

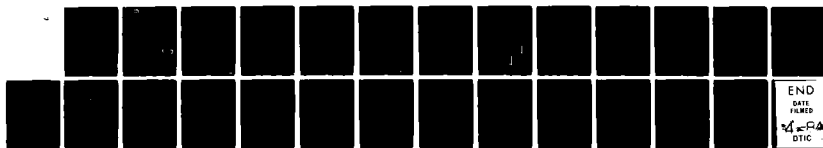
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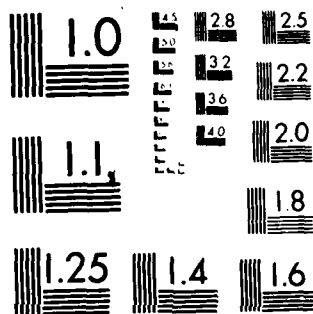
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Hydrologic Engineering Center

Planning Models

by

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Hydrologic Engineering Center Planning Models¹

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ABSTRACT

The U.S. Army Corps of Engineers has broad, nationwide water resources planning and management responsibilities. In response to the needs of Corps planners, the Hydrologic Engineering Center (HEC) has developed and supports a family of computer programs designed to aide them in their work. These programs include catchment, channel, alluvial, and statistical process models, system operation models, plan evaluation models, and data management programs. These models individually and collectively have been used throughout the Corps in a wide range of water resources planning studies.

CORPS OF ENGINEERS PLANNING RESPONSIBILITIES

Overview. - The US Army Corps of Engineers has broad-in-scope, nationwide water resources planning and management responsibilities. These responsibilities are carried out in regionally-dispersed field offices by professionals working under the "Civil Works" arm of the Corps. The Corps water resources planning responsibilities are the result of accumulated congressional acts, court decisions, administrative directives, and interagency agreements. Likewise, the planning process that has evolved to meet these responsibilities is the result of decades of experience in performing a wide range of studies in an open public environment. The public mandate to Corps planning is to consider the broad range of water resources management issues and to develop plans that provide for balanced management of the Nation's water resources: comprehensive multi-objective planning is the charge. Policies governing Corps planning responsibilities and the multi-objective planning process are summarized in the Water Resources Policy Digest (32).

Planning Responsibilities. - The planning responsibilities of the Corps fall into two categories, based on project purposes. In the first are project purposes for which the U.S. Congress has directed the Corps to assume a national leadership role, including navigation (inland waterways and ports), hurricane protection and beach-erosion control, and flood-damage reduction. One of these major functions must be addressed in a proposed plan before the Corps may request congressional authorization for construction. The Corps is, however, charged with considering the full range of multipurpose opportunities in all planning studies, whether or not the Corps has authority to recommend construction. Thus in the second category of planning responsibilities, the Corps considers potential for development of hydroelectric power, water supply, and recreation facilities, for

