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Application of Spatial-Data Management Techniques in Corps Planning

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14. ABSTRACT Spatial-data management techniques allow convenient, cost-effective representation of the spatially-varying data that are necessary for effective water and related-land resources planning. Application of the techniques began in the U.S. Army Corps of Engineers (USACE) in the early 1970's as an experiment. Since then, the techniques have been used for regional planning studies, major flood-control studies, and limited-scope investigations. The HEC-SAM software, developed and supported by the staff of the Hydrologic Engineering Center (HEC), has made practical these applications.					
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US Army Corps of Engineers
Institute for Water Resources
Hydrologic Engineering Center
609 Second Street
Davis, CA 95616

(530) 756-1104
(530) 756-8250 FAX
www.hec.usace.army.mil

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APPLICATION OF SPATIAL-DATA MANAGEMENT TECHNIQUES IN CORPS PLANNING

Darryl W. Davis and David T. Ford

SUMMARY

Spatial-data management techniques allow convenient, cost-effective representation of the spatially-varying data that are necessary for effective water and related-land resources planning. Application of the techniques began in the U.S. Army Corps of Engineers (USACE) in the early 1970's as an experiment. Since then, the techniques have been used for regional planning studies, major flood-control studies, and limited-scope investigations. The HEC-SAM software, developed and supported by the staff of the Hydrologic Engineering Center (HEC), has made practical these applications.

SPATIAL-DATA MANAGEMENT CONCEPTS

To meet the broad objectives of civil-works planning, complex quantitative and qualitative analyses must be performed. The analyses include hydraulic and hydrologic studies, economic evaluations, engineering analyses, social-suitability evaluations, ecological-impact analyses, and community-well-being assessments. Much of the data required for these analyses are geographically oriented. The goal of a spatial-data management system (also known as a geographic information system) is to represent continuous geographically-oriented data in a discretized form, so the data may be stored in numerical form, retrieved, and manipulated for analysis.

Data Representation and Storage. - Geographically-oriented data may be represented by subdividing the area of interest and encoding and storing data descriptive of each subdivision. Three alternative schemes for accomplishing this are in widespread use:

- (a) schemes that represent data with irregularly-shaped areas (polygons),
- (b) schemes that represent spatial data with triangles, and
- (c) schemes that represent data with a uniform grid of rectangles.

The polygon representation, illustrated by Fig. 1, is the most flexible data representation technique. The boundary of an area of uniform data is represented as a polygon. Each polygon is described by the coordinates of its vertices, and the appropriate geographically-oriented data are associated with the polygon in the data base. Numerical values of quantifiable data are stored, and codes or indices for non-quantifiable data are stored. The

shape and size of the polygon are unrestricted, so any feature may be represented at any desired level of detail. If data management is computerized, the storage and processing requirements of the polygonal scheme are greatest of the alternative schemes.

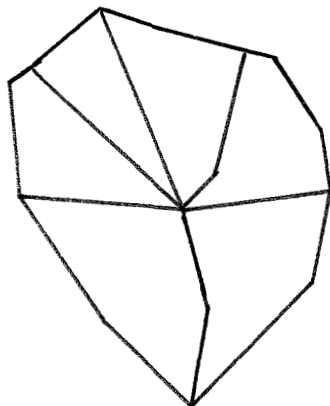


FIG. 1. - Polygonal Representation

Triangular elements, illustrated in Fig. 2, provide a convenient method for storing terrain-related data. With a triangular representation, the catchment boundaries and boundaries of areas of uniform spatially-oriented data are represented by a set of irregular triangles. These triangles are chosen to capture critical features, including topography, soil type, and political boundaries. As with the polygonal representation, the coordinates of the vertices are stored, and data are associated with the triangle with a data base indexing scheme. The triangular representation is extremely flexible, and the computer storage and processing requirements are less than those of the polygonal representation.

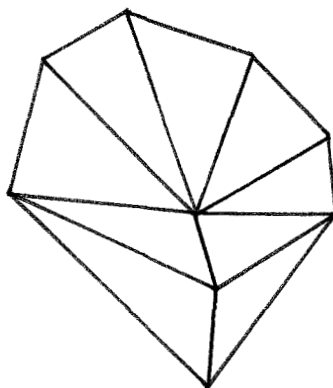


FIG. 2. - Triangular Representation

The rectangular grid-cell technique superimposes a uniform grid on the study area, as illustrated by Fig. 3. The spatially-oriented data are associated with the appropriate grid cell. Topography is represented by assigning an average elevation or the centroid elevation to each grid cell, and other data are represented as with polygonal and triangular systems. Resolution is limited by cell size, which in turn, dictates the computer resource requirements. For a preliminary planning study, for example, a grid-cell system such as that illustrated by Fig. 3 might be used. This system includes only 36 cells, so it could be managed either without computerization or with a small computer. If higher resolution is required, if the number of variables to be stored for each cell is greater, or if the total number of cells is greater, data management can be accomplished more efficiently with computerized schemes.

