US Army Corps of Engineers
Hydrologic Engineering Center

The Development and Servicing of Spatial Data Management Techniques in the Corps of Engineers

July 1978

TP-55

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
July 1978

2. REPORT TYPE
Technical Paper

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
The Development and Servicing of Spatial Data Management Techniques in the Corps of Engineers

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
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5d. PROJECT NUMBER

5e. TASK NUMBER

5F. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
US Army Corps of Engineers
Institute for Water Resources
Hydrologic Engineering Center (HEC)
609 Second Street
Davis, CA 95616-4687

8. PERFORMING ORGANIZATION REPORT NUMBER
TP-55

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/ MONITOR'S ACRONYM(S)

11. SPONSOR/ MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
Presented at the International Users Conference on Computer Mapping and Databases, Harvard University, July 1978.

14. ABSTRACT
The US Army Corps of Engineers is using spatial data management techniques in studies that are structured in a manner that requires spatial data management techniques to play a central and dominant role.

The Corps Hydrologic Engineering Center (HEC) provided the basic developmental work on the spatial data management and attendant processing techniques and it is continuing in the role of the basic technology transfer agent. The significant efforts required to document, maintain and service the technology and provide ready consultation services reported herein were planned for during the developmental efforts and are currently being centrally managed to encourage smooth adoption of the techniques by Corps field offices.

15. SUBJECT TERMS
data management, spatial analysis, computer mapping, computer graphics, database creation

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
U	U	U	UU	32	19b. TELEPHONE NUMBER

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39-18

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Papers in this series have resulted from technical activities of the Hydrologic Engineering Center. Versions of some of these have been published in technical journals or in conference proceedings. The purpose of this series is to make the information available for use in the Center's training program and for distribution with the Corps of Engineers.

THE DEVELOPMENT AND SERVICING OF SPATIAL DATA MANAGEMENT TECHNIQUES [1/] IN THE CORPS OF ENGINEERS

by

R. Pat Webb and Darryl W. Davis[2/]

INTRODUCTION

The U.S. Army Corps of Engineers began using spatial data management techniques in studies on a limited and mostly experimental basis in the late 1960's. More recently a significant number of studies have been initiated (several are already completed) that are structured in a manner that requires spatial data management techniques to play a central and dominant role. The majority of these studies seeks to provide a comprehensive assessment of the impacts of existing and alternative future land use development patterns, both on and off the nation's floodplains in the context of providing a planning service to local units of government with land use and flood plain management responsibilities. (1)

The Corps Hydrologic Engineering Center (HEC) provided the basic developmental work on the spatial data management and attendant processing techniques and it is continuing in the role of the basic technology transfer agent. The significant efforts required to document, maintain and service the technology and provide ready consultation services were planned for during the developmental efforts and are currently being centrally managed to encourage smooth adoption of the techniques by Corps field offices.

[1/] Presented at the International Users' Conference on Computer Mapping Software and Data Bases: Application and Dissemination, Harvard University, July 1978.