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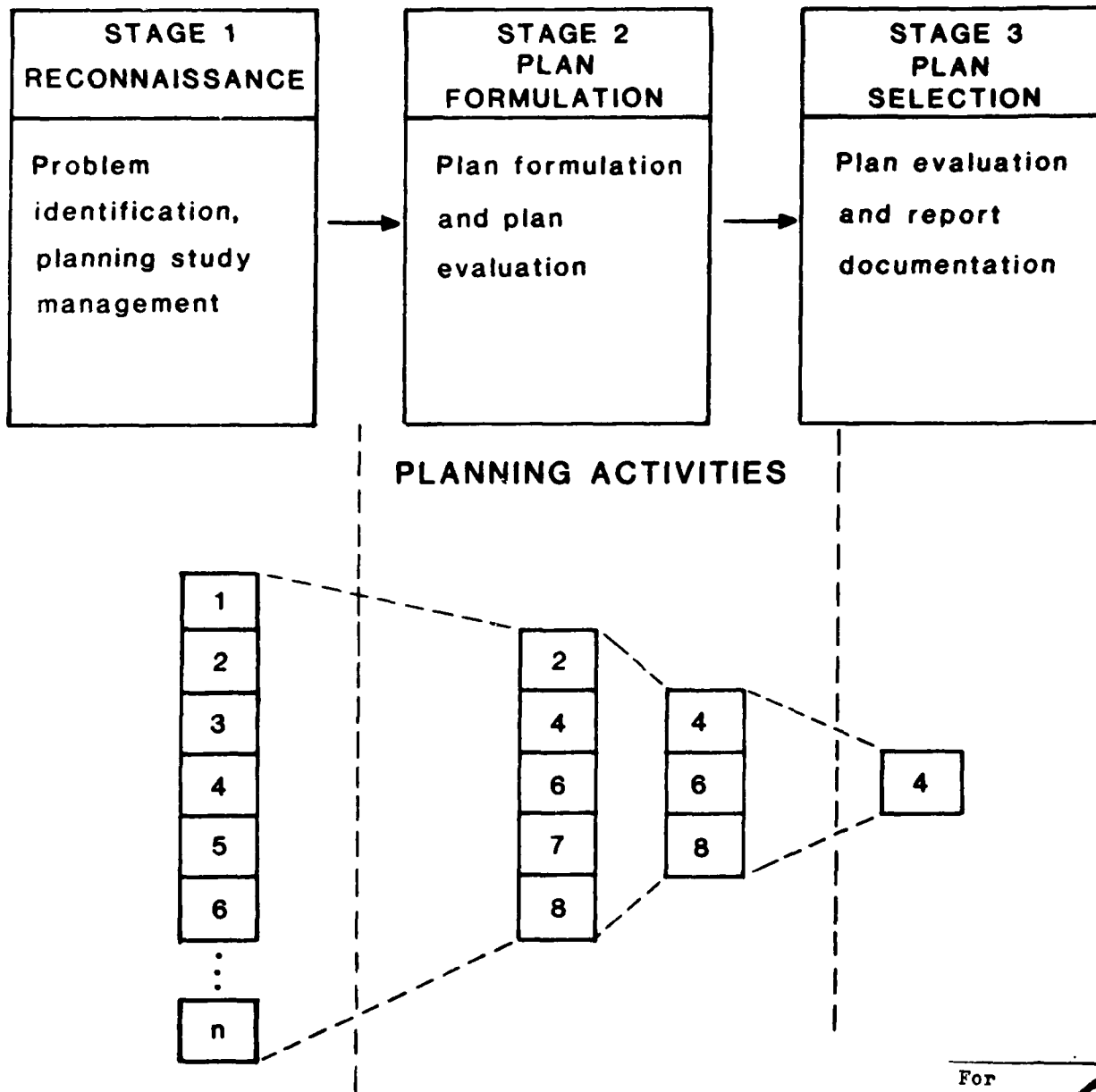
stream-bank erosion reduction, for fish and wildlife enhancement, and for wetlands protection. Congress may authorize the construction of facilities in this second group as a component of a project with facilities in the first group, but cost sharing or reimbursement funding by local governments generally is required.

Planning Process. - The studies performed by the Corps range from regional planning studies to investigations for implementation of specific local projects. Fewer regional planning studies and more specifically-focused project investigations are the general trend today. Regional screening studies, if performed, are commonly early phases of more detailed project studies.

Corps planning studies are staged studies, with the analysis of each stage increasing in detail, and the results of the analysis becoming increasingly specific in plan details. Fig. 1 illustrates the interplay between stage of study and study emphasis. The reconnaissance stage (Stage 1) bounds the problem and determines if feasible solutions exist. Computer-model use in this stage is minor, but decisions regarding subsequent model use are made here. The intermediate plan formulation stage (Stage 2) is the major creative and screening stage and thus is the focus of many planning models. The most significant role for computer models is for plan evaluation in this second stage and early in the final stage. The final stage (Stage 3) is the alternative selection and detailed evaluation stage. In this stage the data displays are prepared, and coordination and other actions prescribed by law and by administrative regulations are performed. The computer models are more useful at this point for developing appropriate displays than for plan formulation. However detailed and specialized programs can be important in this stage if noteworthy problems are examined in detail, particularly environmental impact problems.

ROLE OF HEC COMPUTER MODELS

Perspective. - The process that produces water resources plans is under the control of and is performed by the professionals who individually contribute specialized information and insights while collectively conceiving of plan elements and assuring the "soundness" of the plans that emerge. Water resources planning models are used in this process for identification of alternatives and evaluation of plans. Planning models are not planners nor do they perform planning. Their role is to facilitate the process by assisting the responsible professionals. The models are not substitutes or replacements for professional judgment, and they do not short-cut the planning process. Instead, models develop data that provide information that, in turn, gives insight into problems and to opportunities for solution. Water resources planning models do not necessarily speed studies or reduce overall study cost. They do provide for analysis of many more alternatives than would be possible otherwise. They also permit evaluation of complex alternatives for solution of complex problems in significantly more detail and with an increasingly higher degree of confidence and repeatability than otherwise possible.



SCREENING OF ALTERNATIVES

FIG. 1. - Corps Staged Planning Process

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The emergence of a plan, from the perspective of technical modeling, is envisioned as requiring two essential elements. The first is the ability to emulate the physical processes and thus to understand the physical impacts of management plans. The second is the ability to evaluate the benefits and costs of managing the water and related resources. Plans, or elements of plans, are formulated by people and then are tested against efficiency criteria. The criteria are complex and emanate from various aspects of the planning process. The need is, therefore, to have capability to evaluate proposed plan elements for comparison.

Modelers may argue that another essential element exists from a modeling perspective: plan formulation. The plan formulation task is however a creative, professional, human endeavor. Some models may automate certain aspects of the plan formulation task, but it is improper to group models into something that is a creative activity, requiring much more humanistic insight than models can provide.