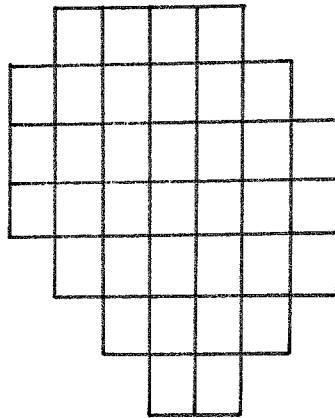


FIG. 3. - Grid-cell Representation

HISTORY OF SPATIAL-DATA MANAGEMENT IN USACE

The Corps of Engineers began exploring the application of spatial-data management techniques to planning studies in the late 1960's, with award of a contract to Harvard University for a comparative study of resource analysis methods. The Harvard Department of Landscape Architecture, a pioneer in the development of methods of geographic data management, published its findings in a research report in 1969 (5). The investigation concluded that GIS technology had advanced to a practical state and that the Corps should use the technology. The Corps subsequently requested the group to develop a strategy for using the technology for planning reservoir recreation facilities. Another research report (4) documented a strategy and illustrated its use in analysis of Honey Hill, a small reservoir in the New England area. Subsequently, the Institute for Water Resources (IWR) co-sponsored with the Los Angeles District a field trial of the proposed grid-based spatial-data

management methods. Los Angeles District personnel attempted to implement the method for a comprehensive planning study of the Santa Ana River basin, California. Several complications caused the trial to be less than a complete success (6).

The IWR staff recognized that a major shortcoming of the Santa Ana River study was the lack of access by field staff to readily-available Corps expertise in the spatial data management technology. To overcome this lack of in-house expertise, the HEC was invited to assume the responsibility for implementation of GIS techniques in Corps studies. The HEC staff had experience in the development and management of computerized technology and in providing field assistance, so it could support applications of GIS. HEC staff investigated the methodology and concluded that spatial-data management techniques had great potential for useful application in hydrologic engineering and water resources planning.

During the initial investigation of the utility of spatial data management techniques, HEC staff was assisting the St. Louis District in formulation and evaluating flood-damage reduction alternatives for Harding Ditch, an authorized interior flood-control project. A mutual interest in applying spatial data management methods for detention-storage location resulted in development of a computerized attractiveness-analysis capability, patterned after the procedures developed at Harvard (4). A data bank with five-acre cells was created, and attractiveness analysis was performed. The capability subsequently was expanded into the comprehensive Resource Information and Analysis (RIA) program (14).

The idea of using the grid-cell data base to perform additional quantitative computations for hydrologic and economic analysis emerged during the St. Louis study. The rectangular, five-acre grid developed for the study was satisfactory for the attractiveness analysis and for hydrologic computations but was unsatisfactory for the detailed topographic representation required for accurate damage calculations. Consequently, a second data bank was created with 1.5-acre cells. A shift of priorities and personnel within the St. Louis District halted progress on the study, so another demonstration project was sought.

In 1975, the Savannah District was studying the upper Oconee River catchment with a goal of providing long-term advice and analytical assistance to local communities for decision-making related to flood-plain development. The assistance was to be comprehensive, continuous, and available to the local agency upon request. HEC was asked to provide advice on the technological aspects of the study, and ultimately recommended use of a GIS. A rectangular-grid system was selected as the spatial data management technique because it offered significant analytical opportunities when compared to other approaches. Subsequent flood-plain studies, known as expanded flood-plain information or

XFPI studies, also employed this technology. The integrated spatial data management and spatial data analysis programs became known as HEC-SAM. The results of the basic research and development efforts are presented in Ref. 13.

The scope of the HEC-SAM and other systems developed independently (19) continued to grow, and the staff of the Office of the Chief of Engineers (OCE) took an interest and sponsored additional pilot studies. The XFPI pilot studies for which HEC-SAM was developed were completed in 1980. Subsequent applications to other Corps studies have been made; Table 1 is a partial list of applications. Detailed information is available in Refs. 2, 20, and 21.