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SPATIAL DATA MANAGEMENT ANALYSIS CAPABILITIES

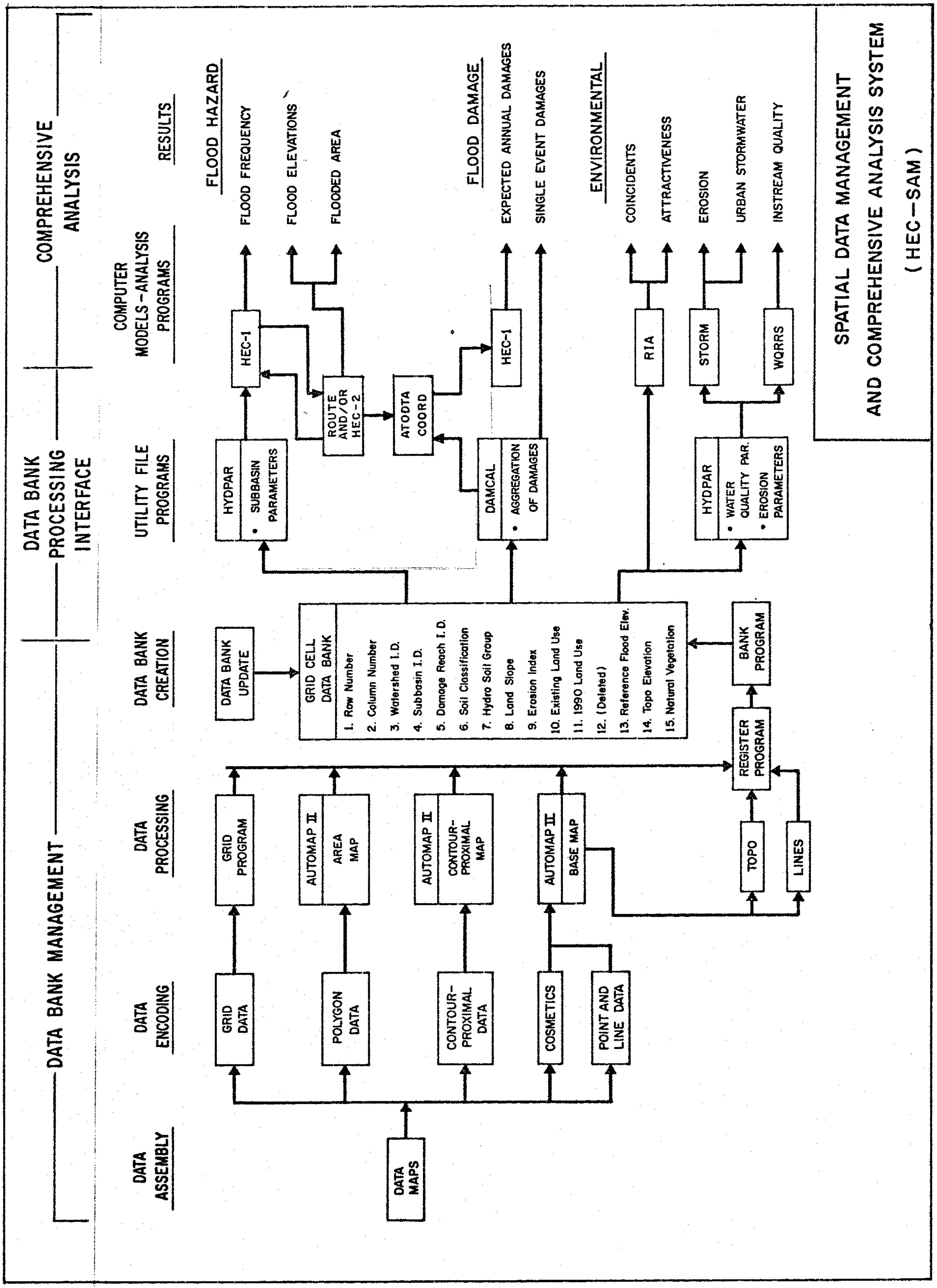
The "system" as such is primarily a rational procedure for managing data and performing comprehensive analysis. Some elements of the analysis process are still performed manually and then linked to other analysis elements, as in the traditional work flow mode, while other elements are highly automated. Figure 1, Spatial Data Management and Comprehensive Analysis System, displays a schematic of the analysis system. Notice that definite functional tasks are labeled with the corresponding supporting software grouped. The great power of spatial data management in contributing to the improved quantitative analysis of alternative land use patterns is accomplished by the group of software contained under DATA BANK PROCESSING INTERFACE. The development of these programs is described in detail in (2). The COMPREHENSIVE ANALYSIS portion of Figure 1 is performed by use of large scale computer simulation models, most of which have been used for some time in normal Corps work efforts. Descriptions of these analysis programs can be obtained through (3).

The analysis capabilities of the system which are commonly used are arrayed in the following paragraphs.

Flood Hazard

Evaluation of the following alternatives for a specific storm event (such as the 100-year interval event) or for a range of storm events (Development of flow and/or elevation exceedance frequency relationships) at all selected important locations within a study area.