HEC Models and Planning. - The Hydrologic Engineering Center (HEC) is a research, training, and consulting organization of the Corps of Engineers, with technical expertise in hydrology, hydraulics, and water resources planning. Since 1964, the HEC staff has developed, tested, supported, and applied computer programs that aid with the planning activities of the Corps. The HEC family of computer programs developed and continues to expand in response to field office needs of the Corps. The HEC water resources planning models are categorized as: 1) physical and statistical process and system operation models, 2) evaluation models, and 3) data management programs. Fig. 2 is a conceptualization of the planning and modeling process as discussed herein, with the role of these categories of models shown. The categorization is conceptual in terms relevant to planning as it is performed by the Corps. No grand design for an ultimate set of HEC programs exists, but instead, as Corps needs continue to become evident, new programs (or changes to existing ones) emerge and become part of the family.

MODELS OF PHYSICAL AND STATISTICAL PROCESS AND SYSTEM OPERATION

HEC's physical and statistical process models allow the water resources planner to simulate these processes and thus to quantify the effects of alternative solutions to water-related problems. The characteristics of the physical system, statistical process, or water uses are described by the model user with input data. The response of the system is predicted by solution of the equations describing the process. Models currently available from HEC are categorized as models of catchment processes, of channel processes, of alluvial processes, of statistical processes, and of system operation. Several of the models are capable of simulating processes in more than one category.

Catchment processes. - The primary HEC tool for evaluation of catchment processes is program HEC-1, the Flood Hydrograph Package (15). HEC-1 is a single-event model which uses a spatially and temporally-averaged description of the catchment to estimate the runoff from discrete storm events. Complex catchments may be modeled

