US Army Corps of Engineers
Hydrologic Engineering Center

Proceedings of a Seminar on

Analytical Methods in Planning

26-28 March 1974
Davis, CA

SP-6

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
26 - 28 March 1974	Seminar Proceedings	

4. TITLE AND SUBTITLE
Analytical Methods in Planning

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
CEIWR-HEC

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
SP-6

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
Collection of papers presented at a seminar held at the Hydrologic Engineering Center, Davis, CA on 26 - 28 March 1974

14. ABSTRACT
A seminar on Analytical Methods in Planning was held on 26 - 28 March 1974 at the Hydrologic Engineering Center (HEC) in Davis, California. These proceedings describe a variety of analytical methods: computer simulation, optimization, computer graphics, input-output analysis; and their application to planning studies. Hopefully, the information provided will give an under standing of the methods themselves, of the information that can be provided, and the cost to obtain this information.

15. SUBJECT TERMS
planning, analytical, water resources, planners, engineers, quantitative, computer, techniques, computer simulation, optimization, computer graphics, input, output, planning studies, urban studies, inland navigation, reservoir, multiple-purpose, HEC-5C, flood control, stochastic, impact assessment, flood plain management, geographic information, water supplies

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	200	19b. TELEPHONE NUMBER

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

Proceedings of a Seminar on

Analytical Methods in Planning

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Attendees:
Corps of Engineers
University of California, Berkeley
Lawrence Berkeley Laboratory
Environmental Systems Research Institute

Location:
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

SP-6

FOREWORD

A wide range of analytical methods are presently available to assist planners and engineers in planning of complex water resource systems. Their purpose is to provide planning information - information not otherwise available, or available only at greater cost. Making effective, meaningful use of the variety of analytical, quantitative computer-oriented techniques available presents a challenge to every planner. It requires an understanding of the methods themselves, of the information they can provide, and of the cost to obtain this information. These, and other topics were the subject of a 3-day seminar on "Analytical Methods in Planning" held 26-28 March 1974 at The Hydrologic Engineering Center and funded by the Institute for Water Resources, Corps of Engineers. These proceedings are the papers presented at this seminar. They describe a variety of analytical methods - computer simulation, optimization, computer graphics, input-output analysis - and their application to planning studies. It is hoped that their availability will encourage greater, more effective use of these techniques in planning.

The papers are, in general, frank discussions by the authors and are not official Corps documents. The views and conclusions expressed are those of the seminar participants, and are not intended to modify or replace official guidance or directives such as engineer regulations, manuals, circulars, or technical letters issued by the Office of the Chief of Engineers.

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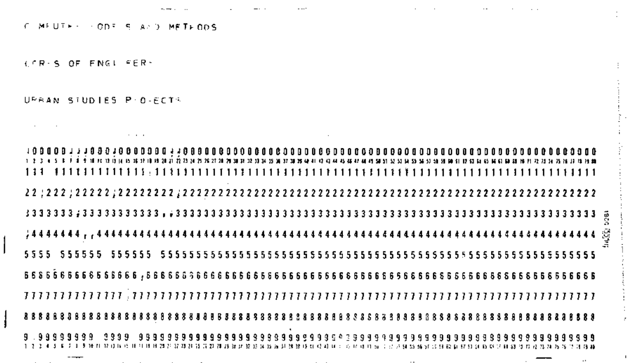

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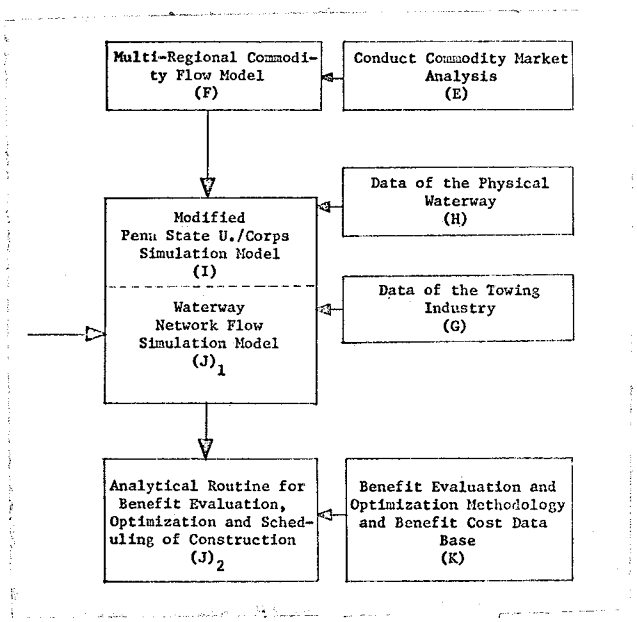

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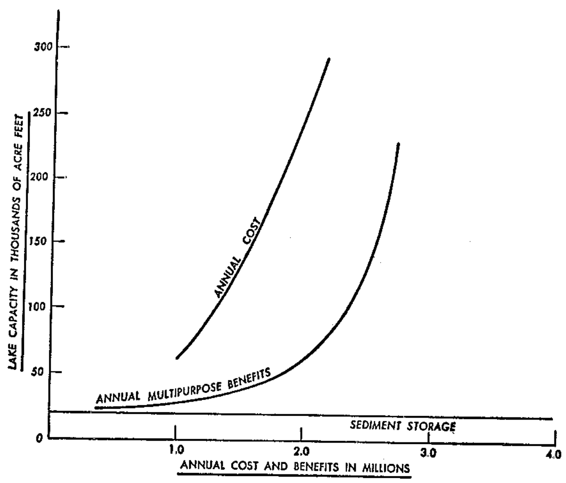

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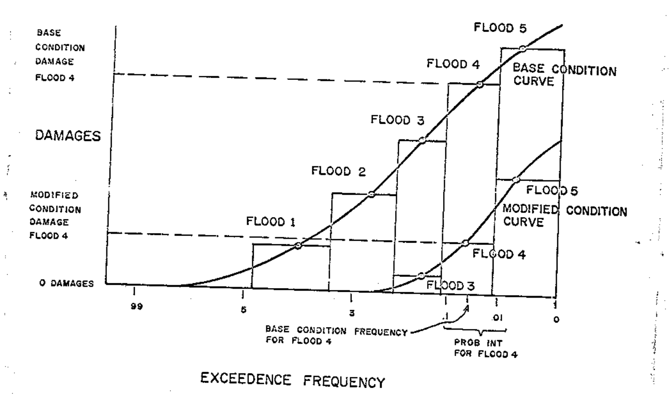

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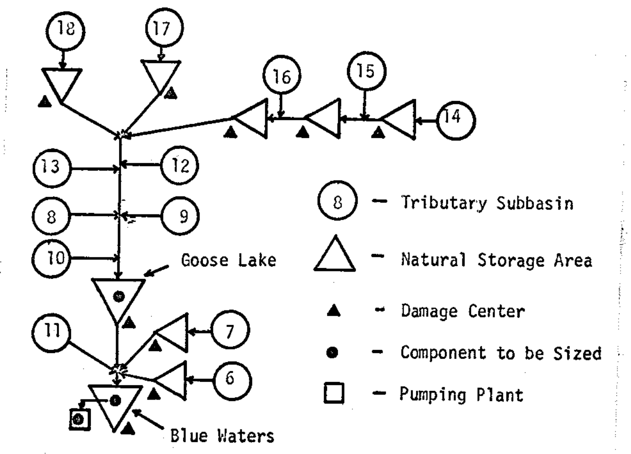

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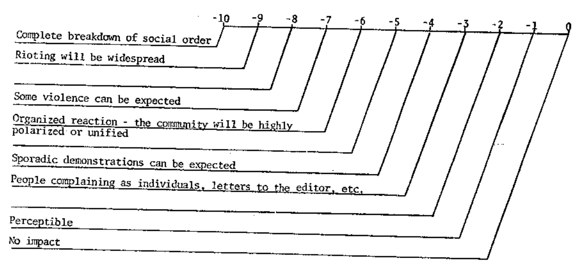

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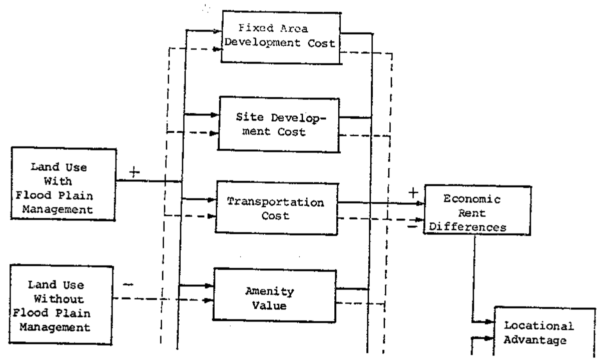

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* Flood Damage Reduction Techniques
* Land Use Requirements Over Time

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TABLE 1a

County X

Ranking Process

Grid Row	Grid Col	Acres in Hvy. Ind. X_1	Access to RR X_2	Ind. Empl. X_3
100	50	50	8	800
105	50	150	10	1000
110	50	30	3	800
115	50	0	1	500
120	50	20	2	77

* Population, Employment Distribution
* Allocation of Land-Use Activities
* Land Use: Industrial, Residential, Commercial, Public
* Variable Ranking Criteria

ALTERNATIVE SYSTEMS FOR COMPUTER MAPPING AND AUTOMATING GEOGRAPHIC INFORMATION

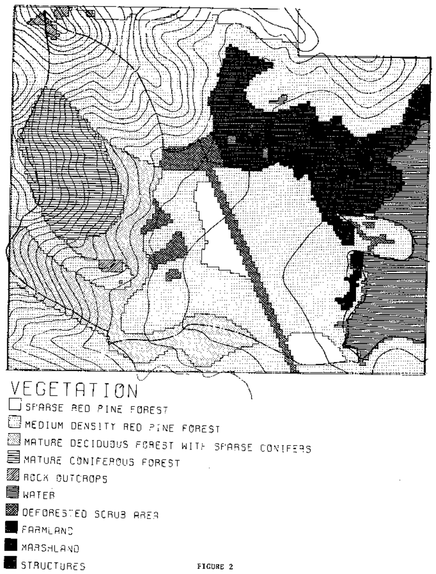

FIGURE 2

* Origin of a Geographic Data System
* A Classification of Spatial Identification Techniques
* Computer Mapping of Point Data
* Polygon Overlay and Related Analysis Applications

DEVELOPING REGIONAL WATER SUPPLIES - A CASE STUDY OF SOME ANALYTICAL PLANNING METHODS

TABLE 1

Problem Definition	Alternatives	Impact Assessment
1. Water supply demand is in excess of yield	1. Diversion from Connecticut River	1. Estuarine ecology
		2. Reservoir ecological investigations
2. Misuse of available supplies	2. Ground-water	
	3. Watershed Management	3. Economic costs
3. New supplies create unwanted growth		4. Socio-economic impacts
	4. Wastewater Reuse	
4. Economy will suffer without new supplies	5. Pricing to reduce demand	5. Effect of groundwater on cranberry bogs
5. Additional recreation opportunities needed	6. Desalting	6. Downstream supply needs

* Regional Water Supply Planning Study
* Use of Analytical Methods
* A Program for Estimating Costs of Hard Rock Tunnels
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A REVIEW OF MODELS AND METHODS APPLICABLE TO CORPS OF ENGINEERS URBAN STUDIES PROJECTS

By

Jerry W. Brown[1]

I. Purpose

The general field of Urban Studies embraces a very wide range of problems. The types of agencies and institutions studying these problems and the methods they employ to solve them are as numerous as the problems themselves. In order to provide some direction to field offices faced with problems in urban planning, the Office of the Chief of Engineers (OCE) initiated a study at the Waterways Experiment Station (WES) 1) to identify the available methods and simulation models of potential use in urban studies, 2) to evaluate the applicability of these methods and models, and 3) to recommend future actions that will enable the Corps of Engineers to meet their continuing obligations in the field of Urban Studies.

II. Scope of Study

The focal point of the study was the role of water problems in urban planning. The areas of primary interest were the socio economic aspects of planning, land-use analysis, water supply, wastewater management, urban hydrological processes, and recreation planning. Each of these areas was thoroughly researched in order to locate all working models of interest to the urban planner or engineer. From the large number of possible models that were found and studied, the most useful and most representative of these were summarized for inclusion in this report. In addition, the general level of research and the state-of-the-art in each area are also summarized here.

These general summaries of the field of urban planning, along with some recommendations to the planner, are given in the next section. The particular models and methods dealing with specific topics are summarized in special format in the Appendix.[2] Also included in the Appendix is a list of institutions active in urban planning.

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[1]Operations Analyst, Mathematical Hydraulics Division, Waterways Experiment Station

[2]The Appendix is not included in this paper; the reader is referred to the final report for the information cited as in the Appendix.

III. Summary and Recommendations

A. Socio Economic Planning

1. Summary

a. Introduction

As part of the overall attempt to identify computerized models of use in the Urban Studies program, social and economic considerations were included in the search. Under the heading "economic," the study concentrated on macroeconomic frameworks for urban economic analysis, benefit measurement for water resource developments and, to a lesser extent, on the application of mathematical programming techniques in the formation of water resource economic models. Even though the specific thrust of the search was directed in the above areas, it was impossible to include the abundance of models analyzed. The models selected for this report represent the state-of-the-art of application of economic models to water resource development in an urban context. Where there was more than one model associated with a particular methodology, the one included in the Appendix was thought to be most representative of the technique illustrated.

b. Economic Modeling

Two basic macroeconomic frameworks were included in the economic section. Input-output modeling was the most widely used technique with varied applications. Econometric modeling was the second technique included. The application of econometric models dealt less directly with water resource problems in urban areas, but represents a viable technique for important economic analysis.

(1) Input-Output Models

The potential applications of I-0 analysis to water resource development planning in urban areas are many. The I-0 matrix provides a picture of the general structure of the economy under scrutiny. In Urban Studies, it is important to understand the interrelationship of industry, manufacturing, households, resource use, etc. in order to plan effectively. The effects of investments in water resources on the economy can be determined more accurately.

Using projections of income, payroll, employment, population, etc., the I-0 matrix is a device which can forecast the requirements for water by relating it directly to the expected growth of the economy. Using linear programming in conjunction with I-0 analysis, one can generate a procedure for the optimum allocation of water or other resource based on sectoral constraints. Trade-offs between sectors can be evaluated by sensitivity analysis.

Another technique involving I-0 is given the general label economic-ecologic analysis. Pioneered by Walter Isard, this technique attempts to relate emission of pollutants to the environment with economic activity. The linkage occurs between the I-0 matrix and an environmental matrix. Dollars of output per unit of pollutants emitted can be roughly estimated.

Even though the potential uses of I-0 are many, the operational use of this technique is still in the developmental stages. Most of the publications on I-0 analysis are the results of academic research, not application. The huge data requirements involved in completing an I-0 matrix are one drawback to its essential large-scale application. The recent use of "modified" data from OBE national I-0 model adjusted to fit a regional area shows promise as a way to cut down the cost requirements for gathering basic data. The San Francisco Bay-Delta Region Industrial Water Quality Study used this method. The I-0 theory itself contains many assumptions of which a potential user should be aware. The model is static, i.e., a snapshot of the economy. The trade and technological coefficients used in the model are derived from base year calculations. Most I-0 models have base years that are at least 10 years prior to the time of analysis. Economic changes during that time span decrease model credibility. I-0 models assume stable and linear trade and technological relationships. Economies of scale and technological progress are not taken into account.

(2) Econometrics

Econometric modeling is an important area of interest to many people in the field of economic forecasting. However, its application to specific economic problems related to water resource development in urban areas has been limited. An econometric model is composed of a number of equations that are used to give forecasts of important economic indicators (output, employment, income, taxes, etc.). Once the equations are verified using historical data, projections are made about the economic future of a region.

An econometric model can simulate the effects of major new developments in a region by assessing the effects upon the economic variables in the equations. This characteristic offers an approach to investigating economic benefits of proposed water resource developments in urban areas.

As with I-0 analysis, however, econometric modeling has practical limitations with respect to data requirements. Regional economic data must be provided for each region modeled. For the Urban Studies program, the spatial area must be delineated and data gathered. Since the econometric model uses standard aggregate economic variables, the availability of these data is more common than for I-0 analysis.

The equations are driving components of the model. These equations are formed by regression analysis and analysis of the area modeled. The model is "fit" to historical data. This technique may be acceptable for short-range forecasts, but does not have the sensitivity required for long-range forecasts. The model may well explain past behavior, but there is no guarantee that it will accurately represent future changes. Cogent analysis is necessary when applying this type of model.

At the present time, the amount of disaggregation of model output is not sufficient for an urban area. Forecasts are usually made at the state level. None are available at the substate or urban level. Modifications must be made to existing data bases before meaningful analysis can be made at an urban level. Thus, the present value of this modeling technique is to large regional planning rather than a single urban area.

(3) Benefit Evaluation

Benefit evaluation is an important aspect of an urban study. Some of the conventional procedures, requiring manual methods in the past, have been computerized. Also, new procedures readily adaptable to computers have been developed. All of the topics in this search touched upon benefit evaluation in their specific modeling area. Land use models deal to a large extent with this subject.

Flood control, urban water parks, long-term investment in water resources, and water quality changes are a few of the areas in which economic benefits have been calculated with the help of the computer. Most of the models use the computer only as an accounting device and calculator. Flood control benefits are associated with "damages prevented" by the institution of flood prevention measures. Using a given probable flood, the damages with and without flood control measures are calculated. The difference in damages is the assumed benefits of the respective projects. The computer memory offers a reliable accounting system to store data on land use, surface elevations and flood inundation levels and produce estimates of damage. The University of Kentucky flood control programs take this analysis a step further. These models evaluate alternative flood control measures, both structural and nonstructural that minimize the economic cost of flooding. Planning level estimates of the optimum combination of flood control measures are part of the output. Similar use of the computer can be found in the application of statistical techniques to give an estimate of benefits associated with various urban water resource projects.

A recent development in this area is the use of an economic trade-off model for use by decision-makers. This type of model uses a set of economic and environmental submodels dealing with important factors associated within a region. Data concerning employment, income, industrial output, land use, natural features and resources, among others, are used as base input. The model attempts to measure prospective changes in the economy, such as a water resource development impact upon the region. Both economic and environmental parameters are affected. These impacts can be assessed more accurately by decision-makers by examining their effect on the economic and environmental factors of the region. The term "trade-off" relates to the final decision which must be made based on (to a large extent) the information supplied by the model. After refinement of the initial model and improvement in data bases, information models of this sort would be a powerful tool for the urban studies program.

(4) Mathematical Programming

Mathematical programming techniques were found in abundance throughout the literature. These include linear programming, non-linear programming, dynamic programming, network theory, and geometric programming. The techniques are used in the study of water quality, water supply, and optimum timing and sequencing of water resource projects. Most of the literature, however, describes a hypothetical situation using simplified assumptions which ignore many of the practical problems involved in real project study. Dracup( ) discusses this problem and calls for a move from theoretical research to analyze sound practical problems. His book analyzes the use of all system analysis techniques as applied to water resources. It is a state-of-the-art study of the most significant research in water resource systems analysis.

Many models that view water resource problems such as water supply, waste treatment, flood control projects, etc. have cost constraints as an integral part of the problem formulation. These were not considered economic models, and the computerized applications which are of use in urban studies are found under the specific water resource area of concern in the Appendix.

c. System Dynamics Models

A relatively new technique for analysis of water resource planning is the system dynamics model. This technique examines the cause and effect relationships between important variables of a system by means of feedback linkages. This framework incorporates the dynamic nature of a system by allowing for changes in important factors (resources, policy decisions, etc.). Once the feedback structure is established, simulations can be run to determine spatial and temporal effects of various policy decisions about resource use.

The KSIM model is a variation of the system dynamics technique. KSIM is a simulation technique that allows a group of participants from different disciplines to evaluate a wide range of interactions among key variables in the planning process. Both economic, social, environmental, and political ramifications of a proposed plan can be examined using the KSIM method. KSIM is not only a computer model, but an entire process. Participants must formulate the problem, identify the variables for study, develop the connection between variables, and, after construction of the cross-impacts table and subsequent computer simulation run, analyze and evaluate the effects of a proposed plan. The application of this method to water resource development projects under the Urban Studies program is a powerful tool. The planning process is condensed in the KSIM session allowing the participants a greater insight into potential problem areas. As a "first cut" approach to a planning problem, KSIM is a methodology with great potential.

d. Social Models

Much of the literature of water resources deals with the need for evaluation of the social effects of project development. Unfortunately, the more elusive question of how to identify, no less measure, these effects is yet to be answered satisfactorily. When one writes of "socio economic" effects in the literature, the economic half dominates the article with a rather brief mention of the need for "recognition" of social problems. Little actual research has been devoted to what impact water resource development has on the social system of a region. The studies that have been completed are explanatory in nature and examine limited aspects of the problem and focus on small areas.

One computerized model presents a method for evaluating the social impacts of alternative urban developments. The method involves evaluating the effect of different alternatives in terms of achievement of social goals. The STRAWMAN model is the result of three years of research work on the development of techniques for estimating the potentials of water resources development in achieving national and regional social goals. The Technical Committee of the Water Resources Conference of the 13 Western States developed the model. Essentially, the STRAWMAN model establishes a hierarchy of goals all assumed under the goal, "general welfare."

The STRAWMAN represents an important step toward eventual inclusion of the social impacts of water resource development in the planning process. The methodology, however, outstrips both the data available for analysis and the state-of-the-art as far as social indicators are concerned. There is not a widely accepted or general group of social indicators currently available for such a methodology. Research is needed in order to identify pertinent social indicators and develop measurement techniques for practical application. Initial tests of STRAWMAN involved basic economic indicators, which are well established, but omitted social indicators. Continued social research into understanding social phenomena will hopefully produce the understanding of the social system to allow the full use of STRAWMAN.

B. Land Use Models

1. Summary

a. Introduction

The initial consideration in urban planning is determining what resources are currently available in the urban area of interest. This resource inventory is required for all aspects of urban planning including wastewater and solid waste treatment and management, flood protection, land use, recreation, etc. Once the resources have been determined, the next step in the process is to predict how individual portions of the urban area will change as a function of time. Since land allocation is one of the most important factors in controlling urban change and development, it is extremely important that mathematical models that simulate the impacts of different uses of the land be provided (or developed) for use in the urban planning process.

In this part of the report, the models related to land use and land-use analysis are presented. The specific details of each of these programs are contained in the program data sheets included in the Appendix, Part C, and therefore, only a general comparison between the models is given in the following paragraphs.

The land-use models that have been developed provide projections and allocations of the uses of the land at prescribed times in the future. In addition to the land-use allocation considerations, some models provide consideration for floodplain management and control measures to obtain the best development in terms of economic benefits.

Eighteen computer programs and concepts related to land use and land-use analysis were reviewed and evaluated in this study. The programs and concepts consisted of a variety of linear and nonlinear functions that performed various operations and calculations to obtain allocations of and forecasting future uses of specified parcels of the land. A few of the programs contained provisions for modeling different land uses such as single-family and multiple-family residential, high-rise apartments (residential), light and heavy industry, commerical centers, transportation arteries (i.e., highways, roads, streets, etc.), agricultural, vacant and public land. None of the land-use models considered in this study provide for allocations of parcels of land for recreational uses. However, it is believed that the model recently developed by Midwest Research Institute (see Part G of this report) contains methods that might have some application in specifying land (and water) for recreational opportunities or uses, such as reservoir access areas for hiking, campsites, picnic areas, etc.

It is believed that one of the major difficiencies of the present land-use models is the shortage of formulated techniques for "deterministically" assigning uses (or multiple uses) for the urban lands. Most of the models contain "methods" for projecting historical trends in the uses of the land, but there are very few, if any, presently acceptable methods for making predictions of the future uses of the land from the standpoint of environmental, social, and aesthetic considerations.

b. Evaluation of the Land-Use Models

Various literature sources were canvassed for models, computer programs, and projections techniques and methods related to land use and land-use analysis. Examination of the various programs and methods obtained revealed some basic commonality, despite some initial difference in structure and appearance. Each of the similation techniques were examined as to what was being addressed by the model in terms of (a) type of use, (b) size of land unit considered, (c) projections and allocation methods; (d) flood protection considerations, and social and environmental effects. In some cases, it was most difficult to determine just how each of the above considerations was being treated in the program(s), and as a result some subjective determinations were made as to what was being considered in the model.

Table 1 in the Appendix, Part C, shows how the various programs and methods compared in terms of what was being considered in the models. These items are briefly discussed in the following paragraphs.

c. Type of Land Use

All of the land-use models reviewed in this study contain specifications for different uses of the land. For example, the Intasa model provides allocation of any number of activities (residential, industrial, commercial, etc.) to the available vacant land; whereas, some of the other models are more specific about the type of activity to be allocated. In the St. Louis SMSA model, the demand for the land is divided into four main categories - industrial, residential, commerical and public and these four categories are then ranked for allocation in a prescribed order of importance. Thus, the St. Louis SMSA model first allocates the industrial uses for the land and then based on this allocation the next land-use type (i.e., residential) is then allocated and so on until the four categories have been satisfied.

d. Projection and Allocation Methods

Most of the programs reviewed herein contain provisions for estimating population and economic activity forecasts for future times. For the most part, the population and economic forecasts are provided exogeneously as inputs to the models, and these data are the basis for allocation of the land for some prescribed use. Most, if not all, of the forecast data have been obtained through the use of linear regression models which project into the future what happened in the past. As a result, the forecast data do not realistically account for any future change in taste or technology that may develop.

The land allocation methods used in the various models are based to a large extent upon a desirability ranking of the land units. For example, in the St. Louis SMSA model, population is allocated to presently used land subject to a user supplied maximum density. This density represents the maximum level to which currently used land can be developed. When this level is reached, the next land-use can be developed. When this level is reached, the next land-use category, in the order of importance as established by the model (or in some cases by control variables), is selected for population allocation and so on until the predicted population estimates have been satisfied.

Since the allocation procedures contained in the various models are quite different in a number of ways, additional study is warranted to determine which allocation methodologies would be most acceptable for Urban Studies.

e. Floodplain Management Considerations

Three of the land-use models reviewed herein contain some consideration for floodplain management. These include the Intasa model, the Galveston model and the University of Arizona model. All three models are directed towards achieving floodplain management objectives by considering the most economically efficient combination of land uses, development policies and engineering alternatives such as the use of dams, reservoirs, levees, floodwalls, channel alterations, etc., to provide different measures of flood protection. The models provide for assesements of flood damage using a reference flood profile as a basis of analysis.