- Changed land use patterns
- Changed drainage system



DATA BANK MANAGEMENT
DATA BANK PROCESSING INTERFACE
COMPREHENSIVE ANALYSIS
DATA ASSEMBLY
DATA ENCODING
DATA PROCESSING
DATA BANK CREATION
UTILITY FILE PROGRAMS
COMPUTER MODELS-ANALYSIS PROGRAMS
RESULTS
DATA MAPS
GRID DATA
POLYGON DATA
CONTOUR-PROXIMAL DATA
COSMETICS
POINT AND LINE DATA
GRID PROGRAM
AUTOMAP II AREA MAP
AUTOMAP II CONTOUR-PROXIMAL MAP
AUTOMAP II BASE MAP
TOPO
LINES
REGISTER PROGRAM
BANK PROGRAM
DATA BANK UPDATE
GRID CELL DATA BANK
1. Row Number
2. Column Number
3. Watershed I.D.
4. Subbasin I.D.
5. Damage Reach I.D.
6. Soil Classification
7. Hydro Soil Group
8. Land Slope
9. Erosion Index
10. Existing Land Use
11. 1990 Land Use
12. (Deleted)
13. Reference Flood Elev.
14. Topo Elevation
15. Natural Vegetation
HYDPAR
• SUBBASIN PARAMETERS
DAMCAL
• AGGREGATION OF DAMAGES
HYDPAR
• WATER QUALITY PAR.
• EROSION PARAMETERS
ROUTE AND/OR HEC-2
ATODTA COORD
HEC-1
HEC-1
RIA
STORM
WQRRS
FLOOD HAZARD
FLOOD FREQUENCY
FLOOD ELEVATIONS
FLOODED AREA
FLOOD DAMAGE
EXPECTED ANNUAL DAMAGES
SINGLE EVENT DAMAGES
ENVIRONMENTAL
COINCIDENTS
ATTRACTIVENESS
EROSION
URBAN STORMWATER
INSTREAM QUALITY
SPATIAL DATA MANAGEMENT AND COMPREHENSIVE ANALYSIS SYSTEM (HEC-SAM)

Figure 1

- Flood plain occupancy encroachments
- On-site water management strategies
- Engineering works such as levees, channel modifications, reservoir storage and flow rerouting
- Watershed management practices

Flood Damage

Evaluation of the monetary damages for a specific flood event (such as the 100-year exceedance interval event) and the expected value of annual damages (expected annual damages) for each designated location in the study area and for each desired damage category (residential, commercial, etc.) for the following:

- Changed flood plain occupancy
- Changed watershed runoff, such as from changed land use
- Changed stream conveyance, such as from flood plain encroachment
- Changed structural construction practices
- Alternative development control policies
- Changed value of flood plain structures
- Modified structure damage potential such as from flood proofing
- Effects of engineering flood control and drainage works of levees, channels, reservoirs, and diversions

Environmental

Some of the evaluations that can be performed for the alternatives and conditions described in Flood Hazard and Flood Damage above are:

- Catalogue environmental habitat changes from changed land use (coincident analysis)

- Forecast changes in land surface erosion and transport for land use and engineering work changes
- Forecast changes in runoff quality from changed land use
- Forecast changes in stream water quality
- Develop first order attractiveness and impact spatial displays
- Identify enriched habitat zones by ecotone analysis

APPLICATIONS SETTINGS

The primary planning environment for which the Corps spatial data management techniques are designed to service is the situation of urban areas where 1) development pressures are either currently significant or expected to be significant in the near future and 2) where there exists a strong desire on the part of local planning agencies to manage development in the best interests of the community, giving balanced considerations to the flood plain and off flood plain development.

In these studies the general analytical strategy is to 1) assemble and catalogue basic geographic and resource information into a computer data bank, 2) cooperatively, with local agencies, forecast and place into the data bank selected alternative future development patterns, 3) perform comprehensive technical assessments of the selected alternative futures and 4) document the assessment for study by the general public and community officials.

The role of spatial data management in these studies is focused on the use of a data bank as an operational repository of basic resource data, from which specific data is accessed for conventional spatial data manipulations such as locational attractiveness, impact overlay and boolean operations, and also for quantitative analysis in which specific data are analyzed to generate modeling parameters that are used as input into large scale hydrologic, economic and ecologic simulation models. Performing these analyses with the use of a geographic data bank has resulted in 1) consistent data use among participating professionals, 2) coordinated data acquisition and processing, and 3) on a large scale provided the analysis tools for the consistent evaluation of alternative future development patterns and land use development policies.

Another recent application setting has been in the Corps traditional project investigation studies which are conducted in an open forum of public participation and they are structured to meet the multiobjective planning concepts as specified by the Water Resource Council's Principles and Standards (4). Even though spatial data management techniques play a lesser role in these studies, they have provided a significant increase in the technical analysis capability to forecast future storm runoff and flood damage potential. The techniques are of particular interest because they have provided a unique capacity for performing nonstructural flood plain management plan formulation studies on a geographic scale never before possible. (5)

PROJECT APPLICATIONS

The techniques reported in this paper were developed to service a series of pilot studies which were designed to test the basic concepts of a broadened community services oriented type of investigation which was under study by Corps management. The studies are referred to as Expanded Flood Plain Information Studies (XFPI). The original pilot study (Oconee River Basin) has been completed (6) and several other pilot studies which were initiated to test the geographic transferability of the concepts and techniques are near completion. Several publications are available describing the research efforts for the pilot studies (1), (2), (3), (5), and documenting the pilot study findings as well (6). Table 1, Spatial Data Management Studies, lists some Corps studies either recently completed or currently in progress that use spatial data management methods. When more than one grid cell size is used, the larger size is used throughout the study area and the smaller size is used for the flood plain area. The status column of Table 1 refers to whether the study is finished (complete), using the data bank for analysis (analysis) or creating the data bank (data bank). The responsible Corps field office should be contacted for up-to-date information on the progress of the study.