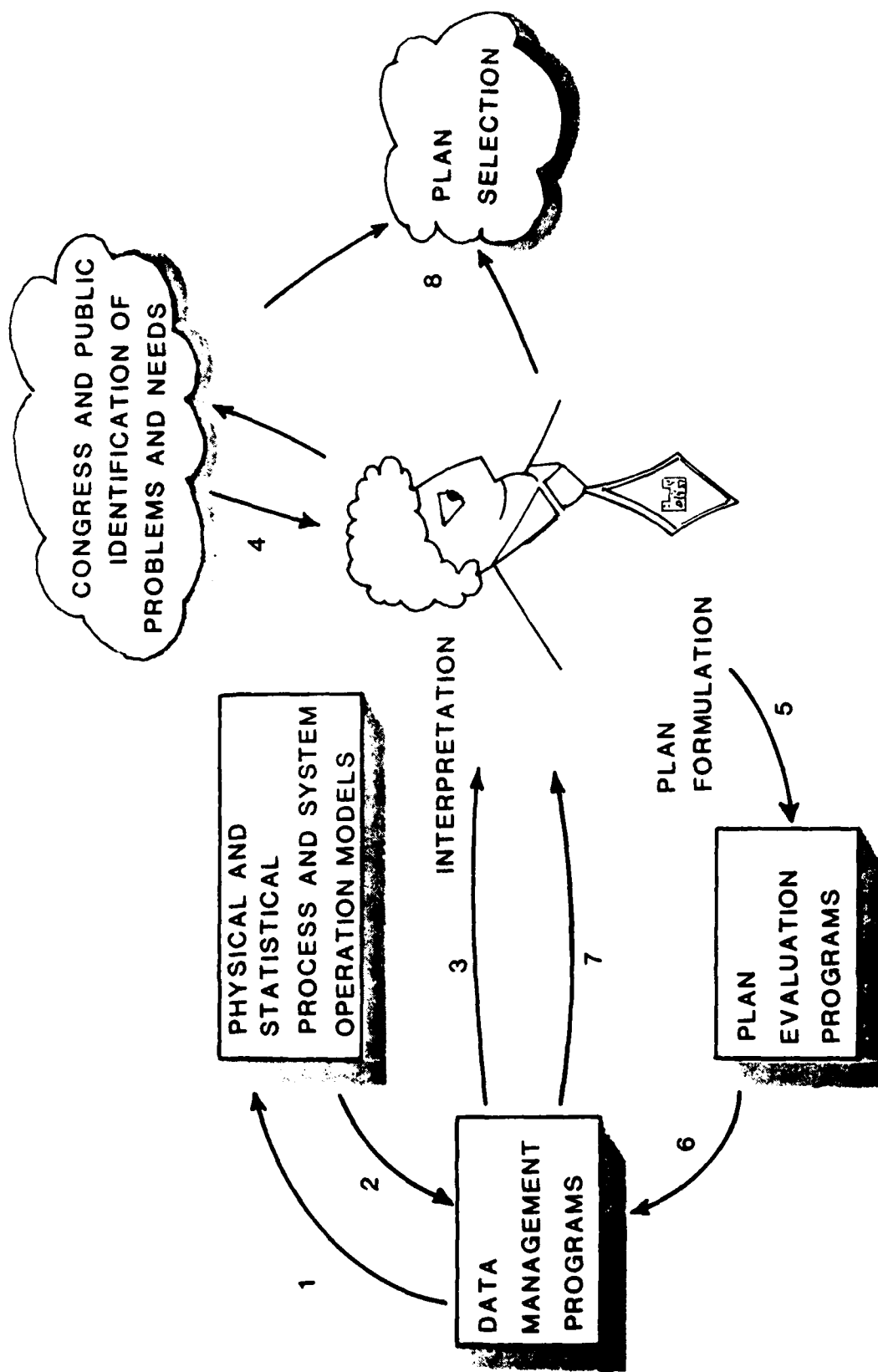


FIG. 2. - Model Use in the Planning Process

by subdividing, analyzing independently the subdivisions, and combining the results. Historical precipitation data are provided by the program user, or hypothetical storm data is derived by the program with National Weather Service (34,35,36) or Corps of Engineers (6) procedures. Catchment snowfall may be specified, and snowmelt runoff may be computed. Interception, infiltration, and other rainfall and snowmelt abstractions are estimated using common techniques. The magnitude and timing of runoff is simulated using a unit hydrograph technique, or the kinematic wave procedure (4). If desired, estimated baseflow is then added to the computed runoff to yield total flow at the catchment outlet. The capability to simulate various catchment processes is available also in smaller, single-purpose programs from which program HEC-1 was developed (7,8,21,26,29,30) and in the STORM program (25).

Channel processes. - The models of channel processes developed and supported by HEC may be categorized as channel routing, reservoir routing, flood-inundation, and dam-overtopping models. The flood-inundation model, HEC-2, computes water-surface elevation at any cross section of a natural channel for subcritical or supercritical steady flow. The standard-step method (16) is used to solve the one-dimensional energy equation, with adjustments and extensions for obstructions and for channel expansion and contraction. Flow through bridges and culverts may be simulated, and the impacts of channel improvements, embankments, and levees may be evaluated with the model.

The Gradually-varied Unsteady Flow Profile program (14) and the DWOPER program (3) are available for simulation of unsteady channel flow or for simulation of flow in channels in which structures or flood-plain geometry cause rapid variation of water surface elevation. Channel routing models simulate the movement of a flood wave in a natural channel by solution of the continuity and energy equations. This may be accomplished with either of the unsteady flow models, but most often is accomplished with a model which solves a simplification of the equations. Programs HEC-1 and HEC-5 (18) and the Hydrograph Routing and Combining (21) program provide the capability to solve, with alternative techniques, the simplified equations and thus, to define the translation and attenuation of a flood wave in a channel.

HEC's reservoir routing models simulate the movement of a flood wave through an uncontrolled reservoir or a detention structure. Program HEC-1 includes this capability, as does program HEC-5. In both cases, the characteristics of the reservoir are described through program input, and a simplification of the continuity and energy equations is solved to determine the reservoir outflow hydrograph, given the inflow hydrograph. Program HEC-5 can also be used to simulate long-term controlled reservoir operation for water supply and for other conservation purposes.

The capability to simulate dam overtopping or dam failing is provided by a component of program HEC-1 and by program DAMBRK (2). HEC-1 uses simplified procedures to simulate dam overtopping, and if desired, to simulate the formation and expansion of a breach. The

previously described reservoir and channel routing components of this model are employed for the simulation. The DAMBRK program, developed by the National Weather Service and supported by the staff of the HEC, simulates the failure of a series of dams on a river, solving the continuity and energy differential equations with a finite-difference numerical scheme. With either model, the results of the simulation are the discharge or stage hydrographs due to the overtopping or failing.

Alluvial processes. - Reservoir sedimentation and erosion and sediment deposition in rivers can be simulated with HEC's alluvial process models. Program HEC-6 (19) simulates the transport of sediment in a river, accounting for scour and deposition within the channel. This simulation is accomplished by linking a model of the channel processes with appropriate equations that simulate the interaction of the water-sediment mixture and the river-bottom sediment material. The Deposit of Suspended Sediment in Reservoirs (9) program simulates deposition of sediment as a function of sediment grain size, reservoir temperature, discharge, reservoir geometry, inflowing sediment load, and the sediment-trapping efficiency of the reservoir. The Reservoir Delta Sedimentation program (23) and the Suspended Sediment Yield program (28) also simulate deposition and transport of alluvial material.

Statistical processes. - Statistical process models developed in HEC permit estimation of the probability of various magnitudes of annual maximum discharge and generation of alternative sequences of monthly streamflow for project evaluation. The Flood Flow Frequency Analysis program (13) implements the Water Resources Council's guidelines for frequency analysis of annual maximum discharge with the log-Pearson type III distribution (37). The distribution parameters are estimated for a single streamflow station, considering the impact of broken and incomplete records, zero-flow years, outliers, and historic events. The fitted annual maximum discharge frequency curve is tabulated and plotted.