C. Water Supply

1. Summary

Water resource management problems are concerned basically with Supply-Demand studies. Historically, governments have concentrated on locating supplies and performing the necessary engineering to distribute the supply in a potable condition to the users. Various studies concerning these methods have appeared for many years. Demand studies and methods of forecasting need have not received nearly so much attention. These methods are only recently being developed and most are rather crude. With supplies becoming limited, and with serious consideration of reuse being evident, the planner can expect future studies to be as concerned with how much water is needed and how it will be used as they are presently concerned with how to treat and distribute supplies.

Most programs that have been developed to aid in water supply studies have not been restricted to urban areas. The large river basin development studies have the capacity to consider storage and release for irrigation and diversion as well as power generation, low flow maintenance, and urban consumption. This would be a useful feature for regional studies.

Supplying water for recreational use has not been an important problem in the past, even though this use of water has always proven of great benefit to urban areas. Water projects were justified on seemingly more important issues such as industrial needs, irrigation, flood control, or urban consumption. With the present interest in multi-objective planning, such areas as conservation, fishing, hunting, camping, and scenic beauty can be raised to their proper level of importance.

An area of water supply that is currently receiving much consideration is water reuse. The EPA is presently conducting research into the many possibilities of reuse, the biological and psychological problems, and the economy of reuse. The state-of-the-art in the area of reuse is not sufficiently advanced to consider it a major source for present water supply planning purposes, but the planner should study the current literature so as not to overlook any important changes in the status of water reuse.

A perusal of the models contained in the area of water supply in the Appendix indicates the very limited attention that problems associated with water supply, i.e., location and pumping of groundwater, transport of surface water, storage, treatment, and distribution, are currently receiving from the builders of simulation models. However, these areas are covered quite adequately in many standard engineering texts which are readily available.

D. Wastewater Management

1. Summary

a. General

The management of wastewater is a primary factor for consideration in the urban/regional planning projects that are being conducted by the Corps. The passage of PL 92-500 in 1972 established a sequential series of goals intended to improve the quality of the Nation's water. Therefore, the planner is constrained to give serious consideration to these goals. Briefly stated they are:

(1) Secondary treatment by 1977.

(2) Best practicable treatment by 1983.

(3) Zero discharge of pollutants by 1985.

Wastewaters eminate from a variety of sources including sanitary sewers, some storm sewers, industrial effluents, cattle feed lots, agricultural runoff, meat processing plants, etc. Management of these wastewaters may be handled in several ways. The associated management schemes fall into one of three general categories, i.e., assimilation of waste by receiving waters, use of conventional collection, treatment and disposal systems, and land disposal of wastewater. In practice, a well-designed system may include all of these systems to optimize treatment and minimize cost.

b. Assimilative Capacity of Streams and Estuaries

There are two schools of thought regarding the use of streams and estuaries to carry a part of the wastewater loads associated with domestic, industrial and agricultural needs and practices in this country. The economist and some engineers and biologists prefer to plan for use of the streams maximum safe capacity for assimilating waste loads without degrading the water quality below some established standard. On the other hand, some engineers, biologists, environmentalists, and ecologists feel that we should strive toward maintaining (or reestablishing) a near pristine environment. Regardless of the position one assumes, it is obvious that there is a need to accurately predict the effect of wasteloads on receiving waters.

Although a number of models are in existence, there is no model available that is a complete and accurate representation of all the physical, chemical, and biological forces at work in either a riverine or estuarine environment. There are, however, a number of models that are good state-of-the-art approximations of these environments. The models vary in complexity depending on the number and types of pollutants to be modeled and the hydrological and geometrical complexity of the aquatic program. The Appendix contains 39 references on models and other articles of recent vintage (1969 to 1973) that pertain to aquatic systems.

Riverine. The most complex of riverine models noted in this review is capable of handling transient (non-steady-state) conditions, both conservative and nonconservative pollutants, electrical conductivity, and temperature. In addition, there are good engineering models of limited scope that may be very useful for certain applications.

Estuarine. Probably the most widely used of the estuary models is the DEM( ). It has been used in a number of estuaries with reasonable success. The model is two-dimensional, it can be used to predict spatial and temporal distribution of both conservative and nonconservative pollutants.

c. Design of Collection, Treatment, and Disposal Systems

A total of 21 models were evaluated that pertain specifically to collection, treatment, and disposal of wastewater. These are referenced in the Appendix, Part E. Within this set, there are several categories of models. There are two general planning models, the WESCAT model(1) and the Regional Wastewater Treatment System model(2). Two of the models (3 & 6) address the problem of overall treatment plant design and 13 of these (4, 5, 7, 10 through 18) are simple models for the design of a single treatment process. Two models deal with sewer designs and stormwater control alternatives (19, 20) and three models' sole purpose is cost estimating and optimization and (8, 9, 21).

d. Planning Models

The WESCAT model (1) is very comprehensive in that it considers options for placement of waste treatment facilities, characteristics of collections systems, and allows an assessment of the effects that various types of municipal and industrial growth might have on receiving streams. The model given in reference (2) is designed to permit a rapid assessment of economies of establishing a regional treatment system as opposed to constructing two or more (up to 20) smaller systems. The cost model currently being used by the San Francisco District (21) may also be considered as a third large-scale planning tool.

References 3 and 6 in the Appendix, Part E, contain models that can be used for system design, evaluation and optimization. Design in this case pertains only to selection of the proper grouping of selected unit processes, general sizing of facilities required an estimation of effluent quality and sludge production. These models contain cost equations as well as design equations and provide for cost and design optimization in a single model.

The EPA has formulated a series of models dealing with specific processes. These models are useful for planning particularly in those instances where planning involves expanding and upgrading of existing facilities in compliance with PL 92-500 where only a limited number of processes need be considered.

The stormwater control model (19) can be used to design urban stormwater systems and to estimate flows. The latter is of particular importance when the urban runoff is sufficiently polluted to require treatment. Muritt's sewer design model (20) can be used for general planning and specific designs.

e. Land Treatment

In 1971, the U. S. Army Engineers in cooperation with the EPA began an investigation of comprehensive wastewater management on a regional basis. In 1972, the U. S. Corps of Engineers initiated a very limited research program at two of its laboratories (CRREL and WES) and at the same time the Corps made funds available for the monitoring of several prototype systems. The monitoring and research efforts conducted to date have not produced sufficient data to warrant the formulation of a comprehensive mathematical model. However, CRREL and WES are in the process of formulating models of certain elements of the process.

In 1973, EPA published a survey of facilities now practicing land application of wastewater in the U. S.(1) It was found that this type of treatment had been practiced successfully throughout the U. S. The facilities included in this survey range from small systems with intermittent flows to continuous operation systems handling as much as 570 MGD. It was pointed out that in present practices most people are not "stressing" the system. While land treatment, in many instances, is an attractive alternative and has the advantage that renovation and recycling are a natural part of the treatment system, it is by no means a panacea. The solution of land disposal as a treatment alternative is dependent on a series of social, economic, and technical factors such as those given in the Appendix, Part E.

f. Cost Models

Although a number of the models in this group contain some cost data, only three are actually labeled as cost models (8, 9, 21) These are: the Wastewater Treatment Plant Cost Estimating System, the Economic Evaluation of Water Supply and Wastewater Disposal including the Cost of Seawater Distillation and Wastewater Renovation and the Cost Optimization Model developed by the Bechtel Corporation in 1970 (21) and modified by personnel of the San Francisco Engineer District in 1972.

E. Hydrological Processes

1. Summary

a. Introduction

The literature review conducted as a major effort in this study revealed much insight into the state-of-the-art of hydrological modeling. An overwhelming amount of work has been conducted in sophisticated hydrological modeling since the advent of the electronic computer. As a result, all models of possible application in Urban Studies could not be studied; however, the models selected are considered to represent a cross-section of the best available at present. Some models were eliminated from consideration by the simple fact that literature could not be obtained in time for review. Others not included did not appear to be applicable to the solution of urban problems.

A brief summary of urban hydrological processes is given below to introduce the reader to the mathematical models currently used to simulate these processes.

b. Urban Hydrology

Urban hydrology is rapidly changing from the "Rational Formula" era to the use of relatively complex simulation models for predicting the effect of land-use changes on the overall hydrologic behavior of the area of interest. Use of such models is no longer restricted to the engineer who must design storm sewers and other drainage works, but is increasingly being adopted by urban planners who are charged with regulating the growth of an urban area.

(1) <u>Basic Hydrological Processes</u>

There are three interrelated but separable effects of land-use changes on the hydrology of any area:

(a) Changes in peak flow characteristics.

(b) Changes in total runoff.

(c) Changes in quality of the water.

The primary transfers of water associated with a large sector of land occur through the processes of:

(a) Rainfall

(b) Infiltration

(c) Surface runoff

(d) Groundwater flow

These processes have been studied extensively and models incorporating these features (such as unit hydrograph techniques) are in widespread use for flood forecast and river development studies.

In a sense, the urban hydrologic system is much more complex than its rural counterpart. The hydrologist's answer to this problem of increased complexity has largely been to ignore it and to use models of great simplicity, e.g., the Rational Formula and its derivatives, to simulate urban basins. Are urban basins too complex to model accurately? No, a number of very good models for predicting the quantity of flow at various points in an urban area have been developed in recent years. A few models also estimate the effects on water quality or urban stormwater runoff, but generally to a lesser degree of accuracy than water quantity. A prerequisite for using the elaborate modern models, however, is the availability of good field data for calibrating a given model to local watershed conditions.

(2) Stormwater Runoff from Urban Areas

Perhaps the most notable change due to urbanization is the change in the runoff characteristics of the basin. Urbanization tends to increase both the flood volume and the flood peak. The volume of runoff is governed primarily by infiltration characteristics and is related to land slope and soil type, as well as the type of vegetative cover. It is thus directly related to the percentabe of the basin made impervious. This increase in runoff has the secondary effect of reducing groundwater recharge and thus decreasing low flows. With increased urbanization, the peak runoff rate will, in general, increase much more than the volume of runoff. This change is related to the increase in the rate at which water is transferred across the land to streams, and the resultant decrease in the concentration time of the basin. This change is related not only to the fact that water runs off faster from streets and roofs than from naturally vegetated areas, but that the construction of artificial channels, especially storm sewers and the increase in the hydraulic efficiency of existing ones, as they are lined or otherwise improved, also decreases log time. This reduction in the log (or concentration) time of the basin has an extremely important effect, which has been sometimes overlooked.

(3) Effects of Urbanization on Water Quality

One of the greatest public concerns will continue to be the quality of water. Changes in water quality due to urbanization are almost uniformly negative. There are two principal effects of urbanization on water quality. First, the influx of waste materials (such as raw sewage, treated effluent, oil and gasoline products) tends to increase the dissolved solids content and decrease the dissolved oxygen content. The addition of nutrients tends to promote algae and plankton growths in streams and lakes, turbidity usually increases, and game fish disappear. Second, as flood peaks increase less water is available for groundwater recharge, with resulting lower flows (and usually the development of stagnant pools) during non-storm periods. One of the more important water quality problems is the very rapid increase in the sediment load in streams due to the exposure of bare soil to storm runoff during construction. Increases in sediment yield in the order of 100 to 250 times that of rural areas are common.

(4) Urban Hydrological Data

Complete and detailed hydrological data would, of course, be the ideal background information for urban drainage design. Continuous streamflow records collected over a long period at key points in the drainage system are needed. Where important, comparable records of water quality are also needed. Although these data are far from complete, useful information is available in the form of streamflow records from the U. S. Geological Survey and in the form of precipitation and other meteorological records from the National Weather Service. Most of the data from these records are available in the STORET system.

c. Hydrological Modeling of Urban Areas

(1) General Requirements

Because all of our metropolitan areas are constantly undergoing dynamic change, a problem exists in predicting changes in the hydrologic behavior of areas where little or no field data have been collected. The data that do exist may be invalid since they were collected under continually changing field conditions. In addition, a variety of catchment sizes are associated with most urban areas, ranging from the small area tributary, to a street inlet, to those of sewered and local stream catchments, and to the basins of large rivers that pass through urban centers. A wide range of prediction requirements, therefore, exist for both the quantity and the quality of runoff.

The physical phenomena involved in urban systems are so complex that an analytic solution for any given problem is, in general, not feasible. The approach generally adopted has, therefore, been to simulate the system to the required degree of complexity, according to the user's desires. Understandably, there can be substantial differences between model requirements for planning, design and operation.

As discussed by McPherson and Schneider, 1972, the procedure used in nearly all current storm sewer design is the "rational method," the numerous inadequacies of which are commonly known. This method yields only an estimate of peak flow. A hydrograph is needed for the design of detention storage, for evaluation of pollution abatement facilities, for designing local flood protection works along streams, and as input for design of river development works. Also, quantification of the effects of urbanization on the hydrologic regimen is dependent in many cases on the availability of sewer outlet hydrographs.

Model requirements for planning require less detail than for design because the investigation of a range of broad alternatives is at issue. Data required for use in planning tools are general parameters or indicators for large-scale evaluation of various alternative schemes. Hence, the degree of model detail required in metropolitan planning is much less than for design. However, a certain amount of intensive detailed modeling is needed to establish parameters and indicators and to provide an understanding of governing hydrologic processes, so that simplified expedients are not misused.

(2) Methodology for Modeling Storm Runoff

Quantitative estimates of flows in a watershed can be made by one of four basic techniques:

Empirical formulae. The oldest and most common method is the rational formula, which was mentioned earlier in this section and will again be discussed in the "Conclusions and Recommendations."

Statistical correlation with watershed characteristics (regression models). Regression models seek to relate a causal factor such as precipitation and/or watershed characteristics with an effect such as peak flow, storm runoff volume, or annual runoff, by statistical correlation. These models are an extension of empirical formulae based on more data and more sophisticated methods of analysis. The application of regression models to urban problems are few, mainly because of the lack of adequate data on urban streamflow for regression analysis.

Frequency analysis of streamflow. If adequate streamflow records exist at a station, a means sometimes used to determine the probability of peak flows for drainage design is the statistical analysis of observed peak flows. Again the paucity of data on urban runoff creates an obstacle. Even if observed flows are available, their utility for urban drainage design might well be low because progressive urbanization could have led to shifts in hydrologic characteristics of the watershed.

Hydrologic Synthesis. Sometimes a hydrograph must be constructed from estimates of rainfall-runoff relationships.

(3) Urban Water Quality Models

Of the many hydrological models reviewed, only three attempt simulation of urban runoff quality: The EPA model, the Hydrocomp Simulation Program (HSP), and the Urban Stormwater Runoff model (STORM) available from the Hydrological Engineering Center (HEC). The MITCAT is currently being expanded to include a water quality prediction capability.

The algorithms in the STORM model, for example, are quite simple, relating BOD, suspended solids, and several other quality indicators to flow volume and days since the last runoff event. This may, for the present, be about all that can be done with respect to quality of urban storm runoff in the absence of some continuous observations of urban runoff quality in many cities. Good data, therefore, are a first prerequisite and a carefully devised accounting model is a second need.

F. Recreation Models

1. Summary

a. Introduction

Water and land have both experienced heavy use of their recreational resources. Justification for land and water resources for recreation is dependent upon acceptable methods for estimating probable use (attendance) and the social value of that use. The role for recreation as a user of both land and water or as one use in a multiple-purpose program is not easy to determine. However, like most other resource uses, recreation has to be measured by those characteristics that permit comparison with other resource uses such as residential housing, industry and others.

Considerable effort has been devoted to improving the methodology for determining the value of water and land recreation resources. Various statistical models have been devised for evaluating some of the recreation resources, and some techniques have been put forth for determining the willingness of people to pay, in terms of national income benefits through use of money and time costs of travel, for the recreation resource. However, the approaches that have been developed do not provide an adequate basis for projecting future use (attendance) of the resource, and most of these techniques have not been computerized and, therefore, require substantial investment for their use.

In this study, a search was made to locate computer models (and concepts) related to recreation and recreation demand that might have some application in Urban Studies. The recreation models are discussed in the following paragraphs.

b. General Descriptions of Recreation Models

At the time of this report, very few computer models and programs related to recreation and recreation demands have been developed. For this reason, only three computer models were reviewed and determined to be of some benefit for Urban Studies. The three recreation models include:

(1) The COMPATRAX Recreation/Demand Allocation model

(2) Nationwide Benefit-Cost Analysis of Outdoor Recreation

(3) The Honey Hill Study; or Systems Analysis for Planning the Multiple Use of Controlled Water Areas

In addition to the computer models listed above, some of the noncomputerized concepts and methods of determining the demand for and value of outdoor recreation that have been developed by Clawson( ) and others were determined to be of some benefit in recreational modeling for urban studies. Since these methods were not reviewed in detail in this study, additional study of these methods is recommended for determining their usefulness in recreational modeling.

To provide a general understanding of the models related to recreation and recreation demands, two of the three models are briefly described in the following paragraphs.

The COMPATRAX model is basically a computer-based model designed to provide estimates of present and future (or projected) usage at individual recreation destination complexes. The model's underlying rational is as follows:

(1) Recreational demands are functions of numbers and characteristics of population groups and are expressed by the desires of the individuals.

(2) The recreational demands are satisfied at the prescribed recreational destinations, which have various resource characteristics such as boating, camping, driving for pleasure, fishing, hiking, hunting, nature walking, sailing, sightseeing, snow skiing, swimming, and water skiing, etc.

(3) The portion of the recreational complex is derived from each market concentrations and depends on the complex's recreational resources, compared with destinations complexes that compete with it.

(4) The total recreational usage at any individual destination complex is specified as the usage generated by all of the individual market concentrations that provide a significant recreational demand. The total demand is determined by each market concentration and is based on the distance and the competitive efforts of all other accessible recreational destination areas.

The COMPATRAX model is quite flexible in that it has the advantage of being able to accommodate a large number of sources (i.e., origin areas) and destination areas. The specific details of the computer program is given in the program data sheets in the Appendix, Part G, of this report.

The Nationwide Benefit-Cost Analysis model provides estimates of benefits and costs of providing outdoor recreation facilities for different geographical areas. The program's underlying rational is given below.

(1) The program projects the quantity of various recreational activities based on estimated demand functions and projected socioeconomic characteristics of the population.

(2) The projected demands are distributed over existing supplies of recreational facilities as to minimize the number of additional facilities that would be required.

(3) The benefits and cost associated with adding recreational facilities of various types to the various geographical areas are then determined.

The details of the Nationwide Benefit-Cost Analysis model is also given in the Appendix.

IMPLEMENTATION OF THE CORPS' INLAND NAVIGATION SYSTEMS ANALYSIS PROGRAM

By

DuWayne A. Koch[1]

In 1787, two years before the adoption of the U.S. Constitution, an act was passed by the colonies which declared the navigable waterways between the St. Lawrence and the Mississippi Rivers to be common highways and forever free. In this way interstate commerce was encouraged through the free use of this nation's navigable rivers, harbors and channels. Through a series of Acts in 1824, Congress extended this general principle and began the federal waterways improvement program which was assigned to the Army Corps of Engineers.

This responsibility was accepted seriously and carried out admirably by the Corps, having developed and maintained over 25,000 miles of navigable channels since that time. There are now 15,000 miles of channels 9 feet or more in depth.

Including domestic deepsea, Great Lakes and Inland Waterway, nearly 950 million tons of commerce was handled in 1970 alone. Since 1940, the Inland Waterways have passed (in terms of ton-miles) nearly 16% of total domestic intercity freight moved in this country. And as the economy grows, so does the demand for reliable low cost barge transportation.

As this nation enters a trillion dollar economy, the demand upon various modes of transportation is being strained. In the absence of expanded and more efficient facilities, the cost of all modes must rise; and in the longrun, the ability to consider one form of transportation as an alternative to another may be less relevant than the ability to transport at all. The less efficient these improved facilities, and the less efficiently they are utilized, the sooner this practical capacity will occur. Highway, truck and rail terminals, as well as airports, are becoming ever increasingly congested adding to both fixed and variable cost. Where suitable land, capital and facilities are limited resources common to all modes, the waterway itself is, for the first time, acting as a constraint upon the future of barge transportation. The options open to the waterway planners is clear: maximize the efficiency of the navigation system or accept higher, possibly prohibitive, costs to shippers.

There are many factors governing a shippers choice of a transportation mode, including length of haul, the bulk nature of the commodity shipped, the annual volume of commerce to be transported from a given origin to a given destination, and the value of the commodity being shipped. Generally

[1]Project Director of the Inland Navigation Systems Analysis Program; Acting Chief of the Systems Analysis and Applications Branch, Planning Division, OCE.

speaking, low value bulk commodities to be moved long distances are typically those moved by barge.

The inland waterborne commerce market is serviced by approximately 1,800 firms. In 1970, the industry consisted of nearly 2,300 vessels and about 15,200 barges. Length of haul has increased 20 fold over the past 40 years while the maximum tow size has increased for 5,000 to 50,000 tons per tow. On any waterway, navigation dams inevitably constitute restrictions to traffic movement because of the time required to transit the lock from one water level to another. This inevitably causes substantial delays to commercial navigation as traffic increases beyond a lock's designed capacity. Until recent years it was not considered necessary to study the complex aspects of the entire navigation system when a lock and dam or other improvement was deemed necessary. Essentially, if a problem of capacity was observed at a given lock, an estimate was made for projected traffic which could be expected to navigate through the facility for fifty years and if it could by economically justified, the facility was constructed. The rest of the waterway was recognized to influence this traffic, improvements would be made as needed. Consequently improvements were made with no clear understanding of the effects of those improvements on navigation in the system as a whole. An improved method of determining and evaluating developmental needs has long been recognized as a requirement for the navigation planning process.

On 1 May 1970, the Special Assistant to the Secretary of the Army (Civil Functions) requested the Corps of Engineers to: (1) develop the logic of the waterway system and its subsystem (2) recommend alternative methods for systems analysis (3) identify data needs (4) develop interim procedures to include this type of analysis for current projects and (5) recommend organizational changes including necessary funds to make systems analysis of the waterways. An Office, Chief of Engineers (OCE) Task Group was formed who in their report conclude that: (1) a systems analysis of inland waterways was desired and required, (2) various methods and models including simulation can be developed as tools, (3) uniform and comprehensive data are required and (4) systems analysis is vital to our planning efforts. Upon receipt of the report the Special Assistant to the Secretary of the Army requested the Chief of Engineers to proceed with these recommendations. As a follow-on to the foregoing effort the Director of Civil Works, with the concurrence of the Chief of Engineers, tasked the Planning Division of the Civil Works Directorate to coordinate efforts to implement a formal system. A 10 man Inland Navigation Systems Analysis (INSA) Coordination Group with a Project Director was established on 18 April 1973 to accomplish this assignment.

The problem which the Corps INSA program addresses is essentially two-fold: (1) there is a need to maximize the operating efficiency of the navigation system as it presently exists, and (2) all reasonable means must be utilized to optimize the design and scheduling of improvements to meet future demands within current and projected budgetary constraints.

Analysis of the inland waterway on a systems basis requires determining the performance of the waterway as a whole and the interaction and interrelationships of its component parts under various assumptions about the economic and technical environment within which it will be operating. In short, this means predicting demand for inland waterway transportation, producing descriptive data on the towing industry, and applying this information to a model representing the inland waterway system. A graphic representation of these components is presented in Figure 1. Models can be developed to represent or simulate a system, typifying its component parts and their interrelationships.

Two general types of models exist: physical models and mathematical models. Physical models represent a system by physically duplicating the system on a smaller scale so that its performance can be studied under various conditions, assumptions, and changes to the system itself. Mathematical models represent a system by describing the performance or operation of its component parts by mathematical formulas or time elements. If such a model is being run on a computer, the computer causes these operations to be "performed" in the proper sequence in time, simultaneously keeping track of these numerous events, interrelationships and in terms of elapsed time. Mathematical modeling was the approach selected for Inland Navigation systems analysis since generally, mathematical models are more flexible, require less time, physical space and expense to develop and operate, and are able to compress time more efficiently than physical models. One can appreciate the space, time, and expense required for a physical model of the entire U.S. inland waterway. Physical models may, however, also be used in this study to generate parameters for or to validate selective components of the mathematical models.

The development of large core 3rd and 4th generation computers has made possible the representation and simulation of large complex systems by means of such mathematical models. Thus it is possible to simulate the operation of the entire inland waterway system on a computer by representing its component functions such as tow reconfiguration, approaches to locks, filling and emptying of locks, exiting, and lock to lock transit, in terms of time elements and their interdependencies. To build such a model and have it accurately represent the waterway system to be studied, accurate knowledge of the system is needed, including its physical description, component costs, method of operation, and time components.

The 3 year, one million dollar INSA program is principally an Office, Chief of Engineers directed in-house effort. The study is under the general guidance of a project director with the actual execution of the work components managed by the Inland Navigation System Analysis Coordination Group. This Group consists of representatives of the Corps Waterborne Commerce Statistical Center (WCSC), Waterways Experiment Station (WES), Board of Engineers for Rivers and Harbors (BERH), and personnel from the Planning, Operations and Engineering Divisions of the Civil Works Directorate, OCE. In addition, a field liaison coordination group was formed of Corps District and Division experts to participate in the INSA program.