Only selected published test results on the Trail Creek watershed from (1), (2) and (7) are presented to illustrate the nature of the products which may be generated from these types of studies. The analysis results are displayed in either map, tabular, or graphic format, much of which is complex and detailed. Because of the complexity of the analysis, an experienced professional is required to interpret the results. This is especially true in the detailed water quality assessments.

TABLE 1

SPATIAL DATA MANAGEMENT STUDIES

Corps District	Type of Study	(River Basin)	DATA BANK CREATION			% Urban	Area (Sq mi)	Grid Cell Size (Acre)	Status
			in-house	in house/ Contract	Contract				
Savannah	XFPI	Oconee		X		5	183	1.15	Complete
Fort Worth	XFPI	Rowlett		X		20	137	1.15	Complete
Fort Worth	XFPI	Walnut-Williamson			X	25	86	.29/1.15	Data Bank
Memphis	XFPI	Wolf			X	20	818	.62/9.88	Analysis
Jacksonville	XFPI	Boggy	X			10	60	4.59	Complete
Philadelphia	XFPI	Pennypack	X			60	55	.25/1.15	Analysis
Pittsburgh	XFPI	Sewickley		X		14	102	1.53	Data Bank
Rock Island	XFPI	Crow	X			10	18	.25	Data Bank
San Francisco	XFPI	Sonoma			X	25	160	1.53	Data Bank
Alaska	XFPI	Willow		X		0	216	1.15	Data Bank
Jacksonville	XFPI	Tallaboa (P.R)		X		5	32	.62/61.8	Data Bank
St. Louis	Planning	Harding Ditch	X					1.15	Analysis
New England	Planning	Moshassic	X					1.53	Analysis
Wilmington	Planning	Upper Roanoke and Dan	X						Data Bank

The Trail Creek watershed occupies about 12 mi^2 of the Oconee pilot study area of 300 mi^2 and includes a portion of the city of Athens, Georgia. The test area is presently about 10 percent urban and expected to grow to 20 to 30 percent urban by 1990. The data bank created for Trail Creek included the 15 data variables shown in Figure 1 at a grid cell size of approximately 0.6 hectares (1.53 acres).

Flood Hazard

Table 2, Hydrologic Data Summary, displays the results of evaluating the Existing and 1990 Alternative conditions. Note that the flow rate increases for each of the specified probabilities, but at a less proportionate rate for the rarer events. Note also that the flow rate change for say the 100-year event is different between control points and that the change in flood elevation is not directly proportional to the change in flow. Study of the table indicates that the hydrologic consequences of land use and engineering works are complex and require careful, professional analysis.

TABLE 2

HYDROLOGIC DATA SUMMARY
TRAIL CREEK TEST

100 YEAR PEAK FLOW AND ELEVATION

Index	Existing Land Use		1990 Land Use	
Station	Flow (cfs)	Elevation	Flow (cfs)	Elevation
1	7600	627.1	9400	628.3
2	3450	656.4	3800	656.7
3	2600	711.9	2900	712.2
4	3900	650.3	5100	651.2
5	1600	694.2	1650	694.3

TABLE 2 (con't)

FLOW - EXCEEDANCE INTERVAL DATA

(cfs)

	Index Station 1		2		3		4		5	
Exceedance Interval (yr)	Exist	1990	Exist	1990	Exist	1990	Exist	1990	Exist	1990
5	2000	2800	950	1200	800	960	1100	1700	500	570
10	3000	3900	1350	1650	1100	1300	1600	2300	700	780
25	4400	5600	2000	2400	1600	1850	2300	3300	1000	1100
50	5800	7300	2650	3000	2100	2350	3000	4000	1250	1350
100	7600	9400	3400	3800	2700	3000	4000	5200	1600	1700

Flood Damage

Table 3, Selected Damage Assessments, summarizes the expected annual damage assessments for a range of hydrologic conditions and land use control policy sets for the three damage reaches within the Trail Creek watershed that sustain significant damages. The 1990 land use condition is a projection based on local agency judgement.