The HEC-4 (17) program was developed recognizing that performance evaluation of a complex water resources system with only available historical data will not adequately reflect the expected long-term system benefits. This program analyzes monthly streamflow data to estimate the parameters for modeling the discharge-frequency relationship with a log-Pearson type III distribution. An autoregressive model is used to generate sequences of monthly discharge. The response of a water resources system to the various sequences subsequently may be analyzed with a model of the physical processes or system of interest, thereby permitting evaluation using long-term performance averages.

System Operation. - In some applications, existing process simulation models did not satisfy planning study requirements, so specialized models of system behavior were developed. Examples of such models are programs HEC-5 and D2M2 (10).

The HEC-5 program simulates the operation of a multipurpose water resources system consisting of reservoirs, points of demand (control

points), and interconnecting channels. The system demands may be specified at any of the system reservoirs and at any of the control points; these demands may include hydroelectric power requirements, requirements of water for water quality maintenance and for water supply, and requirements for capacity to store flood waters. Given the demands, a sequence of reservoir inflows, channel capacities, and the inter-reservoir operating rules, the program selects reservoir releases to satisfy the requirements. The system operation is simulated with these releases, and the resulting system status is reported. This report of system status includes tabulations of volume of water stored in each reservoir each period, release from each reservoir each period, discharge at each control point each period, and a summary of the demands satisfied system-wide.

The Dredged-material Disposal Management Model (D2M2) was designed for systematic simulation and evaluation of alternative disposal system long-term management policies. With the model, disposal-site dewatering rates, containment dike heights, and other characteristics of the disposal system are specified by the model user, so management schemes that involve changes in these parameters can be simulated by systematic variation and re-execution of the model. D2M2 simulates disposal system behavior as flow through a network and solves for the least-costly operation with a mathematical programming formulation. The mathematical programming formulation includes continuity constraints for material sources and for disposal sites, transportation link and disposal site capacity constraints, and carry-over storage constraints.

MODELS FOR PLAN EVALUATION

Models for plan evaluation quantify the efficiency of alternative plans, using results of physical and statistical process simulation or of simulation of system operation. The output reports of the process simulation models allow direct quantification of plan efficiency by permitting comparison of simulated performance with performance targets. For example, to select the best reservoir operation policy, the target rates of reservoir withdrawal for water supply can be compared to rates simulated with program HEC-5 with a candidate inter-reservoir operating policy. As an alternative to using directly the physical criteria of system performance, a plan evaluation model may be used, and the physical performance may be related to economic benefits or to another index of performance. The HEC's Expected Annual Damage (EAD) Program (11), the Structure Inventory for Damage Analysis Program (SID) (27), and the Interactive Nonstructural Analysis Program (INA) (22) use the results of the process models to perform such an evaluation.

Expected Annual Damage Program. - The EAD program was developed for economic analysis of inundation-damage reduction plans. The program follows the requirements and guidelines of the "Evaluation of Beneficial Contributions to National Economic Development for Flood Plain Management Plans" (5). Expected annual flood damage may be computed for a specific location in a specific year with particular hydrologic, hydraulic, and economic conditions in that year, or for a series of future years, to permit discounting to estimate long-term

benefits with changing conditions. The input data for EAD consists of floodplain management plan description, damage reach delineation, damage category identification, flow-frequency, flow-stage, and stage-damage relationship specification, and identification of the time frame for analysis. The damage-frequency integration procedure of this EAD program is also incorporated in the HEC-1 program. A similar procedure that analyzes seasonal and duration effects is incorporated into HEC-5.

Structure Inventory for Damage Analysis Program. - The SID program aggregates the depth-damage relationships for individual structures in a section of flood plain to provide a single relationship for flood damage computation. This aggregated depth-damage relationship is combined with the results of channel process simulation, reservoir operation simulation, and statistical process simulation to permit expected damage computation with the EAD program. The effects of nonstructural flood-damage mitigation measures that alter the depth-damage relationship can be evaluated by describing those measures; the aggregated depth-damage relationship is modified accordingly.

Interactive Nonstructural Analysis Package. - The computer programs of the Interactive Nonstructural Analysis Package were developed to manage large amounts of data for nonstructural planning and to perform the calculations to assess the efficiency of alternative nonstructural flood-damage mitigation measures. The programs focus on individual structures or on user-defined groups of structures as the elements of analysis. Alternative nonstructural measures are evaluated on a structure-by-structure basis, just as these measures would be implemented. For each structure in the flood plain, basic and computed information are stored in a data bank. This information characterizes the structure and the nature of the flood problem at the structure. These structure attributes are used for identifying structures for which nonstructural measures may be appropriate. The program interacts with the EAD program to compute expected annual damage with existing or with proposed modified conditions.