HEC-SAM

The HEC spatial-data management system, HEC-SAM, is an integrated set of general-purpose spatial-data management and spatial-data analysis computer programs applicable to water resources planning and management problems. Programs of HEC-SAM provide the capability to:

1. Estimate runoff from a catchment with existing or modified conditions. These modified conditions may include land-use changes, drainage-system alterations, flood-plain occupancy encroachments, or flood-damage mitigation plan implementation.
2. Estimate damage due to a specific event or estimate expected annual damage for existing or modified conditions. The modifications may include flood-plain occupancy changes, land use and stream conveyance alterations, construction and development regulation, and flood-damage mitigation plan implementation.
3. Evaluate the environmental impacts of proposed or forecasted changes by portraying changes in habitat cover, by estimating land-surface erosion, and by forecasting changes to runoff quantity and quality.

Fig. 4 is a flow diagram of the data management, analysis, and reporting components of HEC-SAM. The solid lines indicate data transfers. For the applications programs, these transfers are accomplished with an HEC-developed general-purpose data storage system, HEC-DSS (12).

The HEC-SAM has three components: a data-management component, an interface component, and the analysis component. The data-management component comprises computer programs required to convert raw map and other data to the grid-cell format of the data bank. The interface component includes computer programs that compile and reformat grid data retrieved from the data bank as required for the analysis computer programs. The analysis component includes generalized computer

programs that perform detailed technical assessments using the linked files. These computer programs are standard Corps

TABLE 1. - Applications in Planning Studies by Corps
District and Division Offices

Miscellaneous Early Studies

San Francisco/San Pablo Bays, San Francisco
Upper Russian River, San Francisco
Lake Erie Study, Buffalo
Santa Ana River Basin, Los Angeles
Ocean City, Baltimore
Upper Roanoke/Dan Basin, Wilmington

Expanded Flood-plain Information Studies

Oconee Basin, Savannah
Rowlett Creek, Ft. Worth
Boggy Creek, Jacksonville
Pennypack Creek, Philadelphia
Crow Creek, Rock Island
Wolf River, Memphis
Sonoma Creek, San Francisco
Sewickley Creek, Pittsburg
Walnut-Williamson Creeks, Ft. Worth
Willow Creek, Alaska
Local Harbor Project, New York
Tensas Basin, Mobile

Other Recent Studies

Passaic Basin, New York
Salt River (Phoenix), Los Angeles
Harding/Cahokia, St. Louis
Mississippi Sound, Mobile
Delaware Estuary, Philadelphia
Lower Mississippi River, LMVD
Tennessee-Tombigbee Corridor Study, Mobile
Trinity River, Ft. Worth

Survey / Phase I Pilot Studies

Kissimmee Basin, Jacksonville
Cooper Creek, Ft. Worth
Conley Creek, Savannah
Upper Clinton River, Detroit
Saginaw Basin, Detroit