The results shown in Table 3 are somewhat surprising and at first glance may be difficult to understand. An initial reaction might be that the evaluation condition of placing new development at the existing 100-year flood (CODE IV) should be similar to the existing condition (CODE I). The large increase in expected annual damages is caused by 1) damage occurring to the basements of new construction, 2) the 100-year flood for the 1990 land use condition is higher than the 100-year flood for the existing land use condition, and 3) damages still occur to the new development from flood events that exceed the 100-year event. Several other evaluations that include a number of alternative control and flood proofing policies are included in Table 3 to demonstrate the broad capability of the spatial data management techniques as well as present some interesting evaluations of policies designed to manage flood losses.

TABLE 3

SELECTED DAMAGE ASSESSMENTS
TRAIL CREEK TEST

(Expected Annual Damage in 1000's $)

	EVALUATION CONDITION		DAMAGE REACH			
CODE	LAND USE POLICY	HYDROLOGY	1	2	3	TOTAL
I	Existing	Existing (1974)	1.5	1.9	11.9	15.3
X	1990 with no development controls	1990	1033.3	350.0	32.7	1416.0
IV	1990 with new development at 1974 100-year flood level	1990	19.3	63.8	23.8	106.9
V	1990 w/new devel. @ 1974 100-year & flood proofed to ground floor	1990	16.8	18.9	4.7	40.4
VIII	1990 w/new devel. @ 1990 100-year & flood proof to ground floor	1990	11.9	16.0	2.8	30.7

The specific nonstructural flood plain management evaluations that may be accomplished using spatial data management techniques are shown in Table 4, Evaluation of Alternatives by Spatial Analysis Methods. Recently the HEC has added the capability to directly interface the damage potential of individual structures to the spatial damage assessment, therefore allowing for a more detailed assessment of unique damageable structures (such as large industry) in the existing land use condition.

TABLE 4

EVALUATION OF 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	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.

Environmental

The potential use of spatial data management techniques for environmental assessments was the initial impetus for the Corps investigation of computerized geographic information systems. The Corps was first introduced to the potential of spatial data management through the Honey Hill study (8) which was based on early work performed by the Harvard Graduate School of Design. As a result of this early work, the HEC subsequently developed the Resource Information and Analysis (RIA) program (9). The RIA program contains the traditional distance determination (centroid to centroid), impact assessment (five level), attractiveness modeling, coincident tabulations, computer line printer graphics (22 map levels), and an executive program which handles all of the data manipulations transparent to the user.

Corps environmentalists in the XFPI studies have primarily used the coincident tabulation capability of the RIA program to tabulate the acreage and percentages of the coincident of the classes of two data variables within the data classes of a third data variable. The third data variable is usually a boundary variable; census tract, township, watershed, damage reach, etc. Table 5 shows the coincidents between land use categories in the existing and 1990 proposed alternative future condition within the Trail Creek watershed. Once information such as this is available, the environmentalists then write impact scenarios based on the habitats lost due to the changed land use pattern.

The Corps has also developed the capability to 1) identify and analyze ecotone or habitat fringe areas, 2) identify the habitat areas impacted by changes in flood elevation-frequency, and 3) generate modeling parameters

TABLE 5

COINCIDENTS TEST

EXISTING AND 1990 LAND USE WITHIN DAMAGE REACHES

1

COINCIDENTS MATRIX

ROW	COLUMN 1	2	3	4	5	6	7	8	9	10	ROW TOTAL
1	648,7	7.7	73.4	153.0	117,8	61,2	191.3	110.2	644,1	122.4	2129,8
2	4,6	21.4	0.0	27.5	3,1	0,0	0.0	30,6	23,0	0,0	110,2
3	15.3	0.0	41.3	53.6	4,6	7,7	4,6	4,6	21.4	0,0	153,0
4	4,6	9.2	0,0	52.0	15,3	0.0	0,0	7.7	3.1	0,0	91,8
5	0,0	6,1	0,0	4,6	1,5	0.0	0,0	0,0	9,2	0,0	21,4
6	166,8	0.0	73.4	174,4	26.0	290,7	156,1	16,8	205,0	26,0	1135,3
7	4,6	0.0	0,0	0,0	0,0	0,0	29,1	0.0	9,2	0,0	42,8
8	1,5	0.0	0,0	1,5	1,5	0,0	1,5	52,0	4,6	0,0	62,7
9	18,4	0,0	16,8	9,2	10,7	0,0	114,8	32,1	68,9	1,5	272,3
10	6,1	0,0	1,5	1,5	0,0	6,1	6,1	0,0	4,6	10,7	36,7
TOTAL	870,6	44,4	206,6	477,4	180,5	365,7	503,4	254,0	993,0	160,7	4056,0