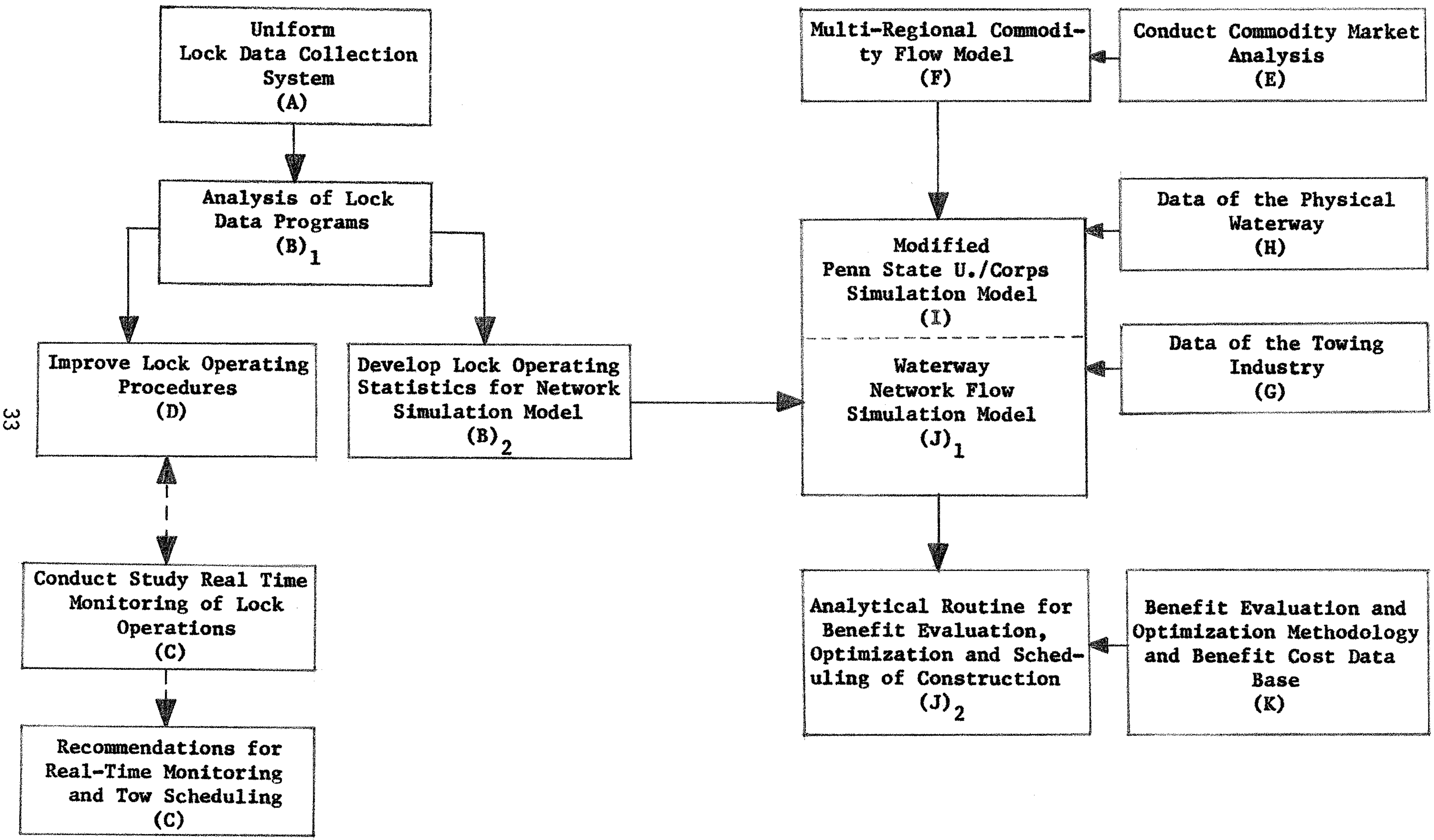
Contractors will be used for those aspects of the study where the Corps of Engineers does not have sufficient expertise or where in-house resources are limited.

The INSA program will permit the long range planning process to be pursued more expeditiously and with a greater degree of confidence than has been possible heretofore. With projections of future tonnages to be moved on the waterway system, changes and additions to the systems at any point in time can be studied and suitable long range plans for system improvements developed. Prosecution of planning procedures utilizing simulation models and other studies of the entire waterway system as discussed above will exert a significant impact on waterway planning and design. This will be felt in the timing and location of improvements to the system; of additions to the system, and of the operation of the systems.

Systems analysis should not only be used in the design and evaluation of a recommended navigation improvement but also in its schedule for construction. These system interrelationships must also be made known to Congress when it is time for authorization of construction funds. Current system information should "follow" the project from the survey stage, through authorization and construction. Improper sequencing of construction can seriously jeopardize the efficiency of a system improvement, thereby significantly reducing the return on the capital expended on its construction. The reluctance to fund the Locks and Dam 26 project at St. Louis, for example, will seriously jeopardize the efficiency of the new Kaskaskia Navigation Canal below St. Louis. Approximately 3.8 million tons of coal was projected to move from southern Illinois coal fields on the Kaskaskia to Upper Mississippi River utility plants in 1976. By 1980 this is expected to increase to an annual level of approximately 6 million tons. But construction of Locks 26, through which this commerce must pass has hardly begun! Indeed, the present structure is already staggering under the demand for its use in excess of its 45 million ton capacity. For this "new" Kaskaskia tonnage to reach its destination by water it must leave the waterway. Even if this commerce does move on the Kaskaskia, and through Locks 26 to its final destination, a loss will occur somewhere else on the system to make way for this tonnage; a loss which could have been avoided, or at least minimized, had the Kaskaskia been analyzed as part of the Inland Navigation System.

The benefits that will accrue to the Nation's economy from development of systems analysis techniques for the Inland Waterways will be difficult to predict in monetary terms. However these benefits are, nevertheless, of prime importance; they are very real in nature and will become increasingly important as the Nation's demand upon its transportation system increases. Benefits to be realized through development of systems analysis include the more efficient operation of waterway facilities. Application of systems analysis techniques to the operation of our locks, dams, canals and channels will result in reduced transit time for tows, less traffic congestion and hazards from accidents, and greater tonnage capacity of the existing system, which in turn will reduce overall investment costs for the facilities required to move a given level of commerce. In addition, the improved planning and scheduling of improvement programs which will result in reduced capital investment. Previously the development and scheduling of inland navigation improvement programs were based largely on judgmental factors. No methodology existed to evaluate effects that changes would cause to the entire river system. The lace of a real systematic methodology has, in some past instances, resulted in building "over capacity" at some locations while at the same time problems with inadequate capacity developed at others. Premature construction or construction out of sequence was also a real possibility. While these possibilities always exist to some degree because of problems inherent to economic forecasting, the INSA program will permit a much more lucid examination of all of the system variables thereby minimizing, if not eliminating, the risk of erroneous system design. Benefits will also result directly to tow operators (and in turn to shippers) through the possession of better information on system conditions, better communications between tow and lock personnel through better scheduling of tow movements and more efficient utilization of towing equipment. This, and the availability of sufficient reliable information of the Inland Navigation system, should contribute significantly to maximizing the operating efficiency and optimizing the design of our system of Inland Navigation. The remaining two years of the INSA program will tell.

INLAND NAVIGATION SYSTEMS ANALYSIS



*Letter in parenthesis refer to the activities in Figure 3.

FIGURE 1

MAKING EFFECTIVE USE OF ANALYTICAL METHODS IN PLANNING

Douglass B. Lee, Jr.[1]

The discussion below is organized around four intendedly controversial statements. They should be controversial because a great many if not most analyses run counter to at least one of the statements, whereas my motive in fomenting controversy is to try to bring efforts at analysis into conformance with these statements. The views expressed are meant to complement those of mine and others that have appeared elsewhere (Lee, 1973).

Two words are used that should be clarified at the outset in relation to the four statements: both "political" and "technical" are neutral descriptive terms, and have no positive or negative connotations by themselves. Political refers to the process by which we make social decisions for which there is no generally accepted technical basis (whether to invest in mass transit, emission controls, or air quality models). Technical decisions are those that are based on expert information (how thick the pavement needs to be to support heavy trucks). Most social decisions are a combination of political and technical, and the proportions of each often shift one way or the other. Political decisions become technical when the decision process becomes routine (management of drinking water quality), and technical decisions become political when the results raise controversy (the construction of urban freeways). The words are used to point out that policy or planning necessarily involves both political and technical procedures, not to label things as good or bad.

Attempts to Do Prediction and Forecasting are Mostly Misguided

Prediction and forecasting emphasize outcomes, but in most systems for which planning is difficult there are so many likely outcomes that the probability of any one is extremely small and hence uninteresting. If forecasting is to be useful, it must aggregate outcomes to the extent that the forecast has a reasonably high reliability. Almost always, this will mean the use of a relatively simple aggregative model. Trying to forecast with complex disaggregated models will have low utility for policy purposes.

A much more sound approach is to develop analytic procedures that list hypothetical outcomes along with the particular assumptions that

[1] Department of City and Regional Planning, University of California, Berkeley.

give rise to each one.[2] Obviously, the simpler the set of assumptions leading to an outcome the more useful the analysis, ceteris paribus. Methodologies of this type (often simply accounting procedures) depend heavily upon a strong body of theory, and their use depends upon a good deal of judgement. Inserting statistically estimated models into this kind of methodology severely reduces the value of the results; statistical estimation should be used to construct and test theory, not to construct operational models.

Forecasting land use, for example, has fallen prey to most of the dangers mentioned above. The best way to avoid these pitfalls is to forget about predicting and direct attention instead towards evaluating specific policy alternatives.

The Optimal Amount of Analysis is the Minimal That Will Distinguish Between Policy Alternatives

Being able to distinguish between policies means that only the differences between the two (or more) choices need to be identified, and only with sufficient precision and reliability to evaluate the policies. Providing more than this is technically wasteful in that the capacity is not needed, and politically counterproductive in that irrelevant information distracts from the relevant. Why then, produce more than the minimum?

One illusion that supports overly ambitious efforts is the belief that many questions can be answered from the same analytic device and/or data source, often a computer model. In practice, the opposite has almost always been the case -- the cost/effectiveness would have been much more favorable if each question had been addressed separately with an independent and minimal analysis. For some reason the fear of repetition of the same tasks completely dominates the consideration of excess capacity never used.

Another possible rationale for premature or excessive analysis is the shortage of lead time for producing results, the idea here being that there may not be time to build the capability when the need arises. Aside from the issue of deciding what unneeded capacity to construct, the short-lead-time problem is not a problem because there is always sufficient time to do the needed analysis (there may, of course, be no answer, in which case no amount of lead time is enough). If attention is directed at the political process instead of attempting to build all-purpose models, there is no reason to be caught in the situation of having too little time to do the analysis that is appropriate at the time it is needed.

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[2] Bella (1974) makes a parallel point by comparing "experimental" models (predictive) and "theoretical" models (hypothetical).

There also seems to be a belief that when the whole picture becomes clear the correct policies will become obvious, or at least much easier to discover and test. Without going into detail, it can be said that analytic procedures not designed to generate and test policy alternatives relating to a specific problem will be less efficient than those uniquely designed to do so. The issue then comes back to whether there are economies of scale from combining problems, as opposed to methodologies.

Analysis Should Be Designed to Be Suitable for Political Implementation

A strong tradition in planning says that we should not make short run decisions until we have taken a careful look at the big picture and the long run, because short run decisions may be counterproductive. Whatever the appeal of this "comprehensive" view -- and its appeal is strong -- it is unworkable for planning or policy purposes. One important reason is that the systems are too difficult to model, and will probably remain so. A more fundamental reason is that comprehensive analytic procedures are suitable only for autocratic implementation, i.e., through an administrative hierarchy, and our social decision processes do not function in that way. Nor do we want them to.

The alternative to technical implementation (from the top down through the hierarchy) is political implementation, and this process can be thought of as organizational negotiation. An organization usually represents some kind of interest (local government, public works agencies, neighborhood groups, conservationists, Federal regulatory agencies, etc.) or group of interests, and the resolution of the inevitable conflicts is achieved not by an omnipotent czar or king but through political bargaining. It is not a question of this being a bad or good process: there is simply no democratic alternative.

We are then left with the choice of trying both to build highly comprehensive methodologies and also convince the population and the policy makers to think and operate in those terms, or trying to create analytical procedures that can be useful in making a sequence of (usually binary) decisions through a messy political process. To me, the question is rhetorical.

Optimizing Algorithms Have Very Little Application in Planning

A large number of methods have been developed for finding the best solution to a problem -- often large in terms of the number of possible solutions -- given that the problem is clearly specified and the objective criterion directly measurable. Examples of methods include linear or mathematical programming, branch-and-bound or hill-climbing algorithms, calculus of variations and optimal control theory.

Several criticisms of models or problem-solving techniques of the optimizing type have been suggested. A major one is the claim that most planning problems are not well specified, which is true; if they were, they would not be planning problems, but simply technical problems. An even more devastating criticism is the obvious fact that only one goal (also well-specified) can be considered, and this is never the case in reality. The difficulty with this criticism is that it implies that if algorithms could be constructed for dealing with multiple goals the methods would be useful, when in fact the failure is more fundamental. For a model to be useful in planning, it must be able to incorporate feedback and learning about both the system performance <u>and</u> relevant goals.

Since planning is a political process which uses technical information, part of that information is for the purpose of re-evaluating goals as well as evaluating progress towards them. If we knew exactly what we wanted we could turn the whole thing over to a computer or a tyrant, but the truth is that we cannot determine whether we want one goal over another until we take at least a step towards the goal. The tradeoffs between environmental quality, energy consumption, and other consumption provide numerous examples of this kind of learning through a political/ technical process.

REFERENCES

Bella, David A., (1974), "Fundamentals of Comprehensive Environmental Planning," <u>Engineering Issues</u>, ASCE, 100, EI1 (January), pp. 17-36.

Lee, Jr., Douglass B., (1973), "Requiem for Large Scale Models," <u>Journal of the American Institute of Planners</u>, 39 (May), pp. 163-178; "Letters," 39 (November) and 40 (January 1974).

A TECHNIQUE FOR OPTIMIZATION OF MULTIPLE-PURPOSE RESERVOIR PROJECTS

BY
PAUL E. JENSEN[1]

INTRODUCTION

Planning can be defined as the orderly consideration of a project from the original statement of purpose through the evaluation of alternatives to the final decision on a course of action. Planning includes all of the preconstruction work associated with a project except the detailed engineering of the structures. The project formulation phase of the planning process is perhaps the most important aspect of the total engineering for the project in that the project formulation phase lays the foundation for all subsequent studies. Because no two water resource development projects are formulated (or planned) in identical physical or economic settings, each project or system of projects must be evaluated on its own merits. Although there is no substitute for experience being carried over from one project to the next, every decision made in the planning process should be supported by quantitative analysis.

PURPOSE

The purpose of this paper is to present a technique for optimization of multiple-purpose reservoir projects. Most water resource planners view the construction of a reservoir project as a permanent commitment of a very valuable resource, the site itself. When a site is committed, it should, therefore, be utilized to the fullest extent possible within physical, political, legal, and economic limitations. In this paper optimization refers specifically to optimization of the scale of development at the site based on maximum net benefits (total project benefits less total project costs). Optimization based on maximation of net benefits yields a scale of development which is generally, if not always, larger than the scale of development that would result in a maximum benefit-to-cost ratio. If the objective in the planning process were to maximize the benefit-to-cost ratio, a slight variation of the following technique would be necessary. The technique described below is a graphic technique but may be adopted to a computer program.

PURPOSES OF RESERVOIR DEVELOPMENT

The first step in planning any reservoir project is a determination of the purposes to be served by the project. Reservoir projects are constructed for any number of purposes, including flood control, hydroelectric

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1 Civil Engineer, Basin Planning Branch, Engineering Division, Kansas City District

power production, irrigation, water supply, navigation, and recreation. The first step in the optimization process is the evaluation of the benefits that would be realized from each project purpose at various levels of multiple-purpose project development. Let us take, for example, a lake project which is being planned to serve the purposes of municipal and industrial water supply, recreation, and flood control. Estimates could be made of the benefits resulting from storage of a 10-year flood, a 100-year flood, and various intermediate floods. These estimates could then be plotted as a flood control storage-flood control benefit curve as in plate 1. Benefits resulting from various amounts of multipurpose storage can be determined next. In our example, all of the multipurpose storage is allocated to municipal and industrial water supply and recreation benefits are based primarily on the surface area available for recreational use. The recreation benefits and water supply benefits can, therefore, be added at any selected multipurpose storage amount. The multipurpose benefits can thus be plotted against multipurpose storage as shown on plate 2.

COSTS OF RESERVOIR DEVELOPMENT

Hand in hand with the evaluation of project benefits must be an estimation of project costs. Cost estimates should be made for projects with varying amounts of total storage capacity so that a lake capacity-annual cost curve can be plotted as shown on plate 3. Unit prices used in estimating costs should be based on comparable construction work, cost analysis of work performed by or under supervision of the Corps of Engineers, and data obtained from local organizations. Field inspections should be made in connection with these estimates, particularly for the real estate and relocation portions. The damsite should also be inspected for geologic characteristics, etc.

COMPARISON-OPTIMIZATION

After plotting the three curves shown on plates 1 and 3 at the same scale, the optimization procedure is reduced to a graphic problem. The origin of the flood control benefit curve, plate 1, is placed on the multipurpose benefit curve, plate 3, and moved up or down on this curve until a point is reached at which the horizontal distance between the flood control benefit curve and the cost curve is at a maximum. See plate 4. This point on the multipurpose benefit curve represents the optimum multipurpose storage capacity and its associated benefit. The point on the flood control benefit curve at which maximum net benefits are attained represents the optimum flood control storage and its associated benefit.

APPLICABILITY

The procedure presented above is applicable to nearly all multiple-purpose reservoir projects at least to some extent. It provides a fairly simple method of simultaneously determining the optimum scale of multipurpose and flood control development. Its results should not be considered final, but an indication of the scale of development which would fully develop the potential of the site. Its applicability may be limited due to legal or political constraints. In the case of municipal and industrial water supply storage, for example, local interests must furnish assurances of the need for such storage. The amount of storage local interests are willing to provide assurances for may be significantly greater or less than the optimum storage. The same is true for storage provided for recreation and/or fish and wildlife enhancement. This procedure can still serve a useful purpose, however, even in these all-to-common situations. A case in point is Garnett Lake which was authorized as a unit in the Osage-Marais des Cygnes River, Kansas and Missouri, flood control system. This system consists of several lakes plus two local protection projects. Garnett Lake would be located in the headwaters area of the basin on a major tributary in eastern Kansas. At this project the total multipurpose storage necessary to meet all present and near future needs for multipurpose storage amounted to only a small portion of the total multipurpose storage necessary to attain optimum site development. Relating this to our previous example and plates, we could assume that the multipurpose storage required to meet all present and near future needs amounted to only 30,000 acre-feet. Development of the project at this size would be economically feasible but hardly acceptable if optimum site development were to be a consideration. In the case of Garnett Lake, planning was discontinued and the project was placed on the inactive list pending development of additional need in the area.

SUMMARY

Planning for a multiple-purpose reservoir project involves the use of many tools which aid in the final decision making process. The optimization procedure described above is but one of these tools. Properly used, however, it can be a very significant and helpful tool.

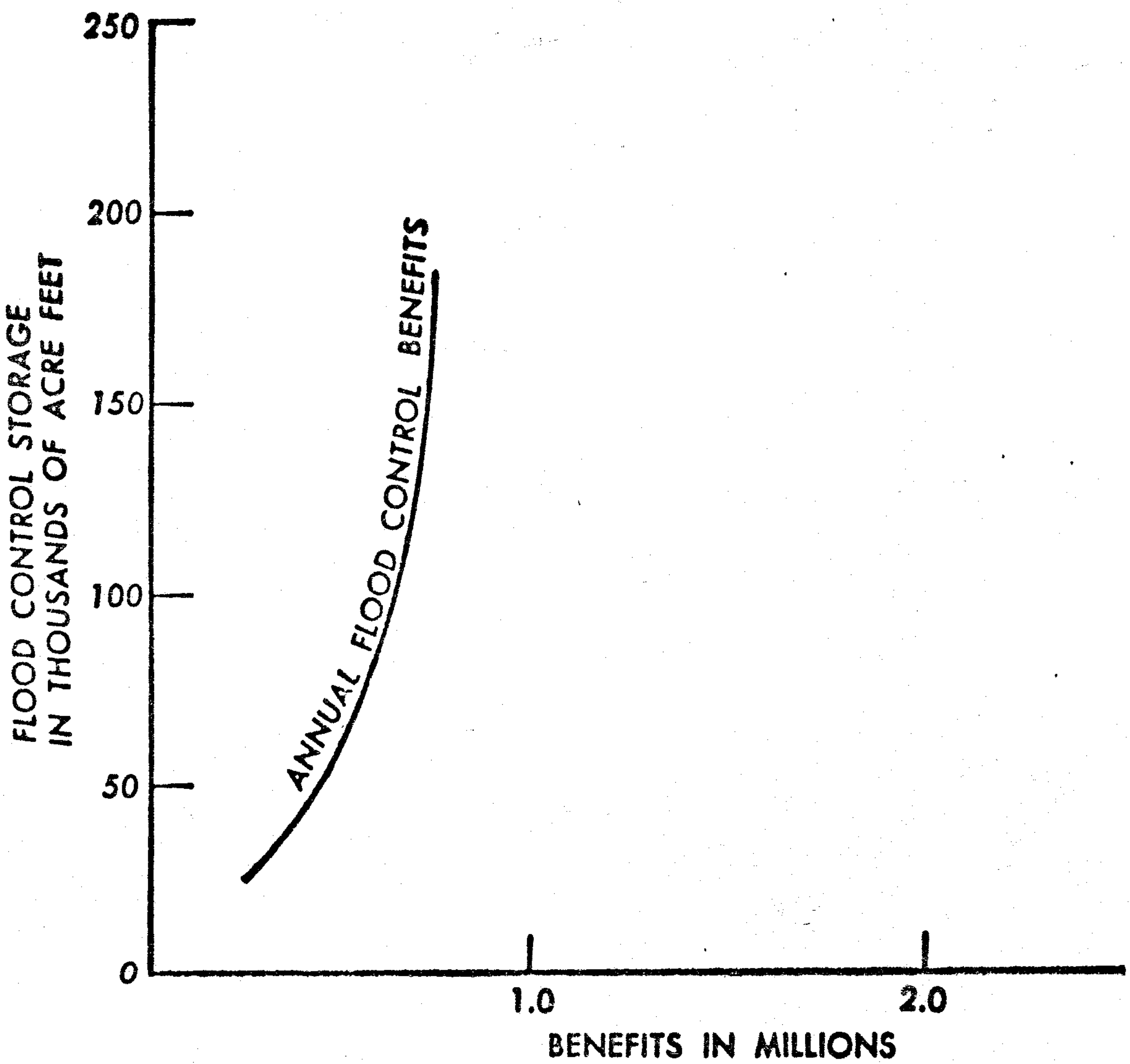

250
200
150
100
50
0
FLOOD CONTROL STORAGE
IN THOUSANDS OF ACRE FEET
ANNUAL FLOOD CONTROL BENEFITS
1.0
2.0
BENEFITS IN MILLIONS

PLATE NO. 1

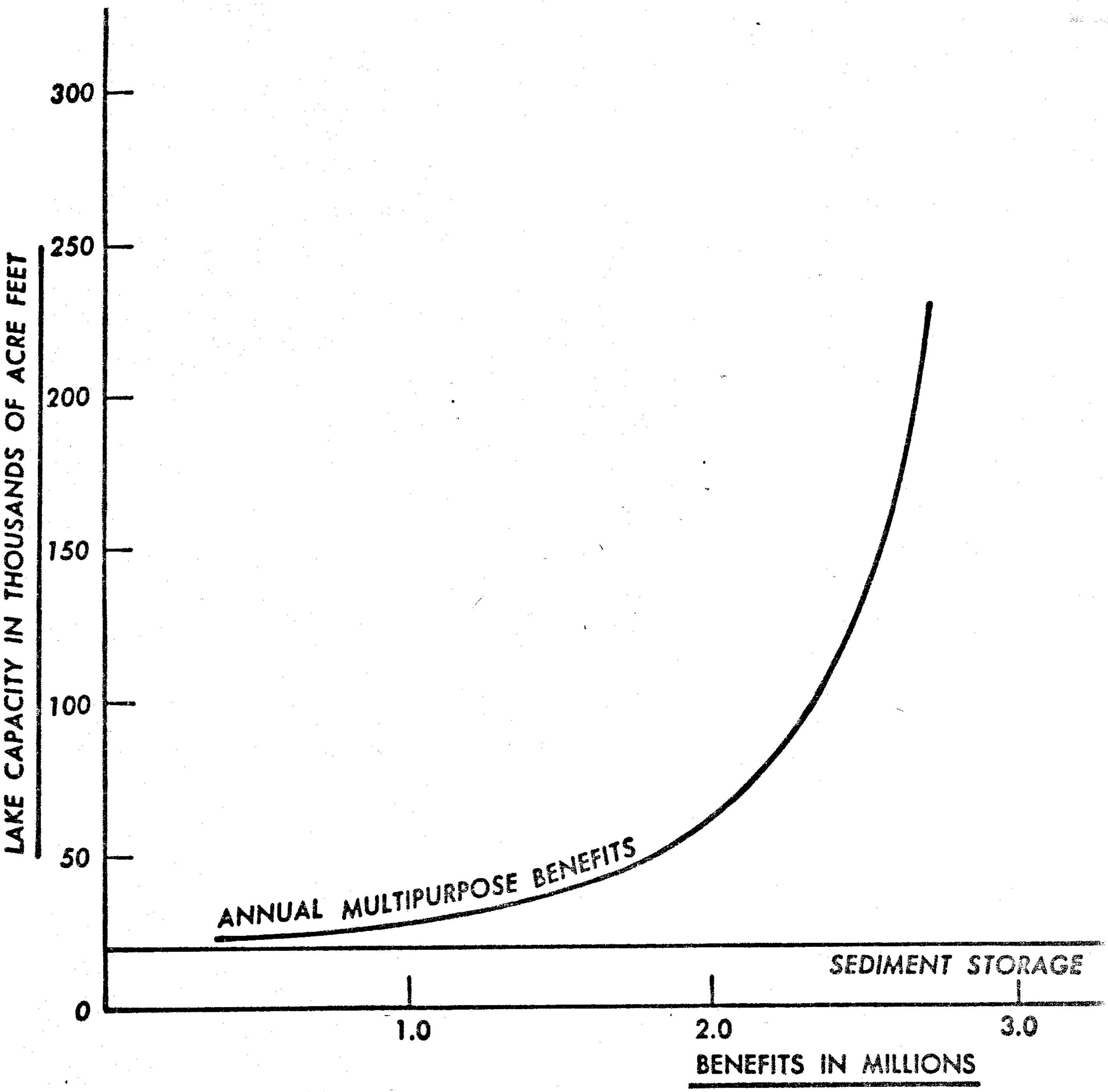
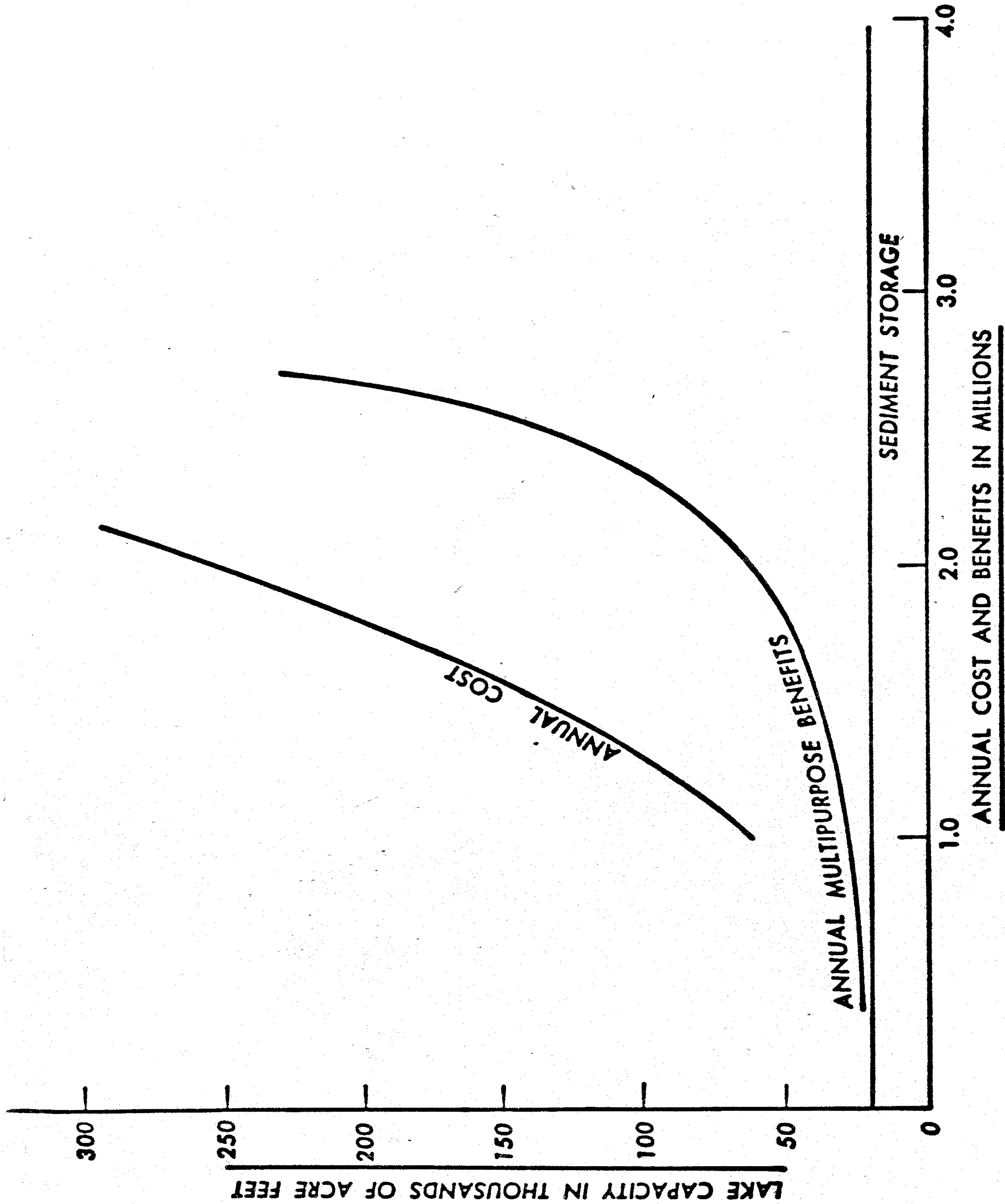