HEC - SAM

SPATIAL DATA MANAGEMENT

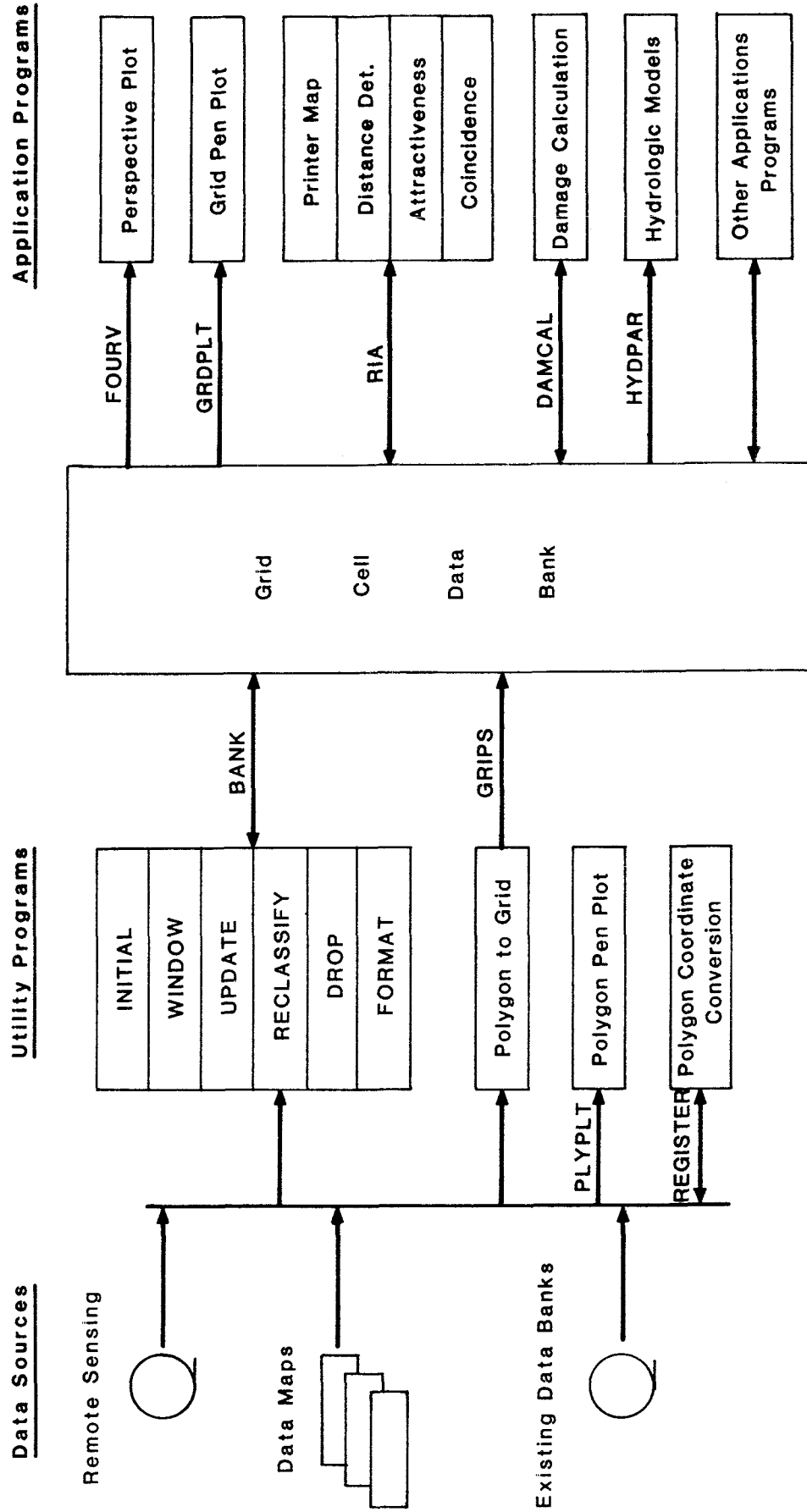


FIG. 4. - HEC-SAM Data Management, Interface, and Analysis Components

analysis tools, with modifications to accept input from the data bank as an alternative to the usual input. In some cases, the analysis programs are modified to take advantage of access to a comprehensive data bank. Thus the use of a GIS by HEC and users of HEC-SAM may be substantially different from the use made by geographers and other landscape analysts. The product sought is the result of quantitative analysis. The contents of the data bank typically are used to calculate parameters for detailed hydrologic and water quality simulation models, to compute damage accurately, and to provide the more traditional graphical and statistical summaries of data included in the data bank.

EXAMPLE APPLICATION: PASSAIC BASIN FLOOD CONTROL

Study Background - The Passaic Basin study was a seven-year, fifteen million dollar investigation by the staff of the New York District, USACE, to identify potential solutions to flooding problems in an area adjacent to the New York City metropolitan area. The Passaic River catchment includes 489 sq mi of wooded, mountainous, sparsely-populated highland area, a broad, flat central basin of 253 sq mi comprised largely of freshwater swamps and urbanizing flat meadows, and a lower basin of 193 sq mi characterized by a narrow flood plain and steep tributaries. This highly-urbanized catchment includes the industrial centers of Patterson, Passaic, and a portion of Newark. About 1.8 million people reside in the catchment.

Major items addressed in the investigation include:

- (1) the impact of future development in the basin and consequent increased runoff,
- (2) the role of and potential need to protect natural storage areas in the central basin, and
- (3) the full range of social, environmental, and economic problems related to water resources of the area.

The alternatives considered were a full array of nonstructural solutions and structural measures, including a massive tunnel diversion.

Basic Approach - To enable study of a wide array of alternatives and to make efficient use of limited study manpower, computerized data management and analysis was used whenever possible. District staff determined which computer models would be used and defined the data needs. Data collection, model calibration, and limited analyses were performed by private contractors. Final analysis and reporting was accomplished by District staff.