ROW CATEGORIES ARE EXISTING LAND USE

1 NATURAL VEGETATION
2 DEVELOPED OPEN SPACE
3 LOW DENS. RESIDENTIAL
4 MED DENS. RESIDENTIAL
5 HIGH DENS. RESIDENTIAL
6 AGRICULTURE
7 INDUSTRIAL
8 COMMERCIAL
9 PASTURE
10 WATER BODIES

COLUMN CATEGORIES ARE 1990 LAND USE

1 NATURAL VEGETATION
2 DEVELOPED OPEN SPACE
3 LOW DENS. RESIDENTIAL
4 MED DENS. RESIDENTIAL
5 HIGH DENS. RESIDENTIAL
6 AGRICULTURE
7 INDUSTRIAL
8 COMMERCIAL
9 PASTURE
10 WATER BODIES

** NOTE ** AREA UNITS

for water quality and sediment-erosion analysis by the EPA approved STORM program.

Table 6, Trail Creek Pollutants, displays washoff (7) which would exit the watershed for the existing and the 1990 alternative conditions based on rainfall data for the period of January through October 1970. These pollutants or STORM pollutographs may be either graphically displayed on a subbasin basis or they may be used as input into dynamic instream water quality models such as the Corps Water Quality for River and Reservoir Systems (WQRRS) program (10). Caution must be used in the detailed water quality application as it is expensive and of questionable value without good calibration data.

TABLE 6

TRAIL CREEK POLLUTANTS
(January - October 1970)

Pollutant	Existing	1990
Suspended Solids (lbs)	1,099,708	2,477,564
Settleable Solids(lbs)	150,069	376,509
BOD_5 (lbs)	77,585	170,838
Nitrogen (lbs)	20,118	43,176
PO_4 (lbs)	6,068	13,253
Coliform (10^9MPM)	846,244	2,365,152
Average annual land surface erosion (tons)	85,000	83,900

A more detailed sediment analysis has been conducted on a cell by cell basis. This approach was ninety percent (90%) successful, with the main problem being the terrain that was captured in the data bank. Since topography is primarily used for the damage assessments, some grid cells had an elevation which reflected the location of a structure in the cell instead of the thalweg elevation of the channel. This caused several artificial sump holes to occur in the channels which could not transport sediment downstream. As a result of this effort, several topographic data capture techniques are under study which would allow multiple uses with the same data set. (11)

Computer Graphics

Extensive use is made of computer graphics in many phases of a Corps spatial data management study. The primary uses are in 1) verifying data which has been encoded, 2) verifying data which has been placed in the data bank, and 3) displaying analysis results. Table 7, Graphic Software, shows the graphic software the HEC currently uses and the primary function of each.

What is not apparent from Table 7 is the high reliance on line printer graphics. This reliance is because 1) all Corps offices have direct access to a line printer with few having direct access to a plotter, 2) for actual working production runs, printer maps are cheaper to produce and they are returned with the other analysis results and 3) the authors have a basic philosophy that before you add the "eye-wash" that the results displayed are as accurate and meaningful as possible. Many users are awed by plotter graphics and either they are reluctant to redo a plotter graphic because of costs or they tend not to question the validity of a plotter graphic because of its quality. However, this high reliance on line printer graphics does require that a grid cell is the size of a computer character on the adopted Basemap.

TABLE 7

GRAPHIC SOFTWARE

Software	Use
RIA	Line printer maps of grid cell data. 22 map levels, variable data range, etc. similar to GRID (13) developed at Harvard. Used to display data bank variables and analysis results.
*AUTOMAP II	Line printer maps of polygon, line, point or contour data. Used to verify polygon data and may be used to create single variable grid cell files.
*GRIDPLOT	Plotter maps (Plot, CRT, 35mm or microfilm) of grid cell data. Used for final graphics.
*AUTOPLOT	Plotter maps (Plot, CRT, 35mm or microfilm) of polygon data. Used to verify polygon data and for some final report graphics.
4-VIEW	Three dimensional plot of grid cell data (primarily topographic elevation) from the four compass headings. Hidden line capability.