LAKE CAPACITY IN THOUSANDS OF ACRE FEET
300
250
200
150
100
50
0
ANNUAL MULTIPURPOSE BENEFITS
SEDIMENT STORAGE
1.0
2.0
3.0
BENEFITS IN MILLIONS

PLATE NO. 2



SEDIMENT STORAGE
ANNUAL COST
ANNUAL MULTIPURPOSE BENEFITS
ANNUAL COST AND BENEFITS IN MILLIONS
0
1.0
2.0
3.0
4.0
LAKE CAPACITY IN THOUSANDS OF ACRE FEET
50
100
150
200
250
300

PLATE NO. 3

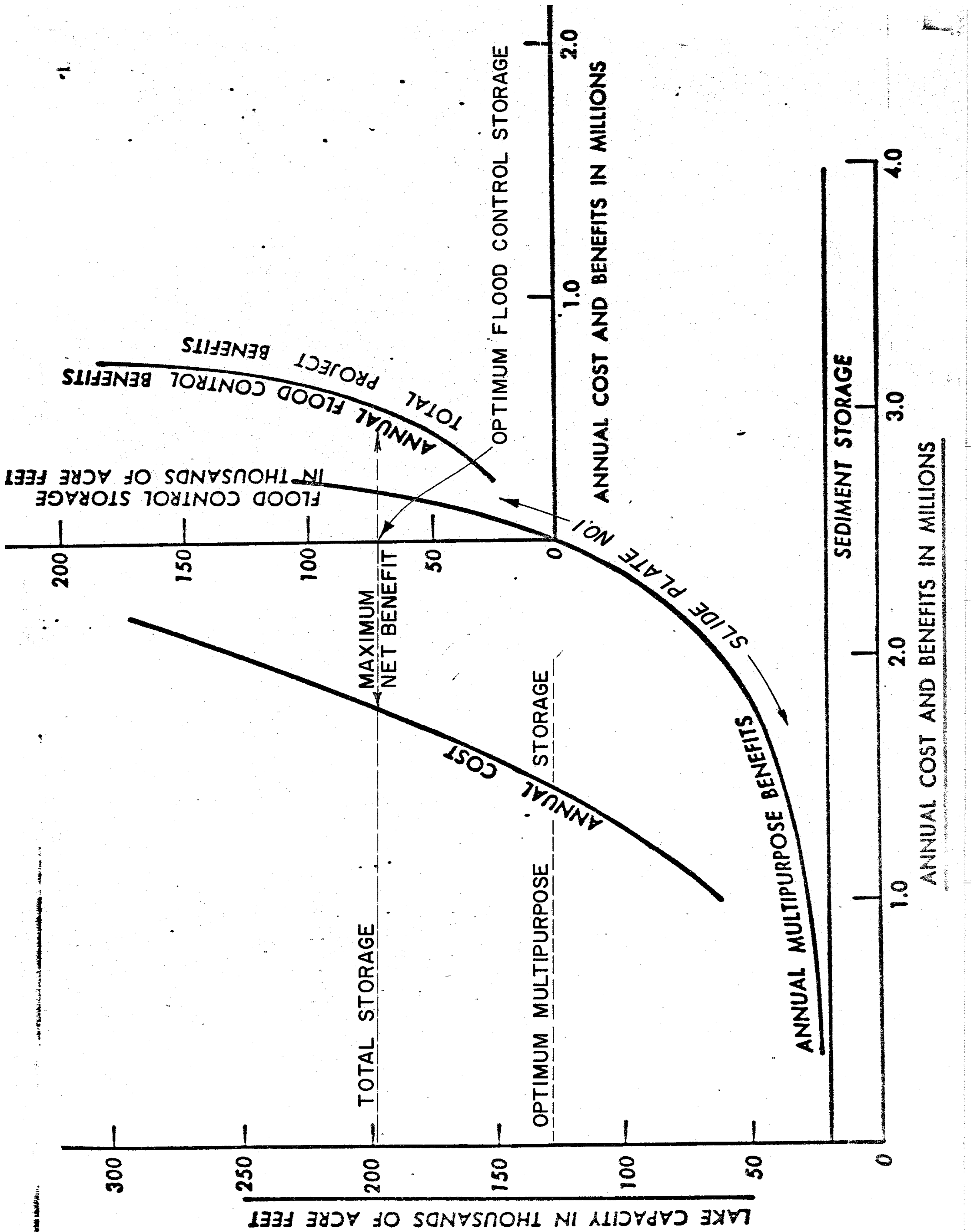

OPTIMUM FLOOD CONTROL STORAGE
ANNUAL COST AND BENEFITS IN MILLIONS
2.0
1.0
TOTAL PROJECT BENEFITS
ANNUAL FLOOD CONTROL BENEFITS
FLOOD CONTROL STORAGE IN THOUSANDS OF ACRE FEET
200
150
100
50
0
SLIDE PLATE NO. 1
MAXIMUM NET BENEFIT
TOTAL STORAGE
OPTIMUM MULTIPURPOSE STORAGE
ANNUAL COST
ANNUAL MULTIPURPOSE BENEFITS
SEDIMENT STORAGE
4.0
3.0
2.0
1.0
0
ANNUAL COST AND BENEFITS IN MILLIONS
300
250
200
150
100
50
LAKE CAPACITY IN THOUSANDS OF ACRE FEET

PLATE NO. 4

HEC-5C, A SIMULATION MODEL FOR SYSTEM FORMULATION AND EVALUATION

by Bill S. Eichert[1]

1. Need for Hydrologic and Economic Simulation Model

Because of the great expenditure of funds required to construct structures to reduce flooding in a river basin, it is important to make sure that each project built is justified and is more desirable than any other alternative. In a complex river basin where numerous system components exist or are required to reduce flooding, the evaluation of each alternative requires a large number of calculations. Until recently all such evaluations had to be done by rather crude techniques or by laborious manual procedures, although a few simple computer models could be used on parts of the study. For example, a study made 10 years ago, required that 10 flood control reservoirs be considered in firming up the design of a few new reservoirs in a flood control system. The hydrology required in operating the system (after the historical flows throughout the basin were known) for several historical floods required three men working full time for about 4 months at a cost of about $25,000. In spite of the large time and cost, many simplifying assumptions had to be made, no economic evaluation was made and no alternative solutions were investigated because of the manpower, funds, and time limitations. The same job can be done today with greater detail and accuracy with a simulation model such as HEC-5C with less cost and manpower and, in addition, each alternative can be studied with a few hours of work and a $20 computer run which will show the average annual damages at all damage centers and the net system flood benefits. The initial work in assembling the reservoir data in the required computer format for the system requires about one man-week of work. The determination of the historical flows for all major floods of record throughout the system is the major task and has to be done by either manual or computer techniques, but could be done with about 3-man months of effort for this basin. The verification of the model on historical floods can be done in a couple of man months. Once the above tasks are completed, detailed simulations can be made easily and with little expense for numerous combinations of reservoirs, and other alternatives including nonstructural alternatives.

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[1]Bill S. Eichert, Director, The Hydrologic Engineering Center, 609 Second Street, Suite I, Davis, California 95616.

2. Purpose of Water Resources System Simulation Model - HEC-5C

This program was developed to assist in planning studies required for the evaluation of proposed changes to a system and to assist in sizing the system components for flood control and conservation requirements for each component recommended for the system. The program can be used in studies made immediately after a flood to calculate the preproject conditions and to show the effects of existing and/or proposed reservoirs on flows and damages in the system. The program should also be useful in selecting the proper reservoir releases throughout the system during flood emergencies in order to minimize flooding as much as possible and yet empty the system as quickly as possible while maintaining the proper balance of flood control storage among the reservoirs.

The above purposes are accomplished by simulating the sequential operation of various system components of any configuration for short interval historical or synthetic floods or for long duration nonflood periods, or for combinations of the two. Specifically the program may be used to determine:

a. Flood control and conservation storage requirements of each reservoir in the system.

b. The influence of a system of reservoirs, or other structures on the spatial and temporal distribution of runoff in a basin.

c. The evaluation of operational criteria for both flood control and conservation for a system of reservoirs.

d. The average annual flood damages, system costs, and excess flood benefits over costs.

e. The determination of the system of existing and proposed reservoirs or other structural or nonstructural alternatives that results in the maximum net benefit for flood control for the system by making simulation runs for selected alternative systems.

3. Computer Requirements

The program, written in FORTRAN IV, was developed on a UNIVAC 1108 computer with 64,000 words of storage. The UNIVAC version can simulate the operation of 15 reservoirs, 25 control points, 5 diversions, and 9 power plants, using up to 50 time periods in each flood or nonflood event. Dimension limits have been increased for a CDC 7600 computer which allows the simulation of 35 reservoirs, 75 control points, 11 diversions, and 9 power plants for up to 100 time periods for each runoff event.

4. General Capabilities of Program

a. Configuration of system - any system configuration may be used as long as dimension limits are not exceeded for number of reservoirs, number of control points, number of diversions, etc.

(1) Reservoirs which have flood control storage may be operated to minimize flooding at any number of downstream control points.

(2) Reservoirs with conservation storage will be operated for their own requirements (power or low flow) and can be operated for any number of downstream control points.

(3) Reservoirs may be easily deleted from the system.

(4) Reservoirs in system are kept in balance (in the same degree of trouble) as much as possible.

b. Outflows can be specified for any number of reservoirs for any or all time periods and program will adjust other reservoir releases as necessary; otherwise program will determine all reservoir releases.

c. Effects of forecast errors can be evaluated by specifying the number of forecast periods and a corresponding contingency allowance (i.e., error in forecasting).

d. Local flows can be calculated from observed discharges and reservoir releases; system operation can be performed or omitted after flows are determined.

e. The multiflood option may be used to operate the system for a continuous period of record (for example, 5 events each containing 4 years of monthly data may be used for a total of 20 years). Also a mixture of computational intervals may be used such as running a monthly operation for a few years (assuming no routing if desired) and then operating for daily or hourly flows during a major flood (with detailed flood routing) and then back to a weekly or monthly routing interval, etc. An unlimited number of events can be simulated in this manner.

f. Evaporation and a monthly variation in reservoir operating levels can be considered in the routings if desired.

g. Voluminous output can be suppressed by requesting only a summary output. Detailed output for a few selected control points can also be obtained.

h. Stream routing may be accomplished by the following methods:

(1) Modified Puls, Working R/D, Muskingum, Straddle Stagger, and Tatum.

(2) Each routing method may be used several times for each reach.

(3) Actual releases that are routed by nonlinear (storage-outflow is not a straight line) methods (Modified Puls or Working R/D) use a linear approximation for determining reservoir releases.

(4) Natural and cumulative local flows are calculated.

i. Reservoir routing is based on:

(1) Accounting methods (release is determined based on desired operation, storage is equal to inflow less outflow plus previous storage).

(2) Surcharge routing - when desired release is greater than physical outlet capacity, the arithmetical method, which is a trial and error method, is used which will provide the same results as the Modified Puls method.

(3) Emergency releases - when desired release for current period plus channel capacity releases for future periods (up to limit of foresight specified) would cause reservoir to exceed maximum flood storage in current or future periods, a release is made for the current period (up to channel capacity or the outlet capacity) so that the reservoir does not exceed top of flood pool in future period.

j. Multifloods

(1) Read and operate an unlimited number of floods for a reservoir system.

(2) The series of floods can each start at different reservoir storages or from same storages or can be continued using the storages from the previous flood.

(3) Operate up to 9 ratios of any or all floods read.

(4) Long floods may be routed by dividing the flood into flow events which are each less than the dimension limit of the time array. This may be done by manually setting in several sets of flow data (with each less than the dimension limit) or by allowing the computer to generate separate floods (when the data read exceeded the dimension limit). A minimum of a 10 period overlap between floods is used to preserve continuity.

(5) Period of record analysis may be made by analyzing a series of floods consisting of monthly or weekly data during nonflood periods and daily or multihourly data during flood periods.

k. Diversions

(1) Diversions can be made from any reservoir or control point. Only one diversion from each control point or reservoir is allowed.

(2) Diversions can be made to any downstream control point or reservoir or out of the system.

(3) Diversions may be routed using any linear method allowed and multiplied by a constant representing the percent of return flow.

(4) Types of diversions

(a) Diversions can be a function of inflows.

(b) Diversions can be functions of reservoir storages.

(c) Diversions can be constant.

(d) Diversions can be constant for certain periods such as 50 cfs for January, 40 cfs for February, etc.

(e) Diversions can be made for all excess water above the top of conservation pool up to the diversion pipe capacity.

5. Reservoir Operational Criteria

a. Reservoirs are operated to satisfy constraints at individual reservoirs, to maintain specified flows at downstream control points, and to keep the system in balance. Constraints at individual reservoirs are as follows:

(1) When the level of a reservoir is between the top of conservation pool and the top of flood pool, releases are made to attempt to draw the reservoir to the top of conservation pool without exceeding the designated channel capacity at the reservoir or at downstream control points for which the reservoir is being operated.

(2) Releases are made equal to or greater than the minimum desired flows when the reservoir storage is greater than the top of buffer storage, and or equal to the required flow if between level one and the top of buffer pool. No releases are made when the reservoir is below

level one (top of inactive pool). Releases calculated for hydropower requirements will override minimum flows if they are greater than the controlling desired or required flows.

(3) Releases are made equal to or less than the designated channel capacity at the reservoir until the top of flood pool is exceeded, then all excess flood water is dumped if sufficient outlet capacity is available. If insufficient capacity exists, a surcharge routing is made. Input options permit channel capacity releases (or greater) to be made prior to the time that the reservoir level reaches the top of the flood pool if forecasted inflows are excessive.

(4) The reservoir release is never greater (or less) than the previous period release plus (or minus) a percentage of the channel capacity at the dam site unless the reservoir is in surcharge operation.

b. Operational criteria for specified downstream control points are as follows:

(1) Releases are not made (as long as flood storage remains) which would contribute to flooding at one or more specified downstream locations during a predetermined number of future periods except to satisfy minimum flow and rate-of-change of release criteria. The number of future periods considered is the lesser of the number of reservoir release routing coefficients or the number of local flow forecast periods.

(2) Releases are made, where possible, to exactly maintain downstream flows at channel capcity (for flood operation) or for minimum desired or required flows (for conservation operation). In making a release determination, local (intervening area) flows can be multiplied by a contingency allowance (greater than 1 for flood control and less than 1 for conservation) to account for uncertainty in forecasting these flows.

c. Operational criteria for keeping a reservoir system in balance are as follows:

(1) Where two or more reservoirs are in parallel operation above a common control point, the reservoir that is at the highest index level, assuming no releases for the current time period, will be operated first to try to increase the flows in the downstream channel to the target flow. Then the remaining reservoirs will be operated in a priority established by index levels to attempt to fill any remaining space in the downstream channel without causing flooding during any of a specified number of future periods.

(2) If one of two parallel reservoirs has one or more reservoirs upstream whose storage should be considered in determining the priority of releases from the two parallel reservoirs, then an equivalent index level is determined for the tandem reservoirs based on the combined storage in the tandem reservoirs.

(3) If two reservoirs are in tandem (one above the other), the upstream reservoir can be operated for control points between the two reservoirs. In addition, when the downstream reservoir is being operated for control points, an attempt is made to bring the upper reservoir to the same index level as the lower reservoir based on index levels at the end of the previous time period.

6. Average Annual Flood Damage Evaluation

Average annual damages (AAD) or damages for specific floods can be computed for up to 9 different categories for any or all control points (nonreservoirs) using one or more ratios for each of several historical or synthetic floods. They will be computed for the following three conditions:

a. Natural or unregulated conditions.

b. Regulated conditions due to the reservoir system assumed.

c. Full regulation at those reservoir sites (uncontrolled local flows).

Damages calculated for base conditions (normally natural flows) using selected floods and ratios are adjusted to average annual damages, computed by integrating the base conditions damage frequency curve or by using a predetermined average annual damage. The corresponding adjustment is printed out to help verify the appropriateness of the floods and ratios selected in integrating the damage curve for base conditions. Damages for modified conditions are based on the cumulative product of the damages associated with the modified peak flow for each flood (for a certain damage center) times the probability interval assigned to each flood from the base condition integration. See figure 1 for an example of the AAD integration. The damage for the uncontrolled local flows are also calculated in a similar manner to the modified conditions.

The damage reduction due to the proposed system is based on the difference between the AAD for the base conditions and the modified conditions. If an existing reservoir system exists the damage reduction can be based on the difference between the base conditions and the modified conditions where the base conditions were determined from another simulation run (existing reservoirs only).

A separate set of damage data can be used if the modified condition damages do not follow the base condition discharge-damage curves as would be the case for a levee, channel improvement or nonstructural alternative such as flood proofing, relocation, purchase, flood plain zoning, etc.

7. Multiflood Selection and Operation

The selection of the floods used in operating the system, is of paramount importance in the determination of the average annual damages. The floods selected must generate the peak flows at the damage centers (particularly the key ones) which represent the full range of the flow-frequency-damage relationship for base conditions as well as for modified conditions.

Even using all historical floods of record may introduce some bias in the average annual damage if most historical floods centered over a certain part of the basin by chance and not over other areas. For instance one dam site may have several severe historical floods while another dam site immediately adjacent to that area may, due to chance, not have had any severe floods.

While it is possible in the program, HEC-5C, to use only a single flood and several ratios of that flood in computing average annual damages, this procedure could introduce considerable bias in the results. It would be far better to use several historical floods with storm centerings throughout the basin and to use several ratios of those floods to obtain flows at the damage centers representing the full range of the flow-frequency-damage relationship for base conditions and for regulated conditions. A good idea of the adequacy of the selected floods and ratios for reproducing base conditions can be obtained by looking at the correction factor printed out at each damage center for each damage category. This correction factor is the ratio of average annual damage computed by integrating the input frequency-damage curve (or from input on DA card) to the average annual damage computed by assigning probability intervals to the system flows computed by HEC-5C. When the correction factor is close to 1.0, it represents the base conditions very well, but may not represent the modified condition if only one or two regulated floods cause damage. It is desirable to have one flood that does not cause damages so that the smallest flood with damage doesn't receive too large a probability interval. It is also necessary to have several modified historical floods produce damages spread out over the modified frequency curve since the integration of the damage-frequency curve is based on rectangular blocks for each flood using the probabilities from the base condition curve.

Studies are currently being made at The Hydrologic Engineering Center to help establish criteria for the selection of the floods and ratios to use.

8. Evaluation of Alternative Reservoir Systems

If this computer program is to be used to evaluate proposed reservoirs, then the data cards should be assembled so that all proposed reservoirs are included, even if some of them would serve as alternatives of others. Control points should be selected and coded for all damage centers, control points for reservoir operation, and information points. Once the entire system is coded, a single card can be used to delete reservoirs from the system for each alternative system selected. This card can be used to delete any reservoir in the system except for downstream tandem reservoirs (these reservoirs can be deleted by removing the reservoir cards). Flood damages for a single flood (or average annual flood damages) can be evaluated at any number of control points. Reservoir costs can also be evaluated by showing how the costs vary with reservoir storage based on the top of flood control storage. If costs and average annual flood damages are calculated, the net system flood benefits will be printed out for each alternative system operated. By careful selection of alternative systems, the system that produces the maximum net flood benefits can be determined by a reasonable number of separate computer runs.

9. Evaluation of Nonreservoir Alternatives

Structural and nonstructural alternatives to certain reservoirs can also be evaluated in the system simulation with or without reservoirs in the system. The existence of a levee or channel improvement can be reflected in the reservoir system operation by changing the channel capacity if appropriate. At the present time only one set of routing criteria can be read for each reach and thus the natural and modified routings use the same criteria. This limitation requires that when the routing criteria is different between natural and modified conditions, the natural flows must be calculated by a separate computer run and entered on cards for modified conditions. Costs of nonreservoir alternatives can be shown as functions of the channel discharges. For a given design discharge an interpolation is made to determine the capital cost applicable to the control point. The average annual flood damages can be evaluated in the same manner as for reservoir alternatives. However, the zero damage point can be automatically changed to the design discharge for modified conditions if a control point cost card is read. Two sets of damage cards can be read as an alternative to the above procedure, in representing natural and regulated conditions, so that the entire damage curve can be changed for regulated conditions.

Nonstructural alternatives (flood proofing, flood plain zoning, etc.) can be handled in the same manner as structural alternatives (usually by using two sets of damage cards), however the nonstructural alternative will require defining the upper limit of the flood proofing, zoning, etc. as a channel capacity or design discharge.

10. Use of HEC-5C in Flood Control System Selection

As can be seen in table 1, quite a few reservoir systems have been simulated using HEC-5. Most of these systems have used the flood control version which was released in May 1973. The version which also includes conservation operation (HEC-5C) has not been officially released yet, but it has been used for flood control simulation and average annual damages have been calculated for the Susquehanna, Red River of the North, and the Grand (Neosho) River basins. Monthly conservation operation has been used on the Pajaro River, the Red River of the North, the Hudson River Basin and several hypothetical systems. Of the studies conducted to date by HEC using this model, five of them have been for preliminary planning studies and have been used for the sole purpose of determining the regulated flows throughout the basin for various historical and synthetic floods. Each one of these basins also had a HEC-1 rainfall runoff data model developed in order to calculate the runoff from synthetic floods and to use rainfall to get a better distribution of runoff for historical floods. The study of the 15 reservoir system for the Trinity River was made in connection with Design Memorandum studies for the Tennessee Colony reservoir in order to determine the flood control storage in that downstream project (14 reservoirs above it) and to evaluate various alternative plans of channel improvements below the project. The work on the existing five reservoir Merrimack basin is expected to use HEC-5 in a real-time operation mode using forecasting routines and automatic data collection by July of 1975.

The Susquehanna River Basin has 12 reservoirs existing or under construction, and another 22 potential reservoir sites are being investigated along with other structural and nonstructural alternatives in a preliminary plannning study being conducted by the Baltimore District office of the Corps, the HEC and a private consulting firm Anderson-Nichols of Boston, Massachusetts. The decision for selection of the desired system will make important use of the average annual damage reduction and net benefits of the alternative systems which will be printed out for each alternative evaluated by HEC-5C.

11. Model Data Requirements and Output

The input data requirements for HEC-5C can be minimal for very preliminary planning studies or it can be very detailed for modeling existing systems. The minimum data requirements are as follows:

a. General Information (4 cards)

(1) Title cards for Job (3 cards)

(2) Six miscellaneous items including the number of periods of flow data, time interval of flows, etc.

b. Reservoir Data (4 cards per reservoir)

(1) Reservoir capacities for top of conservation and top of flood control elevations.

(2) Downstream control points for which reservoir is operated

(3) Reservoir storage/outflow tables

c. Control Point (including reservoirs) Data (3 cards per control point)

(1) Identification number and title

(2) Channel capacity

(3) Channel routing criteria

d. Flow Data

Inflow or local flow data for each control point for one or more historical or synthetic floods.

Additional input information useful for planning studies:

a. Average Annual Damage Data (a minimum of 4 cards per damage center)

Peak discharge-damage-frequencies tables

b. Cost Data (1 card per control point)

(1) Reservoir capital costs vs storage <u>or</u>

(2) Control point capital costs vs channel discharge <u>and</u>

(3) Capital recovery factor

(4) Annual operation and maintenance costs

The output available from the program includes

a. Listing of input data

b. Results of system operation arranged by downstream sequence of control points.

c. Results of system operation arranged by sequence of time periods

d. Summary of flooding for system

e. Summary of reservoir releases and control point flows by period

f. Summary of conservation operation if monthly routing was made

g. Summary of maximum flows, storages, etc., for each flood event

h. Summary of maximum and minimum data for all floods

i. Summary of average annual damages

j. Summary of system costs (annual and capital) and net benefits. Examples of some of the summaries are shown as figures 2-12.

12. Strategy for Selection of Alternative Systems

For systems with only a few possible components the strategy for determining the best alternatives can be quite simple since each possible alternative can be evaluated. For systems with a large number of possible alternatives, the strategy can be difficult to predetermine and the best available procedure to follow may be to simply select alternatives to be evaluated one at a time following a careful review of information obtained from previous runs.

Certain economic criteria must be observed for the final system selected. The incremental cost of the new components of the proposed system must be less than the damage reduction accomplished by the new components. In addition, each project must be justified on the basis of the last increment added. That is to say, the cost of each project must be less than the difference between the average annual damages of the proposed system with and without that project.

