every 25 or 50 years. In studies that will examine floodplain management policies, an accurate 100-year profile is commonly used as the reference flood. The reference flood elevations should be determined from detailed water surface profile analysis. If water surface profiles are not available, one can approximate them by using the slope of the thalweg (channel bottom) of the main stream or the slope of the adjacent floodplain itself.

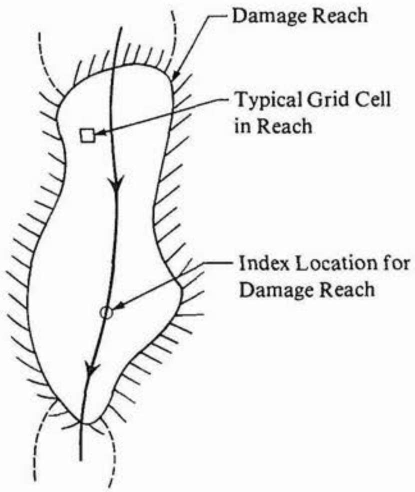
Composite damage function

A *composite damage function* is defined as a stage-damage curve for a unit area of a specific land-use category that is significantly liable to damage. The function may be developed by surveying a sample of structures within each land-use category and averaging their values, by the review of tax records and interviews conducted with regional and local agencies, or by other traditional field survey methods. The composite damage function may include direct and indirect damages associated with each particular land-use category.

Aggregate damage function

The susceptibility to flood damage of each grid cell is determined by matching the land use for each 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 grouped at the appropriate index location by comparison with the reference flood (see figure 3). The computer program DAMCAL, which performs the aggregation, may also be used to develop the composite damage functions. The following types of information are used in developing the composite stage-damage function for a specific land-use category:

1. Flood stage vs. percentage of damage to structure
2. Flood stage vs. percentage of damage to contents
3. Value of structure
4. Value of contents (can be expressed as a percentage of structure value)



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, Group Cells at Index Locations

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

5. Indirect damage (expressed as a dollar amount or as a percentage of structure and contents)
6. Development density (number of structures per grid cell)
7. Vacancy allowance (the proportion of land classified in the particular category that is in fact developed)

The data are prepared by land-use category, and DAMCAL computes elevation-damage relations for all pertinent land-use categories and damage reaches from information stored in the grid data file.

Once the composite damage function has been developed for the land-use pattern under study, it can easily be adjusted to reflect each proposed floodplain management alternative measure. The capability to adjust these functions automatically is provided by DAMCAL.

Land use

The care with which land-use categories are chosen and cells classified controls the accuracy of the results of a damage appraisal. Using a large number of categories (more than 20) can result in an apparent improvement in accuracy in regard to existing development, but it greatly complicates assessment of future possibilities (it is hard enough to forecast 3-5 categories, much less 20 or more). Overemphasizing present use can lead one away from the central concept of all floodplain management actions—preventing damage in the future. Clearly one must strike a balance between adequate description of variation within and among land-use types, and prudence in use of investigation resources. While much is yet to be learned, it appears that an upper practical bound in land-use categories for damage analysis is about 15-20.

Significant characteristics of spatial data management

1. A spatial data management approach to flood damage appraisal emphasizes land use in damage assessments.
2. It is technologically sensitive and responsive to policy analysis.
3. It is highly computerized and amenable to automated analysis.
4. It requires a high quality gridded data base to ensure the fidelity of the results.
5. It encourages a geographic approach to floodplain management.
6. It focuses on categories of land use instead of on specific (and perhaps unique and important) structures.

UNIQUE STRUCTURE INVENTORY

The land-use focus, while significantly advancing toward floodplain management ideals in most respects, can result in loss of important detail and thus of credibility when one attempts to make definitive estimates for existing floodplain development, within which there may exist certain unique structures. Some examples are industrial complexes, special commercial enterprises, churches, and historic buildings.

To offset the shortcomings of spatial data management appraisals, a specific structure inventory computer program (STRUCTURE INVENTORY) was developed with the following features:

1. It inventories special structures.
2. It is adaptable as a complete or partial alternative (or supplement) to the spatial approach.
3. It stores and manipulates information on damage potential and value for unique structures.
4. It is compatible with spatial data files so that aggregation, policy analysis, and data file integration can be performed.

The basic concept of automating a structure inventory is not new. However, the careful construction of the data handling features, so that STRUCTURE INVENTORY files are compatible with spatial gridded data files and sensitive to policy analysis, is unique. In effect, the basic groundwork was laid for integrated analysis using spatial and unique structure data.

INTEGRATED SPATIAL AND INVENTORY APPROACH

Integrated analysis gives us an extremely powerful data management technique with the advantage of both the gridded spatial technique and a structure inventory. The objectives of the integrated approach were defined as:

1. Integrating data management and processing to exploit the respective strengths of each approach.
2. Coordinating data needs between approaches so that efficient field work could serve both.
3. Preparing computer codes so that input and output products are compatible between programs.
4. Preserving, and when possible enhancing, the policy flexibility and sensitivity of the respective analyses.

We wished to preserve the independence of the spatial and inventory processing programs so that they could be used independently when appropriate. A utility program is being developed at the HEC to make the two programs and the data base compatible. This program will scan the data file of inventoried structures to identify the coordinates of cells containing specially catalogued structures, flag those cells in the grid data bank so that processing by the spatial program DAMCAL can be adjusted to prevent double counting, and retrieve from the grid file whatever data are missing in the structure file, such as reference flood or ground elevation. The program will then merge the results into a single aggregate file for subsequent analysis by other computer programs such as HEC-1, or by human beings.

PROGRAM STATUS AND AVAILABILITY

DAMCAL—Spatial processing program for damage functions

DAMCAL was originally developed for the first Corps of Engineers pilot Expanded Scope Flood Plain Study in 1975, and it has undergone steady refinement and improvement since then. It has been applied in several studies on a routine basis. Final documentation and computer code cleanup are nearing completion.

STRUCTURE INVENTORY

This program was developed in late 1977 for the Rowlett Creek study reported on in this volume by Lovell and Smith. The program was successfully tested on a portion of the Rowlett Creek study area; additional testing and application are anticipated in the coming months. We expect that the program will be released to the public in 1979. Informal copies of computer code and user documentation may be obtained from the Hydrologic Engineering Center.

Integrated spatial and inventory analysis

Modifications to the basic spatial and inventory programs have been initiated. The utility program that will allow the programs to be used together is being developed. We expect the integrated package to be available for public release in 1979.

REFERENCES CITED

THE HYDROLOGIC ENGINEERING CENTER, September 1975. Phase I Oconee Basin Pilot Study, Trail Creek Test.

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