* Proprietary software of Environmental Systems Research Institute, Redlands, California.

The grid cell size selected in most studies to date has either been 1.15 - 1.53 acres. This rather odd grid cell size has been chosen because it generally captures the topography and land use in the detail required and it permits an undistorted computer line printer map to be generated from the data bank. Most of the Corps studies have adopted the U.S.G.S. 1:24000 quad sheet maps as the Basemap and at this scale a single computer character space occupies either 1.15 acres (200 x 250 feet) at 8 lines per inch or 1.53 acres (200 x 333 feet) at 6 lines per inch.

Plotter graphics do play an important role in the display of the data bank variables as an atlas, and in the display of selected analysis results in the final report. Plotters also are used in some studies for the verification of polygon boundaries in the encoding process and for verifying topography with contour and 3-D perspective plots.

All of the plot programs are used either on a Calcomp plotter, a Tektronix CRT, microfilm or 35mm film. The creation of the final report graphics is usually accomplished by first executing the display on a Tektronix CRT to design the display, and then that plot is disposed to the plotter or 35mm film. A fairly inovative use has been made of 35mm graphics to create color separation plates for color graphics. Using the 35mm film directly for the Castro Valley data bank has lowered the cost of producing the color separation plates from approximately 350 dollars to only 10 to 15 dollars. This cost reduction makes it possible for a greater number of meaningful color displays which may be used in corps reports or in public involvement meetings.

TECHNOLOGY DEVELOPMENT AND MANAGEMENT

Advanced computer technology development and implementation is the stock in trade of the Hydrologic Engineering Center. A method for successfully functioning in this arena has evolved over the years that generally operates as follows: 1) Needs for new methods and procedures surface through the Center's continual contacts that exist through a traditional consulting type service, e.g. production work for field offices requesting assistance, 2) research and development work is performed to solve the specific problem(s) that surface in the glaring lights of the production environment, 3) the specific solution is generalized if it may service an entire class of problems in both conceptual and geographical scope, 4) high quality documentation is developed and the technology readied for long term service and maintenance, 5) training courses are held and consultation projects performed that gradually, but systematically, move the technology into the normal stream of work efforts in the Corps, and 6) continuing development, servicing and maintenance is commenced to assure timely aid to all potential users and to guarantee that up to date capabilities are continually incorporated.

As a result of HEC's previous efforts in program development, several "truisms" have emerged that are especially applicable to major technology development and implementation tasks such as spatial data management.

1. Large scale, complex, comprehensive computer programs are dynamic entities that require continuous nurturing and support in order to remain viable and useful. Such computer software needs a permanent home; an institution that is philosophically committed to the improvement in procedures, morally committed to servicing and improving the computer programs and

competantly staffed to perform the task.

2. Business-like computer program code generation and its subsequent management is vital if it is important for the software to be portable between computer systems. As a general guide, use of special purpose languages that are proprietary or not generally supported by major computer installations should be avoided. Adherence to ANSI (American National Standards Institute) standards is important and modern modular programming practice with avoidance of machine or language dependent routines will greatly reduce future computer source code maintenance problems.

3. Successful implementation of advanced concepts requires both useful technology available in appropriate form and users that are interested and anxious to take advantage of technologic opportunities. It's important in early stages to encourage applications that are manageable and have high potential for success. A commitment to the service attitude and genuine interest in solving the users specific problems are basic. A series of do's and don'ts with supporting explanation follows which attempt to define a framework and strategy for software implementation.

. <u>Don't require programs/concepts to be used before considerable experience and shake down is accomplished</u>. Nothing kills new technology like forced use that does not deliver the solution to everyone's problems. No new technology can ever be so tightly developed that it can survive an environment wherein the potential users are already somewhat negative by the forced approach. Programs that have been developed outside the environment by professionals with little or no production oriented experience have little chance of <u>initially</u> being responsive to studies in which they may be applied.

A more pragmatic, steady gradual introduction will likely result in earlier meaningful use of the concepts and techniques. NOTHING DRAWS USERS LIKE SUCCESS, NO MATTER HOW SMALL.

. Avoid the grand "demonstration" exercise. Demonstrations that are designed to sell technology usually get too many people involved (usually promoter types) so that the exercise becomes so important that the outcome ends up either being rigged or fails because of the weight of so many observers. Dissemination of basic information and publicizing applications is a valid approach, and provides the opportunity to learn and pursue the shake down process described above. Incorporation of sessions in seminars, general meetings or courses that cause people to work with the technology provides an excellent vehicle for spreading the word.