A certain minimum performance criteria is also necessary. This philosophy says that if a certain level of protection can not be provided by the system then it would be better not to build any structures than to give the public a sense of false security.

With the above ideas in mind it seems necessary to first determine a minimum system that will provide an acceptable level of protection. Next see if various alternatives can be used to get a larger value of the maximum net benefits. When the maximum net benefits appears to be obtained (and it is positive) then each project should be deleted in turn to see if that project prevented more damages than it cost to build. The process of maximizing the net benefits by selecting alternatives and evaluating using HEC-5C, at present, can only be based on good engineering judgment. After a few studies are completed using this new tool, perhaps more definite guidance will be available.

13. Future Use of Model for Multipurpose Systems

The current version of the program does have capabilities for multipurpose operation of reservoir systems, but does not have multipurpose economic evaluation routines. While the program can operate for low flows at one or more downstream points, for flood control operation and for individual hydropower requirements, the conservation capabilities have not been tested on a sufficient number of systems to provide the necessary confidence. When a few more systems have been successfully operated for conservation and flood control together, that confidence will be obtained.

The major additions necessary for the future are in the area of hydropower systems, multipurpose benefit evaluation and extensive testing.

14. Conclusions

It appears that the HEC-5C simulation model should be a useful tool for planners to evaluate the effects of water resource projects and nonstructural alternatives in most river basins because it can accurately, quickly, and inexpensively simulate the hydrologic and economic responses of the system. While much of the detailed analysis of hydrology, reservoir regulations, and economics can be accomplished by the model, considerable engineering ingenuity will be required to insure that the proper data is used in the model, that the model is giving valid results, and that the proper sequence of alternatives are evaluated in order to determine the best plan for the reduction of damages in a basin.

It also seems probable that the model will be useful for simulating multipurpose reservoir operation. In this connection considerable work will be required to develop economic and social parameters to allow multipurpose evaluation of the system alternatives similar to flood control.

Considerable experience and research will be required to develop procedures, techniques and/or optimization subroutines which will enable the program to be used in the most efficient manner in the selection of the best multipurpose alternatives for the basin.

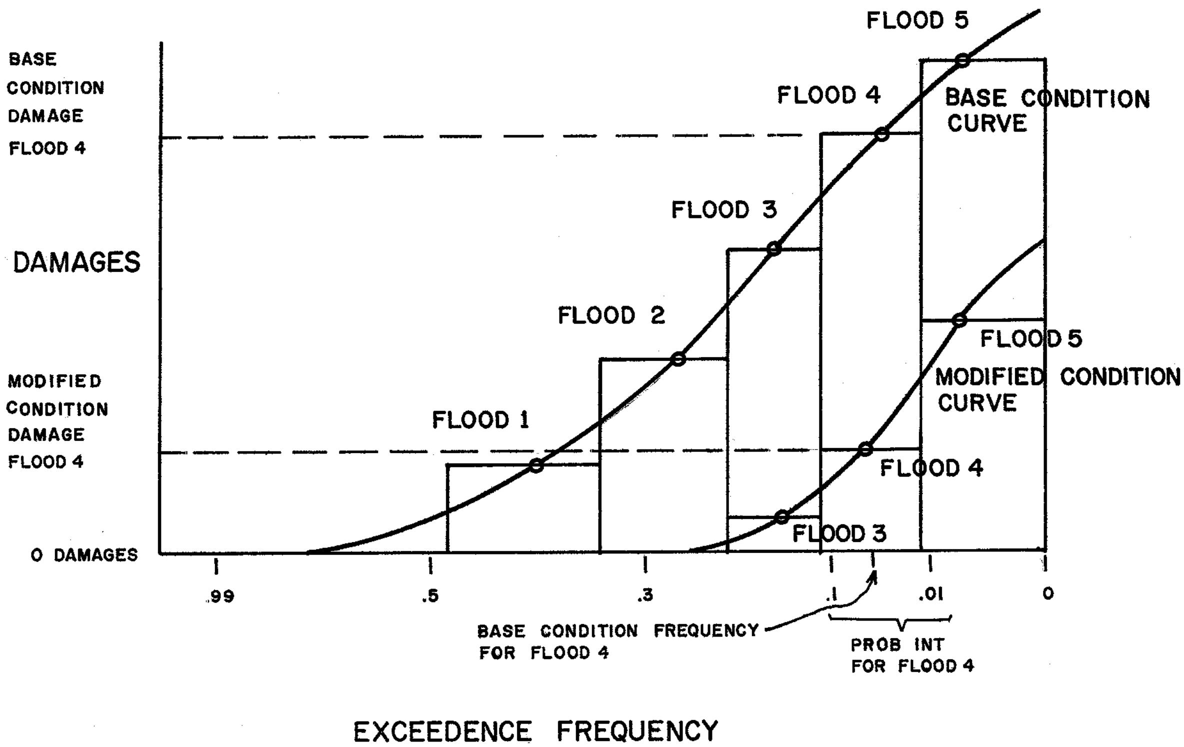
TABLE 1

SYSTEMS SIMULATED BY HEC-5

River Basin	Location	Number Reservoirs	Number Control Points (including res)	Time Increment (hrs)	Approximate Drainage Area square miles
1. Trinity	Texas	15	28	24	18,000
2. Merrimack	New England	5	11	3	4,400
3. Susquehanna	Pennsylvania	34	75	4	24,000
4. Schulkill	Pennsylvania	12	26	3	1,900
5. Potomac	Virginia Maryland Pennsylvania	26	39	2	12,000
6. Red River of North	Minnesota	13	29	24 720	40,000
7. Feather	California	3	4	2	5,900
8. Pajaro	California	3	6	1 720	400
9. Grand (Neosho)	Oklahoma	24	86	2	5,900
10. James	Virginia	22	35	6	6,800
11. Red River 1st Phase	Texas, Okla., Arkansas	14	28	6	12,000
12. Hudson	New York Pennsylvania	3	5	720	500

DAMAGE- FREQUENCY CURVES

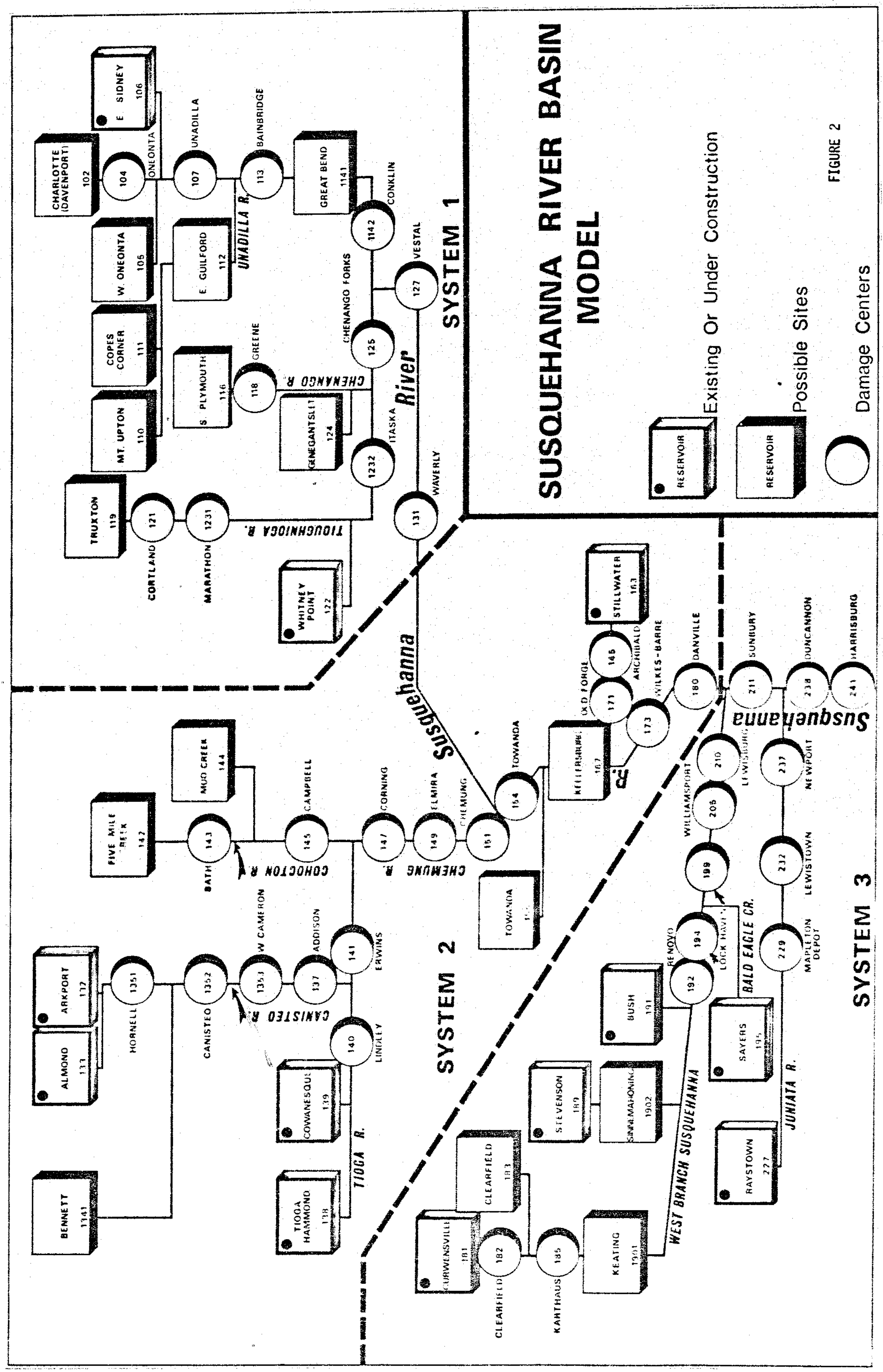
AVERAGE ANNUAL DAMAGE CALCULATIONS



NOTE: This figure is not for same example as Figs. 2-12.

FIGURE 1.

EXAMPLE OF AAD INTEGRATION FOR MULTIPLE FLOODS


SUSQUEHANNA RIVER BASIN MODEL
RESERVOIR
Existing Or Under Construction
Possible Sites
Damage Centers
FIGURE 2
SYSTEM 1
SYSTEM 2
SYSTEM 3
CHARLOTTE (DAVENPORT) 102
E. SIDNEY 106
W. ONEONTA 105
COPES CORNER 111
MT. UPTON 110
TRUXTON 119
E. GUILFORD 112
S. PLYMOUTH 116
GENEGANTSLET 124
GREAT BEND 1141
WHITNEY POINT 122
ONEONTA
UNADILLA
BAINBRIDGE
CONKLIN
VESTAL
CHENANGO FORKS
GREENE
ITASKA
WAVERLY
CORTLAND
MARATHON
UNADILLA R.
CHENANGO R.
TIOUGHNIOGA R.
Susquehanna River
FIVE MILE CREEK 142
MUD CREEK 144
ARKPORT 112
ALMOND 133
BENNETT 1141
COWANESQUE 139
TIOGA HAMMOND 138
TOWANDA
BATH
CAMPBELL
CORNING
ELMIRA
CHEMUNG
HORNELL
CANISTEO
W CAMERON
ADDISON
ERWINS
LINDLEY
COHOCTON R.
CHEMUNG R.
CANISTEO R.
TIOGA R.
STILLWATER 163
ARCHBALD
WILKES-BARRE
DANVILLE
SUNBURY
DUNCANNON
HARRISBURG
Susquehanna
WILLIAMSPORT
LEWISBURG
NEWPORT
LEWISTOWN
MAPLETON DEPOT
RENOVO
LOCK HAVEN
BALD EAGLE CR.
BUSH 191
SAYERS 195
STEVENSON 189
JUNIATA R.
RAYSTOWN 227
CLEARFIELD 183
CURWENSVILLE 181
KEATING 1901
CLEARFIELD
KARTHAUS
WEST BRANCH SUSQUEHANNA

**** LOC 180 DANVILLE SERVED BY -138 -139 -132 -133 -1341 -142 -144 -102 -105 -106 -112 -1141 -119 -122 -116 -124 -155 -163

CUM LOCAL Q	18419	18388	18289	18132	17942	17719	17505	17662	19390	25169		
W/O DIVS	38793	63416	97316	133676	166674	195267	221061	245012	266872	286677		
	304794	320879,	333584	340942	341104	333323	318482	298582	275908	252375		
	229185	206967	186030	166571	148748	132671	118381	105842	94945	85533		
	77425	70436	64386	59113	54478	50363	46672	43330	40281	37480		
	34895	32501	30279	28212	26289	24498	22831	21277	19830	18482		
											AVG= 121688	MAX= 341104 MIN= 17505
NATURAL FLOW	20938	20906	20807	20650	20460	20236	20020	20174	21900	27682		
	41336	66059	100203	137030	170730	200135	226671	251378	274625	297479		
	321337	346435	371168	392236	405513	407645	397506	376423	347512	314543		
	280830	248684	219375	193384	170716	151139	134332	119952	107663	97151		
	88134	80360	73613	67708	62491	57836	53643	49834	46350	43142		
	40178	37430	34878	32503	30292	28234	26316	24528	22864	21313		
											AVG= 138410	MAX= 407645 MIN= 20020
ACTUAL FLOW	20938	20906	20807	20650	20460	20236	20020	20174	21900	27674		
	41293	65903	99781	136118	169101	197693	223496	247465	269346	289156		
	307234	323211	335741	342890	342854	334934	320072	300348	278141	255426		
	233396	212573	193123	175129	158701	143941	130880	119473	109632	101254		
	94201	88280	83279	79015	75350	72158	69296	66629	64091	61697		
	59498	57508	55684	53933	52160	50294	48303	46203	44053	41934		
											AVG= 132261	MAX= 342890 MIN= 20020
Q SPACE	113062	113094	113193	113350	113540	113764	113980	113826	112100	106326		
(134000=CC)	92707	68097	34219	-2118	-35101	-63693	-89496	-113465	-135346	-155156		
	-173234	-189211	-201741	-208890	-208854	-200934	-186072	-166348	-144141	-121426		
	-99396	-78573	-59123	-41129	-24701	-9941	3120	14527	24368	32746		
	39799	45720	50721	54985	58650	61842	64704	67371	69909	72303		
	74502	76492	78316	80067	81840	83706	85697	87797	89947	92066		
											FLOOD PERIODS= 23	TOTAL VOL= 2708091
Q BY US RES	2518	2518	2518	2518	2518	2517	2515	2512	2509	2506		
AND DIVS	2500	2487	2464	2441	2427	2426	2436	2454	2474	2479		
	2440	2332	2157	1947	1750	1611	1590	1766	2232	3052		
	4211	5607	7093	8558	9953	11270	12499	13631	14688	15722		
	16776	17845	18894	19901	20871	21795	22624	23299	23810	24217		
	24602	25007	25405	25721	25871	25795	25472	24926	24223	23452		
											AVG= 10573	
FLOOD BY RES	0	0	0	0	0	0	0	0	0	0		
	0	0	0	2118	2427	2426	2436	2454	2474	2479		
	2440	2332	2157	1947	1750	1611	1590	1766	2232	3052		
	4211	5607	7093	8558	9953	9941	0	0	0	0		
	0	0	0	0	0	0	0	0	0	0		
	0	0	0	0	0	0	0	0	0	0		
											FLOOD PERIODS= 23	VOL FROM RES= 83055

EXAMPLE SEQUENTIAL OUTPUT

FIGURE 3

COMPUTATION INTERVAL IN HOURS= 4 SINGLE FLOOD SUMMARY COPY= 1

***** FLOOD NUMBER 6 *****

T1 SUSQUEHANNA RIVER BASIN - MUD CREEK AND TRUXTON RESERVOIRS
T2 AVERAGE ANNUAL DAMAGE REDUCTION EVALUATION - EXISTING < STUDY RESERVOIRS
T3 USING MULTIPLES OF DANVILLE SPF DAMAGE DATA IN 1963 DOLLARS

LOC		MAX REG Q	MAX NAT	MAX UNC	Q BY RES	NO FLOODS TOTAL	VOL FLOODS TOTAL	NO FLOODS FROM RES	VOL FLOODS FROM RES	PER FLOODS FROM RES
140	LINDLEY	18564	82252	12534	6030	0	-0	0	0	0- 0
1351	HORNELL	11128	20644	10513	615	9	17014	9	4453	10- 33
1352	CANISTEO	34539	42857	33997	542	3	25826	3	1636	11- 13
1353	W. CAMERON	39261	47169	38718	543	5	76297	5	2652	11- 15
137	ADDISON	67310	70350	67000	310	12	236555	12	5406	9- 20
141	ERWINS	90106	154438	89743	362	7	237519	7	2697	10- 16
143	BATH	16703	16703	16703	0	6	24068	0	0	0- 0
145	CAMPBELL	22322	26768	22322	0	12	96166	0	0	0- 0
147	CORNING	122243	195288	121948	295	9	386964	9	5213	11- 19
149	ELMIRA	124290	194700	123979	310	2	16945	2	706	14- 15
151	CHEMUNG	146152	207715	145799	352	21	716554	21	38590	11- 34
104	ONEONTA	29051	29051	29051	0	17	158189	0	0	0- 0
107	UNADILLA	36833	40590	36833	0	18	237569	3	689	11- 13
113	BAINBRIDGE	78741	87877	78741	0	20	572778	4	2331	10- 13
1142	CONKLIN	107753	115306	107645	108	20	811750	10	2505	12- 31
121	CORTLAND	9605	15710	9605	0	7	21035	0	0	0- 0
1231	MARATHON	15378	20592	15378	0	3	7677	0	0	0- 0
1232	ITASKA	17619	40511	17619	0	7	32367	2	6	13- 14
118	GREENE	34734	34734	34734	0	15	213271	0	0	0- 0
125	CHENANGO FORKS	63957	86044	63956	1	15	396787	10	8008	11- 25
127	VESTAL	170875	198581	170667	209	21	1381039	21	13088	11- 31
131	WAVERLY	190767	216500	190513	254	20	1605909	20	13361	12- 31
154	TOWANDA	325815	407096	324669	1146	24	2689751	24	116410	11- 34
165	ARCHBALD	3761	6812	3761	0	1	661	0	0	0- 0
171	OLD FORGE	23076	25798	23076	0	4	30742	2	8	11- 12
173	WILKES-BARRE	341301	409570	339472	1829	25	3164548	25	111091	13- 37
180	DANVILLE	342890	407645	341104	1786	23	2708091	23	83055	14- 36

EXAMPLE FLOOD SUMMARY

FIGURE 4

		RESERVOIRS		STOR1	MAX STG	MAX LEVEL	EXCEEDED TOP F.C. 1ST PER.	LAST PER.	MAX INFLOW	MAX REL.	CHAN CAP.
LOC	138	TIOGA-HAMMOND RES	EX	5000	83472	1.654	0	0	49807	12500	12500
LOC	139	COWANESQUE RES	EX	1000	68329	1.716	0	0	39822	6000	6000
LOC	132	ARKPORT RES	EX	10	1769	2.163	8	33	2388	787	1000
LOC	133	ALMOND RES	EX	150	13353	1.901	0	0	7843	4607	5200
LOC	1341	BENNETTS CK RES	US	0	0	1.000	0	0	8499	8499	2000
LOC	142	FIVEMILE CK RES	US	0	0	1.000	0	0	4243	4243	2000
LOC	144	MUD CK RES	US	38000	49804	1.738	0	0	5169	2000	2000
LOC	102	CHARLOTTE RES	US	0	0	1.000	0	0	11556	11556	2000
LOC	105	W. ONEONTA RES	US	0	0	1.000	0	0	8595	8595	2000
LOC	106	E. SIDNEY RES	EX	1700	20401	1.588	0	0	9639	3886	1900
LOC	112	E. GUILFORD RES	US	0	0	1.000	0	0	38867	38867	2000
LOC	1141	GREAT BEND RES	US	0	0	1.000	0	0	106263	106263	50000
LOC	119	TRUXTON RES	US	27000	39958	1.480	0	0	6433	2000	2000
LOC	122	WHITNEY PT RES	EX	5000	48932	1.539	0	0	18553	3933	5000
LOC	116	S. PLYMOUTH RES	US	0	0	1.000	0	0	6323	6343	2000
LOC	124	GENEGANTSLET RES	US	0	0	1.000	0	0	10525	10525	3000
LOC	155	TOWANDA RES	US	0	0	1.000	0	0	22409	22409	1000
LOC	163	STILLWATER RES	EX	343	5245	1.421	0	0	3784	400	400

MAX SYSTEM STORAGE= 331263

EXAMPLE RESERVOIR SUMMARY
FLOOD 6 (80% SPF)
FIGURE 5

COPY= 2

***** MAX VALUES FOR MULTY FLOODS *****

			FLD.PER	MAX REG Q *	FLD.PER	MAX NAT Q *	FLD.PER	MAX LOC Q *	Q BY RES *	WEIGHTED SHORTAGE DES	INDEX REQ
LOC	140	LINDLEY	7.049	18676 *	7.014	102814 *	7.012	15667 *	10072 *		
LOC	1351	HORNELL	7.012	13809 *	7.012	25805 *	7.012	13141 *	1782 *		
LOC	1352	CANISTEO	7.012	43089 *	7.012	53571 *	7.012	42496 *	592 *		
LOC	1353	W. CAMERON	7.013	48987 *	7.013	58961 *	7.013	48397 *	590 *		
LOC	137	ADDISON	7.012	84087 *	7.012	87938 *	7.012	83750 *	337 *		
LOC	141	ERWINS	7.013	112572 *	7.013	193047 *	7.013	112179 *	489 *		
LOC	143	BATH	7.013	20878 *	7.013	20878 *	7.013	20878 *	0 *		
LOC	145	CAMPBELL	7.014	27902 *	7.013	33459 *	7.014	27902 *	1111 *		
LOC	147	CORNING	7.013	152763 *	7.014	244110 *	7.013	152435 *	2381 *		
LOC	149	ELMIRA	7.014	155322 *	7.015	243375 *	7.014	154974 *	2342 *		
LOC	151	CHEMUNG	7.016	182638 *	7.016	259644 *	7.016	182249 *	2505 *		
LOC	104	ONEONTA	7.015	36313 *	7.015	36313 *	7.015	36313 *	0 *		
LOC	107	UNADILLA	7.017	46041 *	7.016	50737 *	7.017	46041 *	0 *		
LOC	113	BAINBRIDGE	7.014	98428 *	7.014	109846 *	7.014	98426 *	1384 *		
LOC	1142	CONKLIN	7.016	134771 *	7.016	144133 *	7.016	134556 *	1495 *		
LOC	121	CORTLAND	7.013	12006 *	7.013	19637 *	7.013	12006 *	754 *		
LOC	1231	MARATHON	7.013	19222 *	7.014	25739 *	7.013	19222 *	769 *		
LOC	1232	ITASKA	7.015	22023 *	7.015	50638 *	7.015	22023 *	2360 *		
LOC	118	GREENE	7.014	43418 *	7.014	43418 *	7.014	43418 *	0 *		
LOC	125	CHENANGO FORKS	7.015	79945 *	7.015	107554 *	7.015	79945 *	2154 *		
LOC	127	VESTAL	7.017	213692 *	7.017	248226 *	7.017	213333 *	3224 *		
LOC	131	WAVERLY	7.019	238537 *	7.019	270625 *	7.019	238141 *	2860 *		
LOC	154	TOWANDA	7.018	407236 *	7.019	508870 *	7.018	405836 *	4432 *		
LOC	165	ARCHBALD	7.012	4701 *	7.012	8515 *	7.012	4701 *	399 *		
LOC	171	OLD FORGE	7.013	28845 *	7.013	32247 *	7.013	28845 *	392 *		
LOC	173	WILKES-BARRE	7.022	426428 *	7.023	511v62 *	7.022	424340 *	4405 *		
LOC	180	DANVILLE	7.024	428394 *	7.026	509556 *	7.025	426380 *	4784 *		

EXAMPLE FLOOD SUMMARY
FLOODS 1-7
RATIOS OF SPF
(.2, .3, .4, .5, .6, .8, 1.0)
FIGURE 6

RESERVOIRS				FLD.PER	MIN STG	MIN LEVEL	*	FLD.PER	MAX STG	MAX LEVEL	*	FLD.PER	MAX REL	CHAN CAP
LOC	138	TIOGA-HAMMOND RES	EX	7.001	5000	1.000	*	7.026	110556	1.880	*	7.034	12500	12500
LOC	139	COWANESQUE RES	EX	7.001	1000	1.000	*	7.023	91061	1.958	*	7.028	6000	6000
LOC	132	ARKPORT RES	EX	7.001	10	1.000	*	7.013	2387	2.220	*	7.014	766	1000
LOC	133	ALMOND RES	EX	7.001	150	1.000	*	7.019	14800	2.000	*	6.029	4607	5200
LOC	1341	BENNETTS CK RES	US	7.001	0	1.000	*	7.001	0	1.000	*	7.012	10624	2000
LOC	142	FIVEMILE CK RES	US	7.001	0	1.000	*	7.001	0	1.000	*	7.013	5304	2000
LOC	144	MUD CK RES	US	7.001	38000	1.000	*	7.027	53197	1.950	*	7.030	2000	2000
LOC	102	CHARLOTTE RES	US	7.001	0	1.000	*	7.001	0	1.000	*	7.013	14446	2000
LOC	105	W. ONEONTA RES	US	7.001	0	1.000	*	7.001	0	1.000	*	7.014	10744	2000
LOC	106	E. SIDNEY RES	EX	7.001	1700	1.000	*	7.034	25354	1.744	*	6.053	3886	1900
LOC	112	E. GUILFORD RES	US	7.001	0	1.000	*	7.001	0	1.000	*	7.013	48584	2000
LOC	1141	GREAT BEND RES	US	7.001	0	1.000	*	7.001	0	1.000	*	7.016	132864	50000
LOC	119	TRUXTON RES	US	7.001	27000	1.000	*	7.033	43544	1.613	*	3.030	2294	2000
LOC	122	WHITNEY PT RES	EX	7.001	5000	1.000	*	7.035	61557	1.694	*	7.060	4217	5000
LOC	116	S. PLYMOUTH RES	US	7.001	0	1.000	*	7.001	0	1.000	*	7.012	7905	2000
LOC	124	GENEGANTSLET RES	US	7.001	0	1.000	*	7.001	0	1.000	*	7.013	13157	3000
LOC	155	TOWANDA RES	US	7.001	0	1.000	*	7.001	0	1.000	*	7.012	28012	1000
LOC	163	STILLWATER RES	EX	7.001	343	1.000	*	7.021	6608	1.537	*	7.060	400	400