The analysis for which computer modeling is required was

- (1) rainfall-runoff modeling (to analyze changes in storm

runoff and alternatives of storing and diverting streamflow),

(2) stream-profile modeling (to develop the relationship between flow and stage and to analyze levee, channel, and floodwall alternatives),

(3) hydrodynamic modeling (to understand better and thus to model in a simple way, flow patterns and stage relationships in the central basin),

(4) flood-damage modeling (to focus on potential damage areas, to evaluate damage reduction benefits for alternatives, and to formulate and evaluate nonstructural measures).

Seven major computer programs and five smaller utility programs were required for this analysis. Three data files were prepared and managed as part of the overall study. Fig. 5 is a general schematic of the major analysis programs, data files, and data flow paths between the programs.

Data Management. - Automated data management proved to be the key element in effective use of the analytical tools. Once the spatial data files were established with appropriate linkages of programs through the use of the HEC-DSS, complex and comprehensive assessments are possible.

The spatial data file was created by a commercial contractor. The cell size is about ten acres, and the coverage of the 900 sq mi is complete. The following data are included in the data bank:

- (1) study boundary,
- (2) hydrologic subbasins,
- (3) soil series,
- (4) land use (existing and several forecasted),
- (5) damage reach boundaries,
- (6) topography,
- (7) reference flood and topographic elevations,
- (8) political subdivisions,
- (9) other demographic characteristics.

These data, separately or combined, may be retrieved and tabulated, displayed graphically, or directly used in computations. The file serves as the data base for analytical computations.

The data storage system, HEC-DSS, is the link between analysis programs. With this system, the analyses can be accomplished independently, and the results can be stored. The results subsequently can be retrieved for further analysis. Thus, several technical studies can be performed simultaneously, with the HEC-DSS file serving as the "memory".