. Work WITH users to solve their studies. A full commitment to solving the users specific problem in a field study environment is perhaps the single most important facet of successful technology transfer. In a conceptual sense, an approach to developing advanced technology that seeks to solve specific problems in a real world setting from which the general elements are merged into a continuously growing general analytic system is much easier (and perhaps more responsive to user needs) than is an approach that sets about creating the grand solution and then attempts to adapt it to the problems. It is important to recognize that it is an unusual study that does not have some unique aspects. It is strongly suggested that early implementation efforts be directed toward work with users on specific studies.

. Carefully select manageable studies or portions of studies for application. This is the operational implementation of the idea that nothing draws users like success, no matter how small. The careful selection of small (in scope) well-defined problems that provide the opportunity for both developers and users to learn and improve the utility of the programs is important. It should go without saying that the worst strategy is to attempt to "solve the unsolvable" as the early application of the technology, or to take on more complex applications than can be reasonably managed. Ample opportunity to work on difficult problems (we all have an abundance of these) will be present at any point it time; build some experience base to operate from before going for broke. A series of small, growing to more comprehensive and difficult applications over time is the desirable strategy for which to strive.

. Be prepared and willing to perform logic and program code changes as a normal part of virtually all early studies. It would be somewhat miraculous if developers of a system of programs could have foreseen all the potential study environments, objectives, data availability, issues, etc. that the techniques will be used for. Errors will exist; Murphy's Law operates in computer programs even better than in complex machinery. The attitude and ready resources to make the necessary adjustments will reflect the commitment to a "services" approach to implementation.

Status of the HEC Spatial Data Management Programs

The cycle of development and implementation which has been described in this paper is well along for the Corps spatial data management computer software. The initial developmental efforts were conducted in the day-to-day production environment of several field offices, resulting in pilot studies which were quite successful and very enlightening as to future improvements and potential applications.

The software which was originally developed for the Oconee pilot study has been extensively rewritten and expanded in scope for the subsequent applications by other field offices. The newest version of the software, however, has stabilized enough in recent months so that a major effort is currently underway at the HEC to make available for public distribution the computer code (FORTRAN) along with high quality documentation.

The HEC is continuing to cooperate with new Corps applications to help assure that any needed software adjustments may be performed in a timely manner. The HEC has established staff and procedures to implement the short and long term servicing of the software. The Center also acts as the transfer agent of new technology through the publication of guide manuals such as (12) and through the use of seminars such as (11).

The Hydrologic Engineering Center is convinced that the necessary initial steps have been taken to assure the long term growing utility of spatial data management techniques to the Corps of Engineers.

Literature Cited

1. Davis, Darryl W., June 1978. Comprehensive Flood Plain Studies Using Spatial Data Management Techniques. Water Resources Bulletin, American Water Resources Association.

2. The Hydrologic Engineering Center, 1975. Phase I Oconee Basin Pilot Study - Trail Creek Test. Davis, California

3. The Hydrologic Engineering Center, 1977. Annual Report, Davis, California.

4. Water Resources Council, Monday, September 1973. Water and Related Resources, Establishment of Principles and Standards for Planning. The Federal Register No. 174-PTIII-1.

5. Webb, R.P., and M.W. Burnham, 1976. Spatial Analysis of Nonstructural Measures. Symposium on Inland Waterways for Navigation, Flood Control and Water Diversions. American Society of Civil Engineers.

6. U.S. Army Engineer District, Savannah, 1977. Phase I Oconee Basin Expanded Flood Plain Information Study.

7. The Hydrologic Engineering Center, 1977. Oconee River Water Quality and Sediment Analysis. Davis, California.

8. Institute for Water Resources, 1971. Honey Hill, A Systems Analysis for Planning the Multiple Use of Controlled Water Areas. IWR Report 71-9.

9. The Hydrologic Engineering Center, 1976. Resource Information and Analysis Users Manual (Draft). Davis, California.

10. The Hydrologic Engineering Center, 1977. Water Quality in River and Reservoir Systems User Manual. Davis, California.

11. The Hydrologic Engineering Center, 1977. Proceedings of a Seminar on Variable Grid Resolution - Issues and Requirements, Davis, California.

12. The Hydrologic Engineering Center, 1978. Guide Manual for the Creation of Grid Cell Data Banks. Davis, California.

13. Sinton, D. and C. Steinitz, 1971. Grid Manual. Laboratory for Computer Graphics. Harvard University.

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