EXAMPLE RESERVOIR SUMMARY
FLOODS 1-7
FIGURE 7

EXPECTED ANNUAL FLOOD DAMAGE SUMMARY
CONTROL POINT NUMBER 180

BASE CONDITION FREQUENCY-FLOW-DAMAGE DATA
DMGE

FREQ	PEAK	SUM	DMGE 1
.999	108000	96.000	96.000
.900	120000	141.000	141.000
.680	132000	185.000	185.000
.480	145000	232.000	232.000
.330	158000	280.000	280.000
.230	172000	353.000	353.000
.160	186000	420.000	420.000
.100	201000	780.000	780.000
.070	216000	1139.000	1139.000
.042	234000	1829.000	1629.000
.027	250000	2781.000	2781.000
.015	270000	6314.000	6314.000
.012	290000	8215.000	8215.000
.008	314000	11392.000	11392.000
.005	340000	13929.000	13929.000
.004	360000	16466.000	16466.000
.003	387000	18767.000	18767.000
.003	412000	21071.000	21071.000
.002	440000	22604.000	22604.000

AVERAGE ANNUAL DAMAGES BY TYPE
-0.00

EXISTING SYSTEM AVERAGE ANNUAL DAMAGES BY TYPE
338.49

BASE CONDITION FLOOD DAMAGES
TYPE

NO.	FLOW	PROB INT	SUM	TYPE 1
1	101911	.275	17.87	17.87
2	152867	.551	127.90	127.90
3	203823	.167	125.79	125.79
4	254778	.040	130.10	130.10
5	305734	.010	91.45	91.45
6	407645	.006	116.86	116.86
7	509556	.001	21.33	21.33
		DAMAGES	631.30	631.30
EXST SYST DAMAGES			338.49	338.49

EXAMPLE AVERAGE ANNUAL DAMAGE
EXISTING SYSTEM
FIGURE 8

MODIFIED CONDITIONS FLOOD DAMAGES

NO.	FLOW	PROB INT	SUM	TYPE 1
1	90060	.275	7.02	7.02
2	131400	.551	89.56	89.56
3	172776	.167	52.94	52.94
4	215526	.040	40.47	40.47
5	257572	.010	36.57	36.57
6	342890	.006	80.83	80.83
7	428394	.001	17.74	17.74
		DAMAGES	325.13	325.13
		DAMAGE REDUCTION	13.36	13.36

UNCONTROLLED LOCAL FLOW FLOOD DAMAGES

NO.	FLOW	PROB INT	SUM	TYPE 1
1	85276	.275	2.63	2.63
2	127914	.551	83.30	63.30
3	170552	.167	51.27	51.27
4	213190	.040	38.46	38.46
5	255828	.010	33.84	33.84
6	341104	.006	79.55	79.55
7	426380	.001	17.65	17.65
		DAMAGES	306.70	306.70
		DAMAGE REDUCTION	31.79	31.79
		CORRECTION FACTOR		.89

EXAMPLE AVERAGE ANNUAL DAMAGES
EXISTING SYSTEM PLUS
TWO PROPOSED RESERVOIRS

FIGURE 9

SUMMARY OF SYSTEM'S EXPECTED ANNUAL FLOOD DAMAGES

	DAMAGES			DAMAGE REDUCTION		
CONTROL POINT	BASE (EXIST) CONDITION	MODIFIED CONDITIONS	UNCONTROL LOCAL COND	MODIFIED CONDITIONS	UNCONTROL LOCAL COND	RESIDUAL
145	236,17	189,59	169,23	46,58	66,94	20,36
147	75,02	69,66	66,33	5,36	8,69	3,34
149	99,09	84,44	83,12	14,65	15,97	1,32
151	58,02	56,25	51,60	1,77	6,42	4,65
121	20,89	7,04	6,81	13,85	14,08	,24
1232	61,83	62,15	50,58	-,32	11,25	11,56
125	87,14	84,52	74,23	2,62	12,91	10,29
127	305,64	304,70	263,46	,94	42,18	41,24
131	91,96	93,96	84,94	-2,00	7,02	9,02
154	234,09	223,32	203,99	10,77	30,10	19,34
173	3421,06	3300,77	3231,41	120,29	189,65	69,35
180	338,49	325,13	306,70	13,36	31,79	18,43
TOTAL	5029,40	4801,54	4592,40	227,86	437,00	209,14

EXAMPLE

FIGURE 10

SUMMARY OF SYSTEM COSTS

CONTROL POINT	PROJECT TYPE	CAPITAL COST	ANNUAL O,M,&R COST	TOTAL ANNUAL COST
144	RESERVOIR	17400,00	69,95	1267,07
119	RESERVOIR	11900,00	69,97	888,69
145		0,00	-0,00	0,00
147		0,00	-0,00	0,00
149		0,00	-0,00	0,00
151		0,00	-0,00	0,00
121		0,00	-0,00	0,00
1232		0,00	-0,00	0,00
125		0,00	-0,00	0,00
127		0,00	-0,00	0,00
131		0,00	-0,00	0,00
154		0,00	-0,00	0,00
173		0,00	-0,00	0,00
180		0,00	-0,00	0,00

EXAMPLE CAPITAL COSTS

FIGURE 11

SYSTEM ECONOMIC COST AND PERFORMANCE SUMMARY
(EXCLUSIVE OF EXISTING SYSTEM COSTS)

TOTAL SYSTEM CAPITAL COST * * * * * * *	29300.00	
TOTAL SYSTEM ANNUAL OPERATING MAINTENANCE, AND REPAIR COST * * * *	139.92	
TOTAL SYSTEM ANNUAL COST * * * * * * *		2155.76
AVERAGE ANNUAL DAMAGES - EXISTING SYSTEM	5029.40	
AVERAGE ANNUAL DAMAGES - PROPOSED SYSTEM	4801.54	
AVERAGE ANNUAL DAMAGE REDUCTION		227.86
AVERAGE ANNUAL SYSTEM NET DAMAGE REDUCTION BENEFITS		-1927.90

EXAMPLE NET BENEFITS

FIGURE 12

A SELECTIVE REVIEW OF UNITED STATES INTERINDUSTRY MODELS AND APPLICATIONS[1]

by

E. M. LOFTING[2]

The theoretical principles of interindustry economics were well-developed by the late 1930's and basic models had been established for the economy of the United States.[3] During World War 2 generalized models of this type were developed to aid in the solution of problems relating to the strategic allocation of manpower and materials.[4]

After World War 2, the 1947 economic censuses were used to develop the first large-scale interindustry model of the U.S. economy, known as the emergency model (E-M).[5] This work was carried out in the Bureau of Labor Statistics (BLS), U.S. Department of Labor. The model in its most detailed form showed 450 discrete sectors of the national economy and was used for the analysis of potential resource bottlenecks which might arise in connection with various aspects of U.S. international commitments in what was known then as the Cold War.[6]

In 1953, a major review of agency programs was initiated and in the interest of reduced government spending further work in interindustry analysis at the national level was curtailed.[7] Hence, no U.S. interindustry table was structured from the 1953 economic censuses. In 1961 the usefulness of input-output tables was reassessed and based on the 1958 census a modest research undertaking was initiated which resulted in an 82 sector table being published in September 1966.[8] The 1947 table, as noted, was developed by BLS in the U.S. Department of Labor. The research based on 1958 data was sited in the Office of Business Economics, U.S. Department of Commerce and in contrast to the earlier work the 1958 table was made fully consistent with the National Income and Product accounts. In fact the table was used as a benchmark for modifying components of the entire Income and Product Account series extending back to 1929.[9] For the 1963 census year a more ambitious effort resulted in a further 82 order model published in 1969[10] along with 367 and 478 sector models[11] which emphasized manufacturing and construction sector detail.

The February 1974 issue of the Survey of Current Business[12] contains the 1967 input-output table, and computer tapes of the 367 and 478 sector models are expected in the near future.[13] The original 1947 BLS table was re-worked to conform with the later OBE tables[14] so that for the 20-year period (1947 - 1967) a detailed analysis of technological change is possible.

In allied research endeavors the Bureau of Labor Statistics has projected the 1958 and 1963 80-order tables to 1970[15], 1975[16], and 1980[17]. Similar work is underway for 1985[18].

The United States Bureau of Mines undertook the disaggregation of the six original ISP[19] mineral sectors of the 1958 table to show the structural detail of 48 three and four digit SIC mineral industries[20]. This research was extended to the 1963 367-sector table in which the original six ISP mining sectors were disaggregated to show 44 three and four digit SIC mining industry detail.[21] It is expected that similar detail for mining will be generated for 1967, and 1972 with projections to 1975[22].

In a major research undertaking based on the 1963 national table the Economic Development Administration funded the Harvard Economic Research Project (HERP)[23] to develop 80-order state tables that were consistent with (would sum to) the national totals in a multiregional input-output framework[24]. This effort brought the first consistent set of gross outputs, final demands, and state-to-state commodity flow estimates to the field of regional input-output analysis[25]. Plans are currently underway to repeat this procedure for 1967[26].

Having presented this brief summary of interindustry research as a background to the discussion of specific applications, it may be viewed as somewhat disappointing, given the marked inflation of recent years, to stress that work based on 1967 data will be undertaken, or has just recently been released. However, there continues to be hope that this situation can and will be remedied once the value of interindustry studies in regional planning is more fully understood and appreciated. In contrast to the rather slow growth of interindustry economics in the United States, investment planning abroad has received substantial support from generalized multisector models[27].

Perhaps because of the vastness of the United States and its traditional wealth of resources compared to many European countries there appears to be a much greater reliance on what Adam Smith termed the "invisible hand" of the market. It is not uncommon to encounter a strong resistance to input-output methods and the belief that resource scarcity problems i.e. water, energy, air, can be alleviated without conscious, deliberate effort on the part of planners. As Harry Richardson has noted in his recent book[28] "A strange feature about regional input-output analysis is that attitudes towards its usefulness and validity tend to be extreme. Every regional economist seems to be either its dauntless champion or its fierce detractor." Richardson, writing in 1972, documents the contentions noted clearly by Leontief in 1941[29].

The excerpt points up the philosophical difficulties for input-output that remain after thirty years of professional debate. During this timespan, however, the base of factual information in the United States has been greatly fortified.

In matters of practical application, the uses of interindustry economics generally fall into three broad categories. These are: (1) the analysis of economic structure, (2) the formulation of economic policy and programs of action, (3) the projection of industrial activity levels and resource use to future time frames.

As a part of the analysis of the general interdependence or interlinking of the economy it is customary to develop output and income multipliers for each sector under study.[30] The output multipliers show the extent to which sectors are interlinked. A consideration of the magnitude of the income multipliers can aid in policy decisions concerning sectoral programs to stimulate income. An analysis of resource use is aided by the concept of a "factor content" matrix. This matrix is usually formed by premultiplying the matrix of total requirements by a diagonal matrix of coefficients which show the resource inputs per unit of output for each sector. The resulting matrix is (for example) in units of man-years of labor,[31] acre-feet of water,[32] or BTU's of energy.[33] An analysis can then be carried out sector by sector to determine the labor (water or energy) intensive activites and the extent to which industries which use minimal resources as a direct input to their own productive processes are heavily interlinked to other industries which are resource intensive.

The problem can be rephrased somewhat in terms of "impact." It might be asked what impact the expansion of demand for the products of one sector may have on the output of any other industry. The matter is one of analyzing demand interdependence for specific resources. More recently with the awareness of environmental problems it was realized that input-output tables could not only focus on resource inputs but also on residuals output, or wastes, to the environment per unit of product output.[34] Thus the sale of an automobile in Texas has resulted in waste emissions from steel, rubber, and paint production in Gary, Akron, and Detroit respectively. The problem is one of accurately quantifying the emission rates of residuals per unit of production for water, air, and solid wastes.[35] "Residuals" content matrices could be set up for each type of waste being discharged. A materials mass balance of the economy could be studied and the opportunities noted for reclamation and recycling these materials back into the productive process. The associated costs in terms of real energy resources and labor could also be quantified.

The theoretical accounting framework exists for such comprehensive analyses at the national, regional, and local level. However, it may be asked what are the real possibilities for successfully implementing this form of analysis for some specific planning application in the United States? Let us deal point by point with problems of data assembly, model construction, and analysis.

As noted earlier, at the present time the 1967 national input-output table is available showing 80, 367, and 478 sector detail. For discussion purposes let us say that we are interested in applying the analysis to a single county or group of counties. A first objection might be that the use of 1967 technical coefficients for 1974 analysis and projection would be of little value. This objection can be met, at least partially. It can be noted that the 1972 census is currently being released and that these data along with 1972 national income data and sectoral price relatives can be used to "update" the table to 1972. Updating techniques have been used in England and Canada with moderate success.[36] At worst the resulting table would probably overstate resource requirements. Having dealt with the updating problem at the national level the matter of regionalizing remains.

Techniques have been developed for allocating outputs to state, Standard Metropolitan Statistical Areas, and counties.[37] These allocations can be based on county payroll or employment data where a maximum of industry detail is maintained. Frequently <u>County Business Patterns</u> <u>CBP</u> can provide much of this information. Richardson maintains that the use of national technical coefficients for local area input-output work is acceptable if one begins with three to four hundred national sector detail.[38] For practical purposes this assumes four-digit SIC data are needed at the county level. Final demands can be estimated based on population, income, and Federal, state and local expenditure data.

The final structuring of the transactions table can be accomplished by following some variant of the basic Moore and Petersen technique.[39]

Income, employment, water use and other resource data can now be assembled for each sector of the local table and the multiplier or impact analyses described above can now be carried out.

For environmental analyses, Corps of Engineers Permit Application data, Regional Air Quality Control Board information, and other estimates of solid waste generation can be used to make a comprehensive sector analysis of the environmental impacts for certain hypothesized growth patterns.[40]

If it seems desireable the entire analysis can be cast in a linear programming format to maximize regional product subject to certain resource constraints on the supply side and certain environmental constraints on the gross wastes discharged. In sum, it might be stated with reasonable objectivity that for most local areas of the United States and certainly for states and regions comprehensive input-output analyses of resource use and environmental impacts are fully realizeable as part of the regional planning process.

FOOTNOTES

(1) Paper presented at the Analytical Methods in Planning Seminar, U.S. Army Corps of Engineers, Hydrologic Engineering Center, Davis, California, March 27, 1974.

(2) Economist, Energy and Environment Division, Lawrence Berkeley Laboratory, University of California, Berkeley, California.

(3) Wassily W. Leontief,"Quantitative Input-Output Relations in the Economic System of the United States", Review of Economics and Statistics, 18, 105-25, No. 3, August 1936.

(4) T. C. Koopmans, (Ed.) Activity Analysis of Production and Allocation, John Wiley & Son, Inc., New York, 1951.

(5) W. D. Evans & M. Hoffenberg, "The Interindustry Relations Study for 1940", Review of Economics & Statistics, Vol. 34, No. 2, 97-142, May 1952.

(6) H. Chenery, & P. Clark, Interindustry Economics, John Wiley & Sons, New York, 1958. p. 7.

(7) Chenery & Clark, op. cit.

(8) Survey of Current Business, Office of Business Economics, U.S. Department of Commerce, September 1966.

(9) National Income & Product Accounts of the United States 1929-1965, A Supplement to the Survey of Current Business, U.S. Department of Commerce, Washington, D.C., 1966.

(10) The Input-Output Structure of the U.S. Economy: 1963 Survey of Current Business, November 1969.

(11) Available in computer tape form with mimeo tape lay-out and sector description from Bureau of Economic Analysis, U.S. Department of Commerce, Washington, D.C. 1969.

(12) The Input-Output Structure of the U.S. Economy: 1967 Survey of Current Business, February 1974.

(13) Conversation with Staff of BEA, Washington, D.C.

(14) U.S. Department of Commerce, Office of Business Economics, Misc. Staff Papers, "The Input-Output Structure of the U.S. Economy: 1947", March 1970.

(15) 1970 Input-Output Coefficients, Bureau of Labor Statistics, U.S. Dept. of Labor, BLS Rept. # 326, Sept. 1967.

(16) Projections of the Post-Vietnam Economy, 1975, Bult. 1733, U.S. Dept. of Labor, Bur. of Labor Statistics, 1972.

(17) Patterns of U.S. Economic Growth, 1980 Projections of Final Demand, Interindustry Relationships, Output, Productivity, and Employment, U.S. Dept. of Labor, Bur. of Labor Statistics, Bultn. 1672, 1970.

(18) Cited by Jack Faucett Associates, Chevy Chase, Maryland.

(19) Interindustry Sales and Product.

(20) K-L. Wang & R. G. Kokat, The Interindustry Structure of the U.S. Mining Industries - 1958, U.S. Dept. of the Interior, Bureau of Mines, Information Circular 8338, Washington, D.C., 1967.

(21) J. S. Bargur, Computational Aspects of Input-Output Analysis Applied to Resources Management, Berkeley: Sanitary Engrg. Res. Lab., Coll. of Engrg. & School Of Pub. Health, Univ. of Calif., SERL rept. # 70-7, Sept. 1970.

(22) U.S. Dept. of the Int., Bur. of Mines, Grant # G0122078, Dry Lands Res. Inst., Univ. of Calif., Riverside, Calif., March 1972.

(23) The Harvard Econ. Res. Proj. was officially disbanded in 1972.

(24) Karen R. Polenske, A Multiregional Input-Output Model for the U.S., Rept. # 21, Econ. Dev. Adminis., U.S. Dept. of Comm., Washington, D.C., Dec. 1970.

(25) A Summary of Regional Input-Output Analysis in the U.S. is given by P. J. Bourque, and C. Hansen, An Inventory of Regional Input-Output Studies in the U.S., Grad. School of Bus. Adminis., Univ. of Wash., Seattle, Wash., August 1967.

(26) Correspondence with Karen Polenske.

(27) Input-Output Bibliography, 1966-1970, Vol. 1, Authors, Statistical Papers Series M55, Vol. 1, Dept. of Econ. & Soc. Affairs, Statistical Ofc. of the United Nations, New York 1972.

(28) Harry W. Richardson, Input-Output & Regional Economics, John Wiley & Sons, New York 1972.

(29) W. W. Leontief, The Structure of the American Economy 1919-1939, Oxford Univ. Press, New York 1941. pp. 33-34.

(30) Harry W. Richardson, op. cit., chapter 3.

(31) A Factor Content Matrix essentially describes an inter-industry coefficient matrix showing in each entry the amount of a given factor necessary for the delivery of a unit output of product to final demand. The Bur. of Labor Statistics has developed such a matrix showing manpower requirements. "In order to make the new input-output table more useful for manpower analysis, the Div. of Eco. Growth has converted the inverse form of the table into manpower requirements. The original table,which shows the direct and indirect industry output generated by a dollar's worth of final demand, has been used, along with estimates of . . . levels of labor productivity . . . to provide estimates of the direct and indirect employment requirements per billion dollars of final demand ... The basic input-output relationships however, were left unchanged." J. Alterman, "The Fed. Govt's Program of Eco. Growth Study". Paper given at the Seventh Annual Forecasting Conf. of the Amer. Statistical Assoc., New York Area Chapter, Commodore Hotel, New York, New York, April 23, 1965.

(32) E. M. Lofting, The Leontief Input-Output System and Its Application to Analysis and Projection for Water Resources Planning, Proceedings of the IBM Scientific Computing Symposium on Water & Air Resource Management, held on October 23-25, 1967, Thomas J. Watson Research Center, Yorktown Heights, New York.

(33) Robert A. Herendeen, An Energy Input-Output Matrix for the U.S., 1963: User's Guide, Center for Advanced Computation, University of Ill., Urbana, March 1973.

(34) W. W. Leontief, "Environmental Repercussions in the Economic Structure: An Input-Output Approach", Review of Eco. & Statistics, Vol. 52, 1970, pp. 262-71.

(35) See for example J.S. Bargur, E.M. Lofting, and H.C. Davis, Eco. Eval. of Water Quality Part 5 (Final Report): A Multisectoral Programming Analysis for the Mgmt. of the Waste Water Economy of the S.F. Bay Region, Sanitary Engineering Res. Lab., Coll. of Engr., Univ. of Calif., Berkeley, Nov. 1969.

(36) John Bates & Michael Bacharach, "Input-Output Relationships, 1945-1966," Paper No. 3 in Richard Stone, *A Programme for Growth*, London, Chapman & Hall, 1963. See also T. I. Matuszewski, P. R. Pitts, and J. A. Sawyer, "Linear Programming Estimates of Changes in Input-Output Coefficients," *Canadian Journal of Economics & Political Science*, Vol. 30, No. 2, May 1964, p. 205.

(37) "1963 Output Measures for Input-Output Sectors by County," prepared for the Office of Civ. Defense, U.S. Dept. of Defense, Dec. 1968. Jack Faucett Associates, Chevy Chase, Md. "1963 Output Measures for Input-Output Sectors by Standard Metropolitan Statistical Areas and Non-Metropolitan State Areas: Appendix B, Detailed notes on the construction of output measures for non-manufacturing sectors." Report to the Inst. for Defense Analyses, Arlington, VA, Jan. 1967. Jack Faucett Associates. "State Outputs for 3 & 4-digit SIC Industries, 1947, 1958, & 1963." Unpublished data: Jack Faucett Associates, Chevy Chase, MD.

(38) Harry W. Richardson, *op. cit.*

(39) F. T. Moore & J. W. Petersen, "Regional Analysis: An Interindustry Model of Utah," *Review of Economics & Statistics*, Vol. 37, No. 4, pp. 368-383, Nov. 1955; see also Ronald S. Boster, & William E. Martin, "The Value of Primary versus Secondary Data in Interindustry analysis: A Study in the Economics of the Economic Models," *The Annals of Regional Science*, Vol. 6, No. 2, Dec. 1972, p. 35.

(40) S. Basheer Ahmed, "Input-Output Analysis in Environmental Modeling, IEEE Transaction on Systems, Man, & Cybernetics," Vol., SMC-3, No. 6, Nov. 1973.

OPTIMIZING COMPONENTS OF URBAN FLOOD CONTROL SYSTEMS

By

Darryl W. Davis[1]

INTRODUCTION

Flood control works within urban areas frequently consist of a number of interrelated components, such as detention storage reservoirs, channel modifications, land use controls, levees, floodproofing and pumping facilities. There is a wide range of configurations and sizes of these measures that will accomplish a specific technical objective such as a specified degree of protection. The need to determine the size and configuration of the works within urban areas has given rise to many analysis that attempt to determine trade-offs between facilities and performance so as to achieve an overall better solution. For example, if there were two components being studied for an urban system--storage and pumping--water could be stored in some areas and the excess pumped out in the lowers reaches. There would obviously be some best size of these two components that would maximize the system's net value or accomplish a performance standard most efficiently.

The problem of determining the size of a number of interrelated components is not new and for at least the recent past a large number of analytical optimization procedures have been developed. In fact the professional discipline of operations research has concentrated almost exclusively on these problems. These techniques have been quite successful in areas where the objectives are well defined, and the system response to the interaction of system components can be modeled with fairly simple mathematical relationships. The application of these techniques to water resource systems has been mostly by academic research groups in the case study mode (analyzing others' problems) as contrasted with functioning as an integral part of planning studies. A major reason for this is that water resource systems are extremely complex and to accurately define the functioning of the system requires fairly detailed analysis. In addition there is considerable uncertainty in system inputs and desired outputs. Water resources planners have been relunctant to simplify their systems to the degree necessary to make use of the more automated optimization procedures. The belief among planners is that the simplifications result in not capturing the essence of the system performance and component interactions of water resources systems.

[1]Chief, Planning Analysis Branch, The Hydrologic Engineering Center, Davis, California.
March 27, 1974.

This paper describes a technique that has been developed and programmed into an existing Hydrologic Engineering Center (HEC) computer model that permits the determination of the "best" size of the individual components of a complex interrelated system of urban flood control works while using techniques of analysis that are very near to the present state-of-the-art in the Corps in hydrologic modeling, cost analysis and economic damage-frequency analysis. "Best" is defined as the component sizes that yield the maximum value of system net benefits while observing performance standard constraints, if they exist. This capability has been developed so that a system consisting of up to six detention storage reservoirs, two within or out of basin diversions, and two pumping facilities can be automatically sized.

The major contribution of this capability to planning efforts is that it permits the study to focus on broad structuring of alternative systems that include physical works and nonstructural measures and not allow to become dominant the large task of searching out the correct sizes for components for each alternative system.

PLAN FORMULATION METHODOLOGY

The technique has been developed to be as near compatible with current plan formulation procedures as possible. In order to understand the development of the technique and its probable role in planning studies, it is necessary to understand, at least conceptually, the plan formulation and evaluation process in urban flood control studies.

A simplified description of a plan formulation strategy that is employed in urban storm drainage and flood control planning is as follows. Initially, public meetings are held and investigations are initiated to determine the broad social objectives within the study area. The social objectives primarily serve to assist in defining the concerns of the public and concepts to be used in structuring management alternatives and defining technical objectives and criteria that will be used in structuring the technologic components of management alternatives. Stated more completely, such social objectives as alleviating a specific dangerous flooding situation, providing a regional recreation opportunity, removing the cause of stunted economic growth, and providing a better community environment would be translated into a range of management alternatives that would consider the location and severity of flooding, possibilities of joint site use for specific temporary detention storage and urban recreations and appropriate performance standards for components of the systems. Once the general delineation of concerns and opportunities for furthering the social objectives is accomplished, the technical analysis is performed to define the performance of the alternative systems and assess the system's economic and environmental assets and liabilities.

The information developed by these analyses is used in successive refinement of the alternatives and formulation of implementation strategies. An objective within the successive refinement of alternatives is usually to determine the system, which can include physical works and other non-structural measures, that will in the aggregate perform their function most economically. The most economically efficient size for a system exists when the difference between the total annual benefits and the total annual cost is maximized, which is termed the scale of maximum net benefits. In studies with a few components, say two or less, the usual approach is to nominate a few selected component sizes, determine their performance and graphically estimate the particular component scales that would accomplish the economic objective. For more than two components, graphical analysis is virtually impossible.

The next step in formulation is usually to "select" a performance standard, giving appropriate weight to social and environmental objectives. The performance standard is usually expressed as the "degree of protection", or the specific hydrologic event that can be controlled so that flood damages do not result. A 50-year degree of protection would be provided by a system that reduced the flows and stages within an urban area for a 50-year flood to flows and stages below damaging levels.

Another sizing problem exists upon selecting a performance standard which is to determine the scale of the system components that will accomplish the target degree of protection most efficient economically. The usual approach is to size the facilities so that they accomplish the target performance standard at the least overall annual cost. A better approach would be to size the facilities to accomplish the target performance standard while to the extent possible maximizing system net benefits. This concept recognizes that different components, such as reservoirs and levees, perform differently over the entire range of future events, some of which will probably exceed the performance target event.