DATA MANAGEMENT TOOLS

Data management tools provide a systematic means for organizing, storing, retrieving, manipulating, and sorting data for process models and for plan evaluation models. HEC's data management tools include a spatial data management system, HEC-SAM, and a general-purpose data storage system, HEC-DSS.

HEC-SAM. - The HEC-SAM is a system of general-purpose data management models which store, access, update, and manipulate geographically-oriented data (1). The system has two distinct functional components: file management and file-processing interface. The file management element is comprised of computer programs that manipulate and process geographic data so the data are represented in a grid cell format. The file-processing interface component includes programs that sort and reformat data so those data may be analyzed with the appropriate process simulation or evaluation models. Programs in this category are HYDPAR (20), which estimates

catchment model parameters from land-use data stored in grid cell format, and DAMCAL (12), which develops depth-damage relationships from damage data stored in grid-cell format. Other special-purpose display and attractiveness and impact analysis programs are available for analysis of the stored data (24). The previously described simulation and evaluation models are employed for technical analysis.

The objective of the HEC-SAM programs is to provide the data-management capability for systematic assessment of alternative land-use patterns and flood-damage mitigation plans. HEC-SAM programs manage data required to evaluate damage from a specific storm and to develop elevation-frequency relationships for expected damage computation for modified flood plain conditions. The programs can be used also to develop data in the format required to evaluate physical or statistical process modifications, and to evaluate damage or damage reduction due to changes in flood plain occupancy, changes in catchment and stream channel characteristics, changes in structural construction practices, changes in development-control policies, and changes in values and damage potential of flood plain structures. The damage-reduction due to structural and nonstructural damage mitigation measures can be evaluated also. HEC-SAM programs manage data required to perform a variety of environmental evaluations for management alternatives and modified catchment conditions.

HEC-DSS. - The HEC data storage system (HEC-DSS) is a file management system that allows convenient, orderly exchange of data between programs. The HEC-DSS consists of a library of FORTRAN-callable subroutines that store data in a standard format and retrieve those data on demand. The files created are random-access files with a hierarchical system of names to control data flow and to expedite storage and retrieval. In addition to allowing convenient data transfer between programs, the HEC-DSS system allows centralization of utility functions commonly used by process simulation and evaluation models. These utility functions include data editing routines, report generation and data tabulation and display routines, and statistical summary routines.

EXAMPLE APPLICATION: PASSAIC BASIN FLOOD CONTROL

Study Background - The Passaic Basin study is a regionally-large, comprehensive investigation of potential solutions to flood problems within an area adjacent to the New York metropolitan complex. The study is a seven year, fifteen million dollar planning investigation that will conclude in 1984 (31). The study has made extensive use of HEC planning models.

The Passaic River drains a watershed of 935 square miles, including 489 square miles of wooded, mountainous, sparsely-populated highland area, a broad, flat central basin of 253 square miles comprised largely of freshwater swamps and urbanizing flat meadows, and a lower basin of 193 square miles characterized by a narrow flood plain and steep tributaries. It is a highly urban area that includes the industrial centers of Patterson, Passaic, and a portion of Newark. About 1.8 million people reside in the watershed.

Major issues addressed in the investigation include future development in the basin and consequent increased runoff, the role of and potential need to protect natural storage areas in the central basin, and the full range of social, environmental, and economic problems of the areas. The alternatives considered were the normal complement of structural measures, including massive tunnel diversions, and a full array of nonstructural solutions.

The computer models groups used include: catchment and statistical process models (to analyze change in storm runoff and alternatives of storing and diverting streamflow), channel process models (to develop the relationships between flow and stage, to analyze levee, channel, and floodwall alternatives, and to determine flow patterns and stage relationships in the central basin); flood-damage evaluation models (to identify potential damage areas, evaluate damage reduction benefits for alternatives, and evaluate nonstructural measures); and data management programs (to capture efficiently spatial data and to allow systematic exchange of data between computer programs). Seven major HEC computer programs and another five smaller utility type programs comprise the analytical base. Three major data files were prepared and managed as part of the overall analytical package for the study. Fig. 3 is a general schematic of the major computer programs, data files, and data-flow paths within the system.

Hydrologic data (flow frequency) for existing and future watershed conditions were developed by executing the HYDPAR program (Fig. 3 - Step 1), which accesses the spatial-data file, and the HEC-1 program (Fig. 3 - Step 2), using the parameters defined by HYDPAR. The resulting flow-frequency relations were stored with the HEC-DSS. A separate execution of the program was required for each condition of interest. For each, the appropriate spatial data describing land use (existing and alternative future) were retrieved, and the resulting parameters for catchment process modeling were stored with the HEC-DSS.

Flood damage potential for existing development and each alternative was developed by accessing with the SID program the structure data file (Fig. 3 - Step 6). SID computed elevation-damage relationships for all damage reaches and damage categories. The data were stored with the HEC-DSS and were thus available in tabular form and in computer-readable form for access by programs requiring this information, specifically the EAD program.