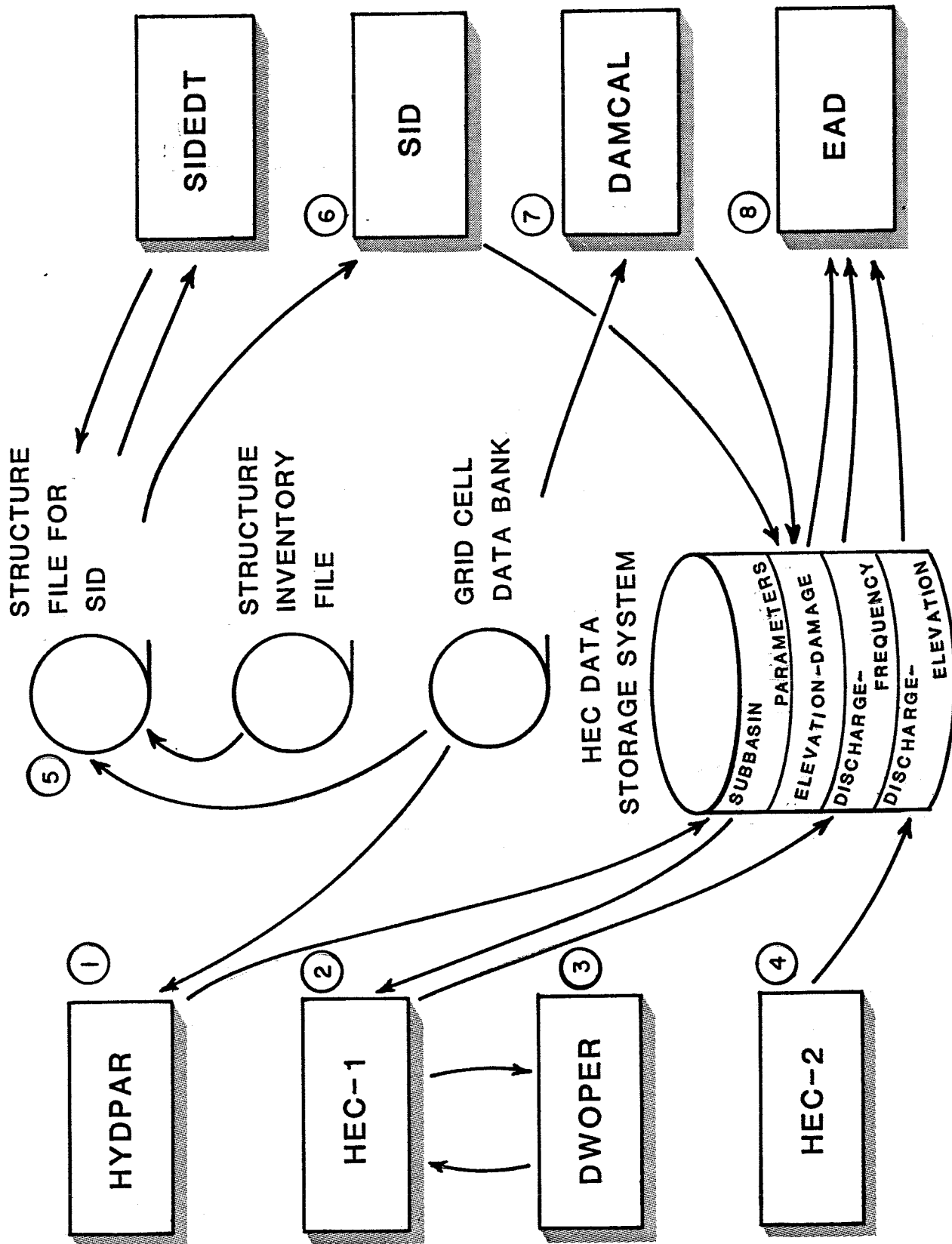


FIG. 5. - Passaic River Study Planning Model Use

Catchment Runoff Analysis. - The HEC-1 computer program is the catchment runoff analysis tool (9). The HEC-1 program provides the capability to develop flow-frequency relationships for existing and future conditions with and without alternative proposed damage-mitigation measures. Geographic and watershed subdivision data are retrieved automatically from the spatial data file with computer program HYDPAR (10). The calibrated HEC-1 / HYDPAR model, linked to the spatial data file by HEC-DSS, permits estimation of runoff changes and flow-frequency changes due to changes in land use, system storage, diversions, and on-site water management.

Stream Hydraulic Modeling. - The HEC-2 computer program is the basic river hydraulic analysis tool (17). The program computes water surface profiles for specified stream geometry and flow conditions, thus developing elevation-flow relationships for flood-damage computation. The calibrated program, linked to the family of analysis programs by HEC-DSS, is used for evaluation of alternatives that alter stream conveyance and geometry.

To model adequately the flow patterns and storage effects of the large, swampy, central basin area, the Dynamic Wave Operational Model (DWOPER) program (3) is calibrated using data describing the geometry and topography of the central basin. This model is used then to predict flood stages and outflows for specific flood events and channelization alternatives. Results of these studies are used to develop a scheme for using HEC-1 in an improved simulation mode.

Flood Damage Computations. - Approximately 60,000 structures in the catchment are subject to flooding, so special efforts were required to inventory systematically, to catalogue, and ultimately to analyze the flood-damage potential of these structures. To accomplish this, a data base was developed that data descriptive of each of the 60,000 structures. A spatial data file was created separately that included damage reach, reference flood, and other data needed to permit estimation of structure flood damage. Each structure was located with geographic coordinates, and the elevation was determined from detailed maps. Data for the structure is then retrieved from both data files, integrated, and formatted to conform to the requirements of computer program SID (16). A special purpose editor, SIDEDT (15), enables systematic manipulation of the file for later update, calibration, and evaluation of alternatives. Elevation-damage functions developed with SID for specific alternatives are stored with HEC-DSS for subsequent processing.

The DAMCAL program (7) is the grid-cell equivalent of the SID program and is used to assess damage within a cell, rather than damage to an individual structure. DAMCAL is executed using the forecasted future land-use data from the spatial-data bank to compute an approximate indicator of damage due to future development (2).

The EAD program (8) accepts hydrologic, hydraulic, and flood damage relationships, forms damage-frequency functions, and computes the expected value of annual damage (and planning horizon annual equivalent) for all situations and alternatives of interest. Data is retrieved automatically from the HEC-DSS file for EAD program access.

The system of calibrated, linked programs is used to perform expeditious single-flood event damage analysis, annual damage computation, and detailed benefit analysis in late planning stages for a wide range of structural and nonstructural measures.

SUMMARY

Spatial-data management technology has evolved to the point that practical applications are made at the USACE field-office level. The HEC-SAM software permits representation of geographically-varying data with a grid-cell data bank. Spatial-data management and spatial-data analysis tools provide the capability to perform the complex analyses required for civil works planning.

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