The determination of the system that maximizes net benefits or accomplishes the performance standard as specified by a degree of protection is by no means trivial when there are more than one or two major components whose individual sizes may vary over a considerable range and the system's performance is complex. For complex urban flood management systems, the analysis can be extremely tedious and consume a very large portion of the efforts and energies of those performing the studies, if they are done at all.

The technique that has been developed and described herein is designed to be compatible with the above plan formulation methodology. The objective in its development was to create the capability for performing this analysis in the usual fashion but to remove the tedium of searching for component sizes and thus provide the capability for studying a wider range of system alternatives than might otherwise be considered. It also would therefore permit determining the relative sensitivity of the system to changes in facility costs, project interest rates, assumed economic conditions, and hydrologic performance standards, so that an array of information could be easily developed that could be used in formulating a desired management plan.

OPTIMIZATION TECHNIQUE

The grand strategy for developing the technique consisted of first devising a computer simulation model for simulating the hydrologic and economic performance of flood control systems, then structuring an automatic search procedure that would exercise the simulation model by successively adjusting the scales of each component of the system until the solution is found. When it is decided to automatically determine the best size or the "best" anything in a mathematical sense, a certain number of requirements immediately become apparent. The first is that "best" must be precisely and uniquely defined by an indicator or index that integrates all of the desired performance characteristics of the system that is being analyzed. This index is normally termed the objective function. The capability to automatically adjust the component size within a feasible range and evaluate the performance of the system for the components must also exist. The last requirement is the necessity of developing a search procedure that is as nearly foolproof as possible.

Objective Functions

The plan formulation strategy described earlier included initially determining an economically optimum system (unconstrained maximum net benefit) as a starting point for determining a performance standard for subsequent analyses. The unconstrained economic optimum can be characterized by an index of the system performance (objective function) that consists of the sum of the total annual system cost and the total value of the system's expected annual flood damages. If we label this the total social cost of flooding, then the objective is to find the component sizes of the system that results in the minimum total value of system social cost of flooding. It can be proven that the system that results in minimum total social cost as defined above is exactly the system that will result in the maximum value of system net benefits.

The problem then is to numerically perform the analysis to accomplish

$$\min \text{(OBJ FTN)} = \sum_{i=1}^{n} C_i + \sum_{j=1}^{k} AD_j$$

where

C_i = equivalent annual cost of system component i

AD_j = expected annual damage at location j

n = number of system components to be optimized

k = number of damage locations (damage centers)

The second phase in plan formulation was to determine the component sizes that would accomplish the performance standard (degree of protection) most efficiently economically. The objective function that was developed for determining the system that will satisfy the performance standard while maximizing system net benefits to the extent feasible is:

$$\min \text{(OBJ FTN)} = \left(\sum_{i=1}^{n} C_i + \sum_{j=1}^{k} AD_j\right)\left[\left(\frac{|Q_z - Q_t|}{A\ Q_t}\right)^4 + \text{CNST}\right]$$

where

C_i, AD_j, n, k = as before

Q_z = flow (stage) for target degree of protection of system

Q_t = target flow for target degree of protection

A, CNST = normalizing constants and weights, usually .1 and 1.0, respectively

This function is similar to the previous function except that the system components are penalized whenever they result in performance that is not within a certain tolerance of the desired system performance target. If the flow (Q_z) is equal to or less than the target flows (Q_t) for a given system then for a constant CNST of 1.0 the objective function is exactly the same as the unconstrained function. Providing a value of 0.1 for the normalizing constant A in effect says that when performance (Q_z) is within 10 percent of the target (Q_t) the weight between the cost and the performance is the same. For deviations larger than 10 percent the components are penalized at the rate of the fourth power and for deviations less than 10 percent the penalty is reduced rapidly. In practice, one needs only this objective function since by setting CNST to 1.0 and Q_t to a large value, the unconstrained solution may be found.

The objective function is meaningful only if it is possible to accurately calculate, and have confidence in, the components of the function. For example, the annual damage at a control point (AD_j) results from economic analysis that define the damage functions and hydrologic analyses that define the exceedence frequency relationships. In order that this procedure be as nearly acceptable to Corps users as possible, the hydrologic and economic analysis have been performed in the computer simulation model by approximately current state-of-the-art standards in the Corps.

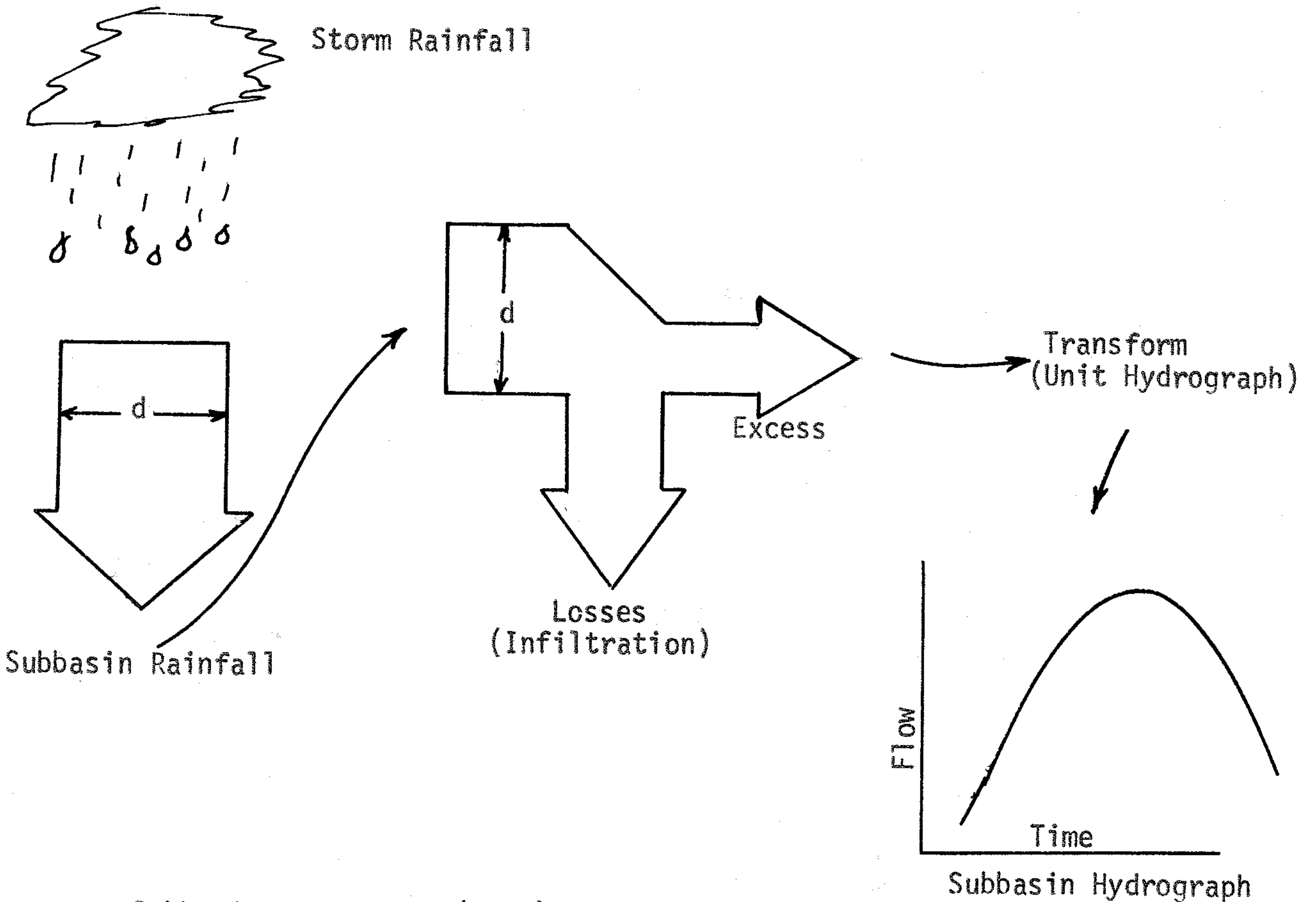
The hydrologic simulation is performed using accepted Corps procedures of subbasin average rainfall analyses, extraction of losses to yield rainfall excess for individual subbasins, and the computation of a runoff hydrograph from individual subbasins by use of the unit hydrograph procedure, thence routing subbasin hydrographs for the system by application of the usual hydrologic routing procedures such as the Muskingam and Tatum methods, and then combining hydrographs at concentration points. The simulation is performed by the HEC-1 computer program that has been in use by Corps hydrologists for a number of years. A schematic of computations of the hydrologic runoff from a complex basin is illustrated in figure 1.

The economic calculation of the expected value of annual damages is performed using the Corps procedure of defining the economic consequence of a flood in terms of damage functions that relate the damage for a flood event to the peak flow or stage, and combining this function with the exceedence frequency relation of peak flow or stage to yield an exceedence frequency relationship of damages. This relationship is subsequently integrated by numerical methods to yield the expected value of annual damages. The simulation program accepts damage functions in the form of flow damage or stage damage relations, accepts exceedence frequency functions in the form of flow or stage exceedence frequency, develops from input a range of hydrologic runoff events for the watershed so that modified conditions (with the system) exceedence frequency relationships at all damage centers can be developed and the expected value of annual damages automatically computed within the simulation. Figure 2 illustrates a schematic of this procedure which is explained in detail in Addendum 3 of the HEC-1 Users Manual (reference 1).

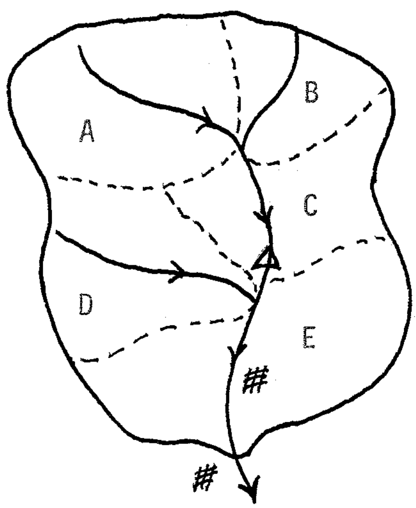
The components whose scales (sizes) may be automatically determined include detention storage reservoirs, pumping plants and diversions.

Storage Reservoir Characterization

The detention storage reservoirs that may be considered are those for which it is possible to define the operating characteristics as a unique function of the storage content within the reservoir. A reservoir with an uncontrolled outlet works exactly meets this requirement. Reservoirs that have operating rules that are determined by reservoir storage content also meet this requirement. To provide capability for automatic adjustment of operating characteristics, a reservoir is characterized by (1) the outflow characteristics of a low level outlet, which is defined by the centerline elevation of the outlet and an orifice equation of the form:



a. Subbasin Hydrograph (H.G.)

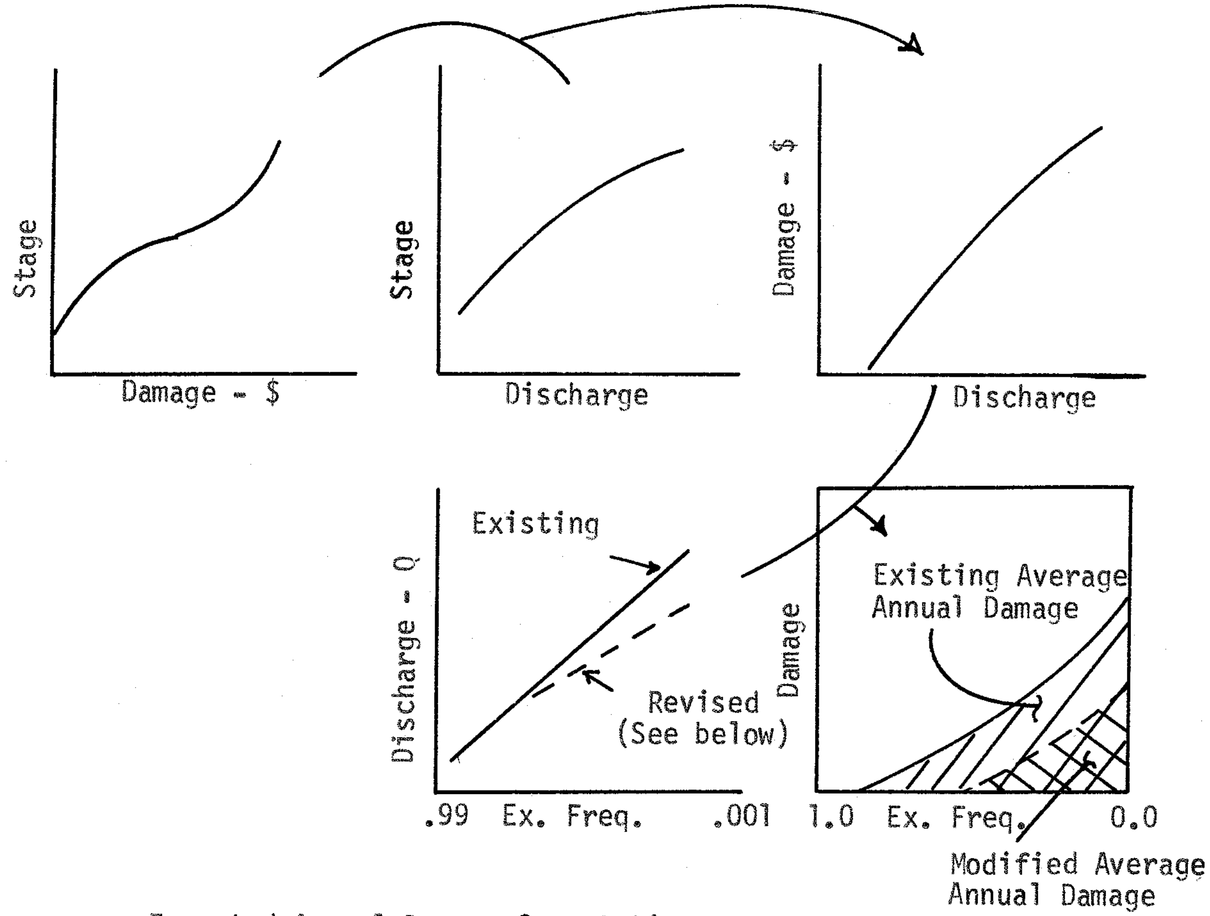


b. Modelling Concepts

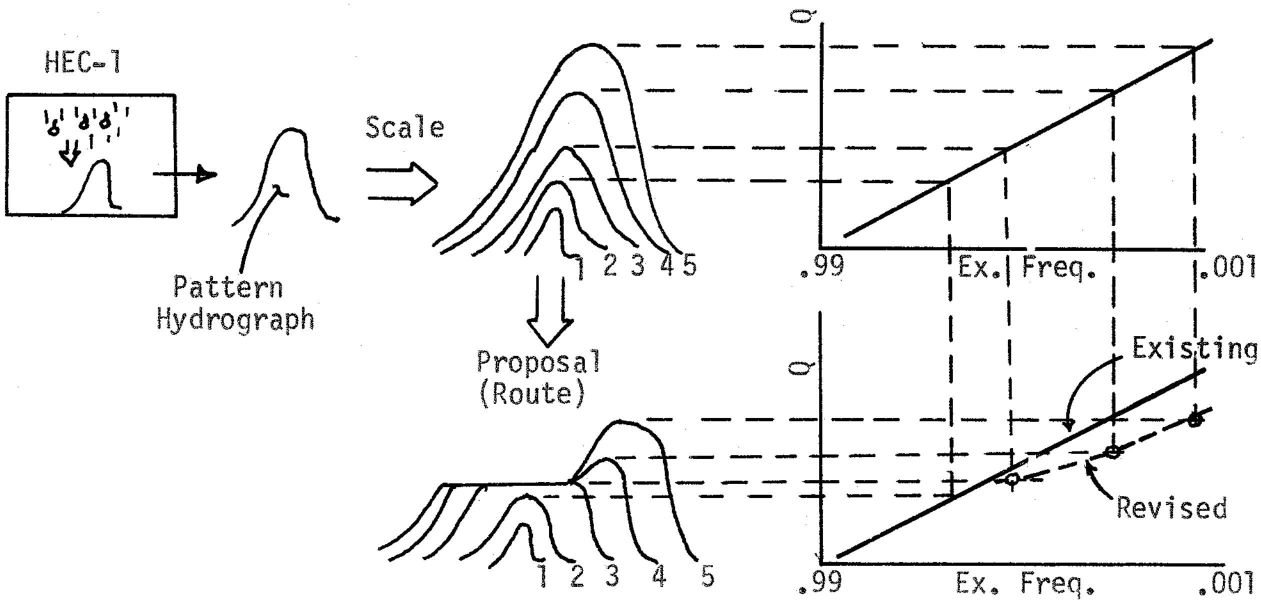
I. Subdivide basin into Subbasins A, B, C, D, E to accommodate Alternatives, Damage Centers and Watershed Hydrology.

II. Computation Sequence
Compute Subbasin H.G. at A
Compute H.G. at B
Combine and Route to Reservoir at C
Compute local C H.G.
Combine and Route through Reservoir
Compute H.G. for D
Combine and Route to outlet
Compute local E H.G.
Combine

Figure 1
Rainfall-Runoff Calculations



a. Expected Annual Damage Computation



b. Frequency Function Revision

Figure 2
Flow-Damage-Frequency Analysis

$$Q = CA\sqrt{2g}\,(H)^{EXP}$$

where

C = discharge coefficient

A = outlet area

H = head on low level outlet

g = acceleration of gravity

EXP = exponent dependent on tailwater conditions, 0.5 if no tailwater

and (2) the overflow characteristics of a spillway which is defined by a weir equation of the form:

$$Q = CLH_*^{3/2}$$

where

C = discharge coefficient

L = length of spillway

H_* = head on spillway

and (3) the site storage characteristics which are defined by an elevation-storage capacity relationship. For an index storage to be optimized, which is the storage at the elevation of the spillway crest, the above relationships are merged to define the reservoir's outflow as a function of the storage level in the reservoir (storage outflow function).

Two modes are possible for optimizing a reservoir. In the usual mode a reservoir that can be characterized by a low level outlet and an overflow weir as above will be automatically adjusted in its index storage capacity, along with all other system components, to achieve the minimum value of the objective function. The cost function for the reservoir in the usual mode consists of a capital cost function and an associated capital recovery factor for converting the capital cost to annual cost, and the annual cost of operation, maintenance and replacement expressed as a proportion of the capital cost. The capital cost function includes land acquisition and construction costs, interest during construction, etc., expressed as a function of the index storage size of the reservoir. The capital cost for a specific size is interpolated from this function and the equivalent annual cost is computed as the product of the capital cost and the capital recovery factor for the appropriate discount rate. The annual cost of operation, maintenance and replacement is the product of the annual cost proportion and the interpolated capital cost. The total annual cost of the reservoir is the sum of these two costs.

In initial test applications of the technique to the Blue Waters Ditch studies of the East St. Louis and Vicinity Interior Flood Control Project, it became apparent that for one component the "reservoir size" that was to be determined was in actuality the lands that were to be acquired since the "reservoir" embankment was sufficiently high so as to contain all floods. The embankment was in fact a large proposed highway fill. The flow of the reservoir would therefore pass only through the low level outlet and thus the only variable to control the operation of the reservoir was the capacity of the low level outlet. For this particular situation a reservoir's operating characteristics are specified uniquely by the outflow characteristics of the low level outlet and the item regarding the reservoir that is to be optimized is the "size" of the outlet. The reservoir performance is characterized as before except it simply has no spillway and the discharge coefficient for the low level outlet is held constant and the area of the outlet opening varied. The cost characterizations include a capital cost of outlet works function, and the reservoir capital cost function which would be primarily the cost of acquiring the reservoir site for the ponding level equivalent to a specified exceedence probability, taken here as the degree of protection. This characterization will also be necessary for studying systems for urban areas that are protected by major levees, as is typical in many local protection projects where pumping is necessary to remove flood waters and the amount of ponding near the pumping facility is a function of the size of the pumping facility.

Pumping Plant Characterization

A pumping facility removes volume from the system at a rate equal to the pumping capacity. The performance characteristics of a pumping plant are defined by an initial threshold water level at which the pump is activated and the discharge capacity of the pumping facility. In this analysis, it is assumed that water pumped from the system does not later appear at other locations in the system. The cost of a pumping facility is computed from a capital cost function and an associated capital recovery factor for converting to equivalent annual cost, the annual operation, maintenance and replacement cost that is a proportion of the capital cost, and the annual power cost. The power cost is adjusted if the volume to be pumped changes as the system components sizes are being optimized. It can be demonstrated that no matter the pumping capacity the power costs would not materially change if the volume to be pumped does not change. The annual power costs are therefore adjusted only for water that is removed from the system by diversions or other pumping facilities.

Diversion Characterization

A diversion transfers flow between locations within the system. The performance characteristics are defined by a threshold flow and a diversion capacity. The concept of the diversion relationship is indicated in figure 3. Water diverted may be returned to the system at any downstream location so that it is possible to characterize facilities which would bypass a portion of flood flows around a damage center. Flow may also be permanently diverted from the system. The cost is characterized similar to a pumping plant by a capital cost function, a capital recovery factor and annual operation, maintenance and replacement factor.

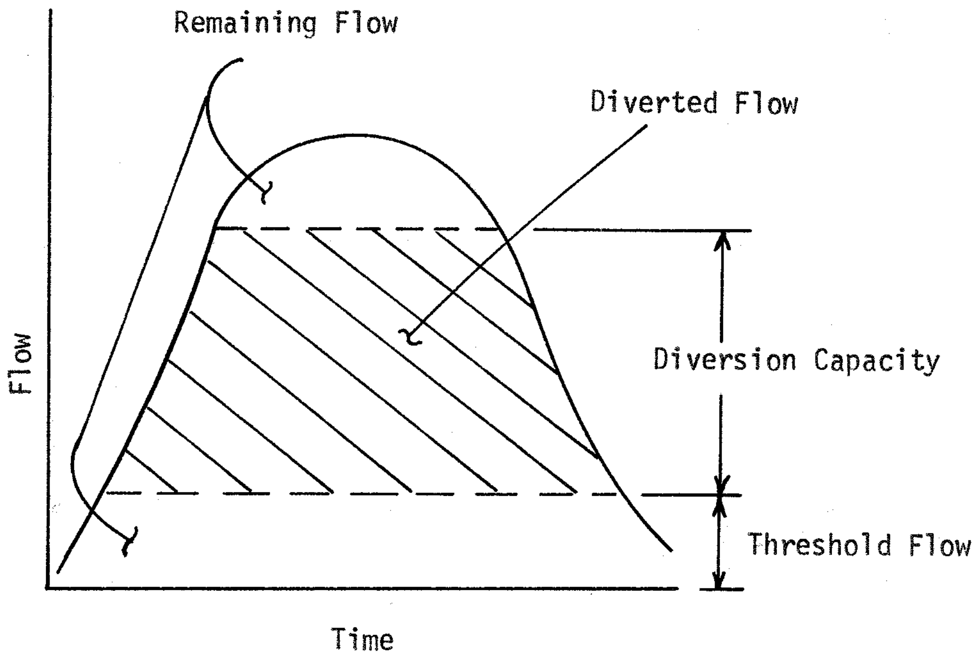


Figure 3
Diversion Concept

THE SEARCH PROCEDURE

The mathematical strategy for automatically adjusting the component sizes such that the objective function can be minimized is that described previously by Beard in "Optimization Techniques for Hydrologic Engineering" (reference 2). The procedure is the univariate gradient procedure which makes use of the trend characteristics of the objective function for selected small changes in each component size. The convergence procedure used to project the trend to determine improved component sizes is the Newton-Raphson convergence procedure. The optimization methodology proceeds as follows:

- First, trial sizes of all system components are nominated and the entire system is simulated in all of its hydrologic, costs, and economic detail to calculate the value of the objective function, which for unconstrained optimization is the sum of the equivalent annual cost and annual damage.

- Then the size of one component is decreased by a small selected amount (1 percent) and the simulation is repeated for the entire system to compute a new value of the objective function. This is repeated again resulting in three unique values of the objective function for small changes in the size of one component.

- From these three values, an estimate is made of the component size that would result in the minimum value of the objective function. The computation of the adjustment is illustrated schematically in figure 4.

- After adjustment of the size of the system component, the entire system is simulated again in detail to compute the new value of the objective function and, provided the objective function has decreased, the procedure then moves to the second system component whose scale is to be optimized.

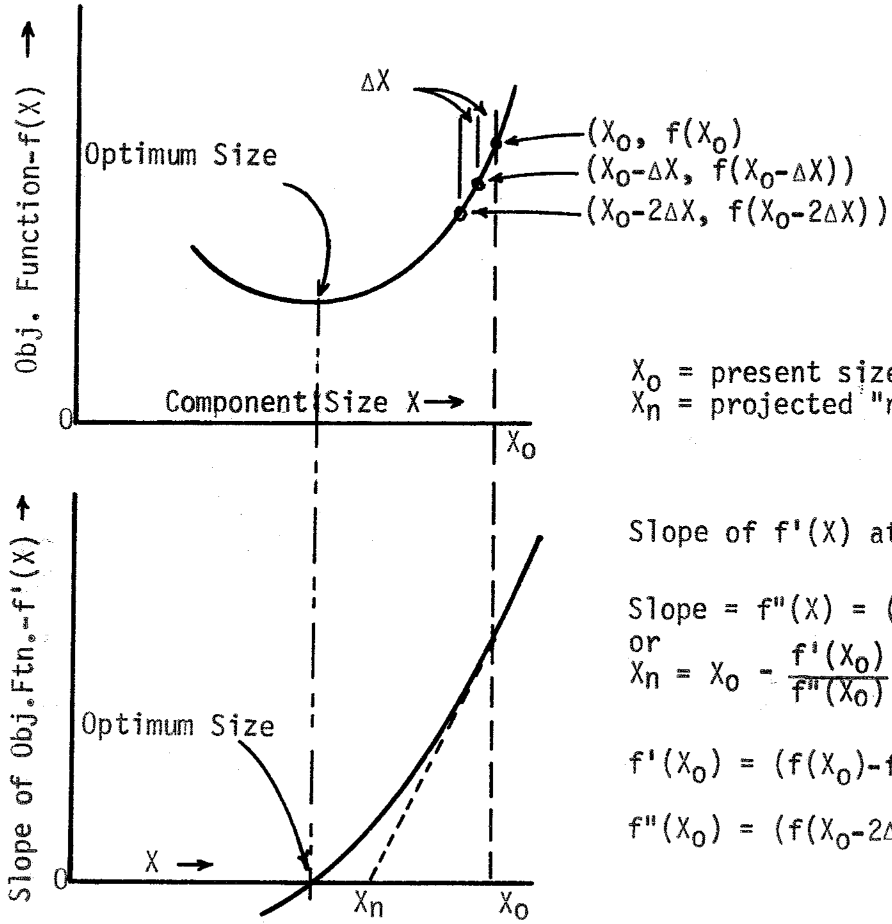
- The above procedure is repeated for the second and all subsequent components to be optimized.