The HEC-2 program was executed (Fig. 3 - Step 4) to compute flood elevation at each stream cross section; these data were stored with the HEC-DSS. The data were then available in tabular, graphical, and computer-readable form for access by other programs.

The EAD program was executed (Fig. 3 - Step 8), automatically retrieving the discharge-elevation relationships, elevation-damage data, and flow-frequency relationships for existing and future conditions and alternative plans. The annual damage by location (reach), damage category, and time (decades plus equivalent annual) thus was computed.

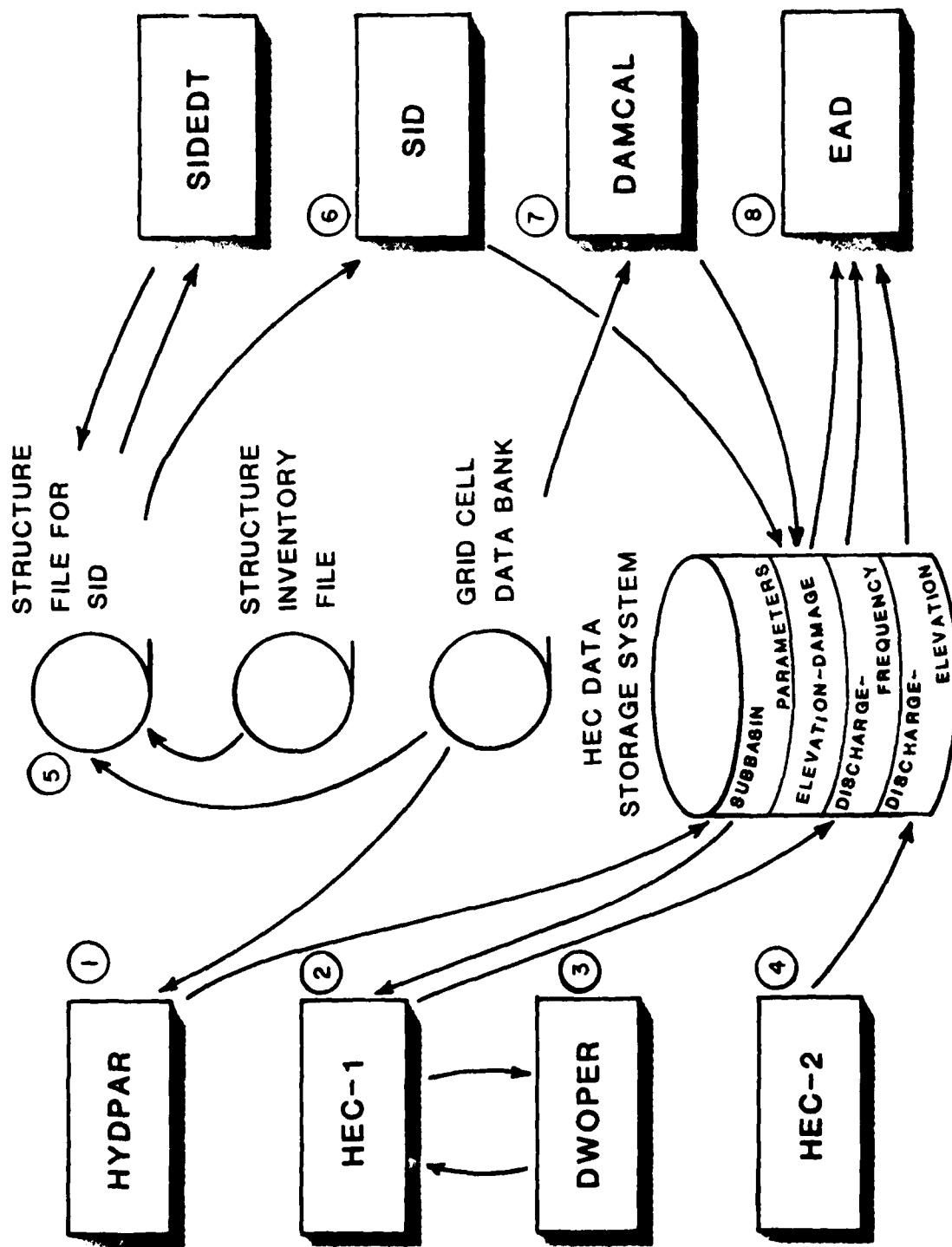


FIG. 3. - Passaic River Study Planning Model Use

To evaluate alternative flood-water detention plans, the appropriate reservoir characteristics were specified for the simulation with HEC-1, and Step 2 (Fig. 3) was repeated for conditions of interest. HEC-5 would have been used had controlled reservoirs been specifically operated to achieve target flood-discharge reductions. EAD was executed with modified frequency curves and damage potential and discharge elevation relationships.

Tunnel and other basin diversion alternatives were evaluated with the same procedure as used for reservoirs, with the characteristics of the diversion altered in HEC-1. Levee alternatives were analyzed by modifying the appropriate stage-damage relationships and re-executing the EAD program.

The SID program was executed to evaluate the nonstructural measures for structures of interest. The SIEDT program, a specialized data editor, was used to retrieve data for candidate structures and reaches. SID was used in a screening mode for several runs to identify structures for which nonstructural measures seemed reasonable. Then the program was re-executed, and the modified elevation-damage data generated by SID were stored with HEC-DSS, as in Step 6. The EAD program (Fig. 3 - Step 8) then was executed to evaluate damage reduction due to the nonstructural measures.

EXAMPLE APPLICATION: DELAWARE RIVER DISPOSAL MANAGEMENT

Delaware River System. - The Corps of Engineers is charged with maintenance of the navigable waterways of the United States. Maintenance of the Delaware River, Delaware Bay, and associated tributaries is the responsibility of the Philadelphia District, Corps of Engineers. The maintenance requires dredging and disposal of the sediment deposited in the waterways. Within the Delaware River system 23 federal navigation projects yield approximately 6.5 million cu. yd. of dredged material annually. Non-federal maintenance dredging contributes an additional 2.5 million cu. yd. The material currently is disposed in 18 containment sites. According to estimates published in a 1979 study, with continued maintenance dredging at the current rate, these sites will be filled to capacity or otherwise unavailable by 1999 if no management action is taken (33). This in turn would mean reduction or cessation of dredging and consequent reduction or cessation of navigation.

A planning study initiated in the Philadelphia District sought to answer the following questions regarding the disposal of dredged material from the Delaware River system:

1. What is the optimal long-term management policy for the existing disposal system?
2. When the existing disposal sites fill, where can new sites be located?
3. When should these new sites be acquired?
4. Is it economically effective to renegotiate and to extend leases on currently available sites?
5. Are other management alternatives, such as improvements in site management, cost effective?

Two HEC planning models were to answer these questions; the spatial analysis programs were employed for new disposal site identification, and program D2M2 was used to simulate the physical process and to evaluate the efficiency of alternative management schemes.

Data Management for Site Selection. - Selection of feasible new upland disposal sites required simultaneous consideration of social, political, environmental, economical, and technical constraints. To accomplish this, a spatial data bank with approximately 43000 grid cells was created, and manipulated using the programs of the HEC-SAM package. For each grid cell, data descriptive of the area represented were stored. These data were weighted, combined, and displayed with the HEC-SAM programs, and through a public-participation program, potential sites were identified.

Physical Process Simulation. - The physical processes that must be simulated for planing future operation of the Delaware system are (1) deposition of the alluvial material, (2) removal, transportation, and disposal of the material, and (3) operation of the disposal sites. Estimation of the rates of deposition of alluvial material was accomplished by Philadelphia District staff using traditional simulation procedures, and the other processes were simulated with D2M2. In this application, execution of the D2M2 program provided an assessment of the volumes removed from shoaling sites and transported to disposal sites, of the dredging and shipping vessel utilization rates, and of disposal-site status. Simulation of physical processes for various management alternatives was accomplished by systematic application of the model with variation of the appropriate input parameters. The improvements attributable to alternatives were expressed in terms of the user-defined system characteristics. For example, to simulate use of trenching devices that speed the drying of deposited material in the disposal sites, the volume-reduction factor and the maximum allowable volume addition per period to a disposal site per period were changed to reflect the improvement possible. The model was then re-executed to determine the results of following the least-costly operation scheme.

Plan Evaluation. - Plan evaluation also was accomplished with program D2M2. Unit costs were specified for dredging, transporting, and disposing dredged material, and for site acquisition, and lease renegotiation. Operation, maintenance, and replacement (OMR) costs are defined also. For any system configuration, with a specified management policy, the cost was determined from the physical process simulation results.

For evaluation of management alternatives, the appropriate unit costs were varied along with physical process parameters. For example the unit disposal cost was increased to reflect the cost of operating trenching machinery, and the OMR and acquisition costs were increased. Following simulation of the physical processes, the total operation cost was computed, OMR and acquisition costs were added, and this total cost was compared to costs of other alternatives, thereby allowing selection of a "best" management plan.

SUMMARY

In response to needs of Corps planners, the Hydrologic Engineering Center has developed and supports a set of computerized planning models. The set includes models for simulation of physical and statistical processes, models of water-resources system operation, models for plan evaluation, and programs for data management. These models have been used Corps wide to aid professionals in formulation and selection of solutions to water resources planning problems.

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The U.S. Army Corps of Engineers has broad, nationwide water resources planning and management responsibilities. In response to the needs of Corps planners, the Hydrologic Engineering Center (HEC) has developed and supports a family of computer programs designed to aide them in their work. These programs include catchment, channel, alluvial, and statistical process models, system operation models, plan evaluation models, and data management programs. These models individually and collectively have been used throughout the Corps in a wide range of water resources planning studies.		

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