- A single adjustment has now been made for each component for one complete search of the system component sizes.

- This procedure is then repeated for four more complete system searches and concludes by adjusting a few additional times, those components that are making the greatest contribution to decreasing the objective function.

- The procedure is terminated when either no more improvement in the objective function can be made (within a tolerance) or the complete search cycle is completed.

The efficiency of the search procedure (see figure 4) and the degree of success in determining the optimum sizes for the components is a function of the behavior of the objective function. If the objective function varies erratically with small adjustments in the component scales, chances of finding a unique optimum are less than with an objective function that varies regularly (termed well-behaved). Results of applications to date suggest that the objective functions are reasonably well-behaved and that unique answers do in fact come out of the procedure. It should be noted, however, that this particular methodology (univariate gradient procedure) does not mathematically guarantee that the true optimum (global optimum) is achieved. All that can be stated is that the system that is derived out of this procedure will perform, as indicated by the objective function, better than the system that was initially specified. Applications to date indicate that the procedure arrives at very nearly the optimum values for a range of starting values. A study methodology that considers that local optima may occur, such as testing a few starting values, would be appropriate.



X_o = present size of component X
X_n = projected "new" size for X

Slope of f'(X) at $X_o - \frac{\Delta X}{2} = f''(X)$

Slope = $f''(X) = (X_n - X_o) / (f'(X))$
or
$$X_n = X_o - \frac{f'(X_o)}{f''(X_o)} - \frac{\Delta X}{2}$$

$$f'(X_o) = (f(X_o) - f(X_o - \Delta X))/\Delta X$$

$$f''(X_o) = (f(X_o - 2\Delta X) - 2f(X_o - \Delta X) + f(X_o))/\Delta X^2$$

Figure 4
Convergence Procedure

APPLICATION TO AN URBAN FLOOD CONTROL PROJECT

The development of the technique and the programming of it into the computer program HEC-1 was requested by the St. Louis District for use in plan formulation studies for the Harding Ditch component of the East St. Louis and Vicinity, Interior Flood Control Project. The District desired a technique that would enable automatically determining the scales of flood control system components comprising three to four reservoirs, a diversion and one to two pumping plants. The development work had proceeded well so that when it became necessary for the District to perform additional analysis of a component of the project that had previously been studied, an application of the technique was undertaken to assist the studies and provide for testing. The area studied was the Blue Waters Ditch component of the project which encompasses approximately 9,000 acres of the American Bottoms area. Figure 5 is a schematic of the system.

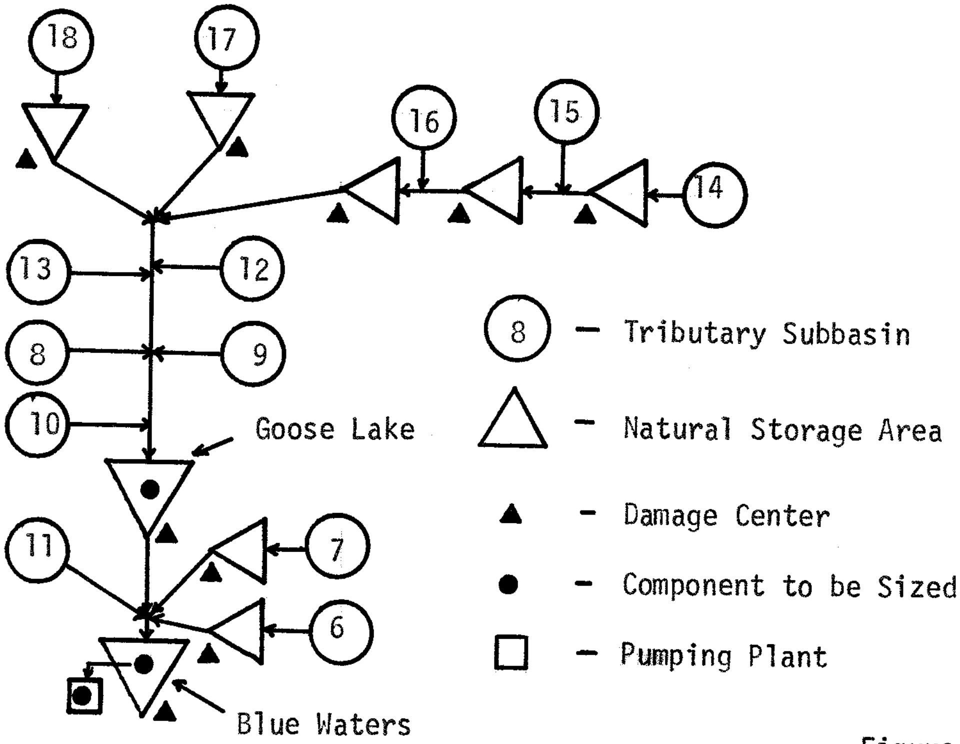


Figure 5
Blue Waters Ditch System

Previous studies had defined two detention storage sites and a pumping facility as potential system components. The technique was applied to determine the best size of the pumping facility and detention storage areas for a range of storage site characteristics, interest rates, assumed economic conditions and performance standards. A major objective was to determine the sensitivity of the component scales to assumed flood plain land use controls. This was accomplished by optimizing for no target degree of protection and economic flow-damage functions prepared for damage potential as it exists in 1973, then optimizing for economic-flow-damage functions reflecting (a) uncontrolled future growth, and then (b) repeating the optimization for a reasonably controlled future growth compatible with the flood control system. Optimization was then repeated for a target degree of protection of 100-year return period. The sensitivity of the system to detention site characteristics was examined by altering the reservoir elevation-storage and reservoir storage-cost functions and optimizing. The sensitivity to the project interest rate was examined by optimizing one of the previously studied conditions for three interest rates.

The results of the studies are preliminary and should be considered as a test application of the methodology rather than the final results of the formulation studies for Blue Waters. The studies, however, were a real component of the plan formulation and evaluation strategy and the results presented in Table I are not a selected case study. The solutions were sufficiently promising that design will probably ensue based on the analysis performed. Table I presents a summary of results of selected optimization runs. An important revelation from this application was that it is possible to quantitatively determine the effect of a number of interesting system conditions, such as land use controls. Also, the range of component sizes that are optimum under a variety of assumed conditions was surprisingly (pleasantly) limited in most instances so that considerable confidence was developed in system component scales. The studies indicated a meaningful role for land use controls as a component of an urban flood control system and, to a limited extent, its contribution quantified and its role explicitly evaluated.

No additional development work is contemplated before the technique is applied to the Harding Ditch area. It should be possible in the Harding Ditch study to further test the methodology as to its value in plan formulation and evaluation studies. If the results of the initial rather hurried application in the Blue Waters Ditch plan formulation studies are an indication of its utility, it will have considerable value in studies where a range of alternative systems with a number of components are to be studied.

INPUT REQUIREMENTS AND RESULTS

The methodology has been designed to be consistent with plan formulation strategies in use by Corps offices that are studying urban flood control and major drainage projects. The methodology is in fact not limited to urban flood control studies and is equally applicable to other flood control studies for which the assumptions of the operating characteristics of storage reservoirs, pumping and diversions apply. The technique provides a means of assisting studies so that study effort can be focused on a wide range of alternatives. The information needed to apply the technique is essentially no different than the usual procedures used in Corps of Engineers flood control plan formulation studies.

Data Requirements

The level of data refinement needed to model the rainfall-runoff response of the basin, characterize the operation of system components, compute system costs and perform economic damage computation can vary but should be at least feasibility level. The hydrologic data required

TABLE I
(1000's of Dollars)

System Condition[1/]	All Pump, EF, PT=.01 6-7/8 @ 50, NS	EF, PT=.01 6-7/8 @ 50, NS	EF, No PT 6-7/8 @ 50, NS	EF, PT=.01 6-7/8 @ 50, MS	EF, PT=.01 3-1/4 @ 100, NS
System Capital Cost	$24,600	$16,880	$13,229	$24,800	$17,000
Amortized Capital Cost	1,777	1,204	944	1,771	578
O, M, P & R Cost	94	61	45	66	61
Total Annual Cost	1,870	1,265	988	1,838	639
Existing Annual Damages	1,085	1,085	1,085	1,085	1,085
Residual Annual Damage	25	49	106	23	50
Annual Damage Reduction	1,060	1,036	979	1,062	1,035
System Net Benefits	-811	-229	- 9	-776	396
Optimum Goose Lake Storage	200 Ac.Ft.	800 Ac.Ft.	1,800 Ac.Ft.	600 Ac.Ft.	800 Ac.Ft.
Optimum Blue Waters Storage	400 Ac.Ft.	1,400 Ac.Ft.	1,700 Ac.Ft.	1,200 Ac.Ft.	1,400 Ac.Ft.
Optimum Pump Capacity	7,000 cfs	2,600 cfs	1,100 cfs	3,300 cfs	2,600 cfs

1/ PT - performance target, NS - natural storage,
MS = modified storage, EF = existing land use for future

are the subbasin breakdown and areas, precipitation for each subbasin for a representative storm, unit hydrograph, loss rates, and base flow recession for each subbasin, streamflow routing criteria for each channel reach, and reservoir routing criteria for all reservoirs. Exceedence frequency relations for each damage center for existing conditions must be developed and provided.

The system cost functions require tabulation of capital costs for a range of facility sizes, the capital recovery factor for each facility, the annual operation, maintenance and replacement costs, power costs and costs of any fixed facilities (not considered variable) to be included.

The economic functions required are flow-damage or stage-damage relationships for each damage center. The functions must capture all economic consequences of a flood event and should be present worth for the assumed future conditions. A number of damage functions should be prepared representative of a range of assumed future conditions. The study of nonstructural measures requires manipulation of the damage functions, for instance flood proofing measures are reflected by displacing a portion of the damage function within the elevation range that flood proofing is considered.

As might be expected, when a tool becomes available that provides expanded capability there is the tendency to attempt to more precisely define the hydrologic and economic performance than would be done otherwise. For example, in the usual study procedure, two damage centers might be used as index points for a reach of stream whereas with the capability available herein twice that many damage centers might be used and this generates additional study. The fault is probably more in the application than in the tool itself; although, it seems to be a very real situation in the present age. An even stronger urge seems to arise to answer more "what if" questions. While this is somewhat the objective of a technique like this one, the urge should be at least mildly resisted.

Development of general performance and cost functions for the system components requires additional analysis. In a study that is of necessity not considering a wide range of component sizes, a single or perhaps two detailed cost estimates might be developed. For the optimization methodology, cost functions that relate to component size are needed which requires a different philosophy of cost estimating. General cost functions are needed initially and the detailed cost estimates deferred until approximate component scales have been determined by the studies. The generalized reservoir performance characteristics require additional hydraulic analysis to develop preliminary sizes for outlet works and spillways.

The information output from the application of this methodology could if not carefully controlled by a pragmatic study procedure, engulf the analyst. The technique provides the capability to "what if" a great number of items that probably would not be otherwise analyzed. Tools of this kind should of course be applied to conduct sensitivity analysis but within reason so that only information useful in the planning study is generated. It is worth emphasizing here that all analysis tools, and in particular computerized methodology, have as their primary function the generation of information that will be of use in decision-making; not removing any decision-making requirements from the planning function. Data is not necessarily information.

The outputs of a system optimization for a set of system components, performance cost, and economic functions are:

1. The scale (size) for each component of the system.

2. Complete hydrologic simulation of the entire system.

3. Economic expected annual damage analysis for each damage center in the system.

4. Costs for each component of the system.

5. A system summary of cost, performance and system net benefits.

Figure 6 is an example of output from an optimization run.

Resources and Costs

The Blue Waters Ditch analysis provides some insight into the manpower requirements and computer costs of applying this technique. For this study the information had been previously developed. The primary effort was to assemble the hydrologic data of loss rates, unit hydrographs, routing criteria, etc., economic flow damage information for the damage centers and cost relationships in a form acceptable to the computer program. The specific studies were processed and information analyzed as the results became available. There were nine damage centers within the basin; nine storage areas, two of which were variable in size; and one pumping facility. The data preparation for the processing required about a man-week on the part of each of a hydrologist, economist and water resources planner. The detail processing and interaction for the studies required about another week's time of each of these individuals. The computer time associated with processing a run was not trivial. Efficient processing for a complex system such as Blue Waters requires a large capacity high speed computer. Even though computer execution times are rather meaningless

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******************************
            BLUE WATERS DITCH ANALYSIS 6 7/8  DISCOUNT RATE 50  YEAR PERIOD
            FEB 74 EXISTING + MODIFIED CONDITIONS WITH 10 YEAR LATERL DITCHES IN PLACE
            OPTIMIZATION + PERFORMANCE FOR .01 DGPRT TARGET STORAGE-NAT DETENTION AREAS

                                     JOB SPECIFICATION
                     NQ    NHR   NMIN  IDAY   IHR  IMIN METRC   IPLT   IPRT NSTAN
                    110      1     -0     1    -0    -0    -0     -0      4    -0
                                        JOPER       NWT
                                            7        -0

                              MULTI-PLAN ANALYSES TO BE PERFORMED
                                   NPLAN= 2 NRTIO= 9 LRTIO= 1
            RTIOS=     .30     .45     .60     .70     .80     .90    1.00    1.50    2.00

                                        SYSTEM OPTIMIZATION
               RES 1    RES 2    RES 3    RES 4    RES 5    RES 6    DIV 7    DIV 8    PMP 9   PMP 10
                -200       -0       -0       -0       -0       -0       -0       -0    -3000       -0
                                                  ANORM     CNST
                                                    .10     1.00

                                         FIXED COST INPUT
                                     FCAP      FDCNT        FAN
                                     4714      .0713      .0004
                                     4714        336          2

                                                                 ISTA   INT FLOW   TRG FLOW    FLW OBJ    FLW DEV
                                                                   10    922.034    750.000     27.683    172.034

                                                                 ISTA   INT FLOW   TRG FLOW    FLW OBJ    FLW DEV
                                                                    4   1199.032   1380.000     27.683      0.000

                                        NC  M M1    VAR(M)   VAR(M1)    OBJ DEV     IANCST    ANDMG O FTN(NC)
                                         1  1  1   200.000   200.000     27.683   1357.155    43.256 39307.733

                                                                 ISTA   INT FLOW   TRG FLOW    FLW OBJ    FLW DEV
                                                                   10    934.969    750.000     36.996    184.969

                                                                 ISTA   INT FLOW   TRG FLOW    FLW OBJ    FLW DEV
                                                                    4   1190.369   1380.000     36.996      0.000

                                        NC  M M1    VAR(M)   VAR(M1)    OBJ DEV     IANCST    ANDMG O FTN(NC)
                                         2  1  1   198.000   198.000     36.996   1357.232    43.423 52079.084

                                                                 ISTA   INT FLOW   TRG FLOW    FLW OBJ    FLW DEV
                                                                   10    947.927    750.000     48.504    197.927

                                                                 ISTA   INT FLOW   TRG FLOW    FLW OBJ    FLW DEV
                                                                    4   1181.679   1380.000     48.504      0.000

                                        NC  M M1    VAR(M)   VAR(M1)    OBJ DEV     IANCST    ANDMG O FTN(NC)
                                         3  1  1   196.000   196.000     48.504   1357.309    43.590 67865.162

OBJECTIVE FUNCTION FOR VARIABLE 1  39307.7334  52079.0842  67865.1616

                                                                 ISTA   INT FLOW   TRG FLOW    FLW OBJ    FLW DEV
                                                                   10    875.394    750.000      7.814    125.394
```

Figure 6
Sample Output

EXPECTED ANNUAL FLOOD DAMAGE COMPUTATION

ISTA	NFLOD	NDMG	ISAME	TRGT	DGPRT	IAGST	ADSCNT	AANCST
4	10	3	0	1380	.010	1	.07133	-0.00000

ECONOMIC DATA FOR STATION 4 PLAN 1

FREQ	PEAK	SUM	TYPE 1	TYPE 2	TYPE 3	TYPE
.100	640	5.000	0.000	0.000	5.000	
.100	780	32.000	25.000	0.000	7.000	
.200	950	60.000	50.000	0.000	10.000	
.200	1700	785.000	750.000	0.000	35.000	
.080	2200	2170.000	2100.000	0.000	70.000	
.040	2800	4035.000	3900.000	0.000	135.000	
.015	3150	4900.000	4700.000	0.000	200.000	
.008	3400	6260.000	6000.000	0.000	260.000	
.004	3700	7460.000	7100.000	0.000	360.000	
.004	3800	7690.000	7500.000	0.000	390.000	

AVERAGE ANNUAL DAMAGES BY TYPE

-0.00 -0.00 -0.00

FLOOD DAMAGES FOR STATION 4 PLAN 1

NO.	STOR	PROB	SUM	TYPE 1	TYPE 2	TYPE 3	TYPE
1	780	.260	7.66	5.95	0.00	1.72	
2	1103	.116	22.15	20.50	0.00	1.65	
3	1375	.062	26.70	25.29	0.00	1.41	
4	1553	.044	26.30	25.03	0.00	1.27	
5	1712	.049	37.18	35.51	0.00	1.67	
6	1864	.051	58.18	55.94	0.00	2.24	
7	2012	.073	110.10	106.20	0.00	3.90	
8	2719	.064	221.40	213.80	0.00	7.60	
9	3356	.032	176.15	168.65	0.00	7.51	
AVG ANN DMG			685.82	656.85	0.00	28.97	

ECONOMIC DATA FOR STATION 4 PLAN 2

PEAK	SUM	TYPE 1	TYPE 2	TYPE 3	TYPE
820	20.000	10.000	0.000	10.000	
960	37.000	25.000	0.000	12.000	
1100	113.000	100.000	0.000	13.000	
1750	390.000	370.000	0.000	20.000	
2200	1230.000	1200.000	0.000	30.000	
2800	2980.000	2900.000	0.000	80.000	
3300	4650.000	4500.000	0.000	150.000	
3700	6260.000	6000.000	0.000	260.000	
4200	8350.000	7900.000	0.000	450.000	
4600	10140.000	9500.000	0.000	640.000	

AVERAGE ANNUAL DAMAGES BY TYPE

-0.00 -0.00 -0.00

FLOOD DAMAGES FOR STATION 4 PLAN 2

NO.	STOR	PROB	SUM	TYPE 1	TYPE 2	TYPE 3	TYPE
1	227	.260	.37	0.00	0.00	.37	
2	268	.116	.23	0.00	0.00	.23	
3	321	.062	.17	0.00	0.00	.17	
4	344	.044	.13	0.00	0.00	.13	
5	499	.049	.25	0.00	0.00	.25	
6	438	.051	.22	0.00	0.00	.22	
7	601	.073	.47	0.00	0.00	.47	
8	1147	.064	7.80	6.99	0.00	.81	
9	1422	.032	7.33	6.83	0.00	.50	
AVG ANN DMG			16.98	13.82	0.00	3.16	
AVG ANN BFT			668.84	643.03	0.00	25.81	

EXCEEDENCE FREQUENCY = .010 TARGET FLOW/STOR = 1380 REGULATED FLOW/STOR = 1422

RESERVOIR CAP COST = 2585 TOTAL ANNUAL = 184

Figure 6 (cont'd)

SYSTEM OPTIMIZATION RESULTS

RES 1	RES 2	RES 3	RES 4	RES 5	RES 6	DIV 7	DIV 8	PMP 9	PMP 10
224	-0	-0	-0	-0	-0	-0	-0	2576	-0

SYSTEM COST AND PERFORMANCE SUMMARY
(UNITS SAME AS INPUT - NORMALLY 1000'S OF DOLLARS)

TOTAL SYSTEM CAPITAL COST * * * * * * * * * * * * * *	16880	
TOTAL SYSTEM AMORTIZED CAPITAL COST * * * * * * * * *	1204	
TOTAL SYSTEM ANNUAL O,M,POWER AND REPLACEMENT COST *	61	
TOTAL SYSTEM ANNUAL COST * * * * * * * * * * * * * *		1265
AVERAGE ANNUAL DAMAGES -- EXISTING CONDITIONS * * * *	1085	
AVERAGE ANNUAL DAMAGES -- OPTIMIZED SYSTEM * * * * *	49	
AVERAGE ANNUAL DAMAGE REDUCTION (BENEFITS) * * * * *		1036
AVERAGE ANNUAL SYSTEM NET BENEFITS * * * * * * * * *		-229

***** OPTIMIZATION OBJECTIVE - MAXIMIZE SYSTEM NET BENEFITS FOR TARGET PROTECTION LEVEL *****

Figure 6 (cont'd)

since they are unique to specific computer and optimization problems, the following computer resources used for Blue Waters might be of interest. To process a given system configuration to determine the optimum size of each of three components optimized and output of the results required 15 minutes of accounting unit equivalents on a CDC 7600 computer and resulted in costs that ranged between $30 and $50 per computer run. The actual execution time ranged between 1.5 and 2.0 minutes but a great amount of input-output and system storage were required. The study results were generated by about 12-15 successful computer runs.

SUMMARY AND CONCLUSIONS

A technique has been developed and programmed into HEC-1 that automatically determines the sizes of urban flood control system components that results in maximizing total system net benefits subject to accomplishment of performance targets. The system is described by hydrologic data, component performance and cost functions and flow damage information for damage centers. The system components that may be optimized include detention storage reservoirs, pumping and diversion facilities. Initial applications suggest that the technique has considerable value in urban flood control plan formulation and evaluation studies.

ACKNOWLEDGEMENTS

The technique described herein was developed at The Hydrologic Engineering Center by the author at the request of U.S. Army Engineer District, St. Louis. The sponsorship, encouragement and support of Mr. James Dexter of the Urban Studies Section was instrumental in the development of the technique.

BIBLIOGRAPHY

1. HEC-1 Flood Hydrograph Users Manual, January 1973, The Hydrologic Engineering Center, Davis, California.

2. Optimization Techniques for Hydrologic Engineering, Leo R. Beard, Technical Paper No. 2, April 1966, The Hydrologic Engineering Center, Davis, California.

A STOCHASTIC APPROACH TO IMPACT ASSESSMENT

By

Major Harvey C. Walker, Jr.[1]

INTRODUCTION

Since enactment of recent legislation, the Federal planner has broadened the scope of his planning to include the environmental and social effects of his plans in addition to the traditional economic and engineering considerations. The trend toward more comprehensive planning and a greater emphasis on the noneconomic effects induced by alternative plans can be expected to increase in the future. To fully exploit the potential of effects assessment, it will be necessary to begin early in the planning process while technical solutions are still at the conceptual stage and use the results in developing the alternative plans rather than to wait until the plans are almost complete and then try to determine what the overall effects will be.

Purpose

In order to be fully integrated into the planning process, the method chosen to assess and analyze effects must (1) be relatively easy to use; (2) provide output quickly; and (3) respond to varying degrees of data confidence. This paper describes an approach built around a time-sharing simulation program which attempts to meet these criteria.

Definitions

Throughout this paper, the following definitions apply:

Parameter: A component of man's environment which, when changed, directly contributes to or detracts from the accomplishment of a

[1]Specialist in Operations Research Applications, Planning Division, Lower Mississippi Valley Division

planning objective or quality of life. Parameters are qualitative in nature and not measurable directly. This is the level at which people establish priorities; for example, they generally prefer air which is clear and free of smog, contains no unpleasant odors or substances which are detrimental to health, and does not contain excessive particulates; they are not interested in specific component concentrations, only in their effects. The public may be willing to trade degradation of one parameter for gains in another. The degree of willingness to trade is expressed in relative priorities.

Indicator: A component of a parameter which is often measurable and expressible in quantitative terms. Changes in the indicator can be predicted by examining the physical structures and processes involved in a plan. The planner may then use these changes to estimate changes in a parameter. Examples of indicators of air quality which are quantifiable are: particulate, SO_2, CO, and NO_x concentrations. Other indicators, such as odor, cannot be quantified, but they can be described in qualitative terms and their effects predicted.

Assumptions

The following assumptions are implicit in this approach:

- The purpose of the analysis is to provide a relative measure of net change in some function; for example, social well-being or environmental quality.

- The function can be modeled in terms of definable parameters.

- The transfer function between changes in the parameters and changes in the function can be approximated by some form of summation process.

- The effect produced by a change in a parameter is a function of the magnitude of the change and the perceived or measured importance of the parameter.

DESCRIPTION OF THE APPROACH

Parameter Selection and Definition

The selection and definition of the parameters to be used are critical to the success of this approach. Referring to the basic definition of a parameter, you will recall that it represents an unmeasurable attribute of the function under evaluation, although there may be measurable indicators which predict changes in it. One of the basic problems in impact assessment today is the inability to rigorously synthesize all the predicted changes in the indicators into some meaningful conclusion about what the net effect of a plan will be. Anyone who has studied a typical cause-effect linkage diagram on even a relatively minor project can appreciate this problem. Given the current state of the art, this synthesis can best be accomplished by applying professional judgment. One of the roles of the parameter is to provide an area of focus on which an evaluator can exercise his judgment. A second function is to provide a means for the public to express its priorities.

The first step in applying this procedure is to identify and define the parameters to be used in the evaluation. It is important that, when the definitions of all the parameters are combined, the function under evaluation is described as fully as possible, even though no change may be anticipated in several of them. During field-testing, it was determined that the social well-being function could be adequately described with as few as 6 parameters or as many as 22, depending on how inclusive each parameter definition was. It was also discovered that, when 6 parameters were used, the focus was not narrow enough for the team to draw conclusions with an acceptable degree of confidence; and 22 parameters were unmanageable because the focus was too narrow. The number finally selected was 12, which provided sufficient focus for meaningful evaluation, while providing parameter definitions which were broad enough to allow synthesis. The number of parameters, their names, and their definitions will vary depending on the function being evaluated and the individual or individuals performing the evaluation.

A parameter is most easily defined in the form of a series of questions and conditions. It may also specify aspects which are not included. An example of what a parameter labeled "Employment" might look like in a function to evaluate social well-being is as follows:

- Will the plan create jobs or stimulate the creation of jobs commensurate with the locally available work force?

- Will these jobs cause workers to move up the employment ladder into more satisfying jobs?

- Will there be jobs created at the entry level which would be filled by unemployed people from the region?

- If the jobs created will be filled by imported labor, they will not be credited as an improvement in this parameter.

- Increases in income will be credited to an economic parameter.

The above example is given for illustrative purposes only. The exact scope of this parameter would be determined by the others used in the evaluation. It should be noted that these parameters are not study-, plan-, or area-dependent.

Assessment of Public Priorities

Once the parameters have been identified and defined, it will be necessary to determine how much degradation in one parameter the public is willing to trade for a gain in an other. There are several methods for measuring public priorities, which are discussed at length in the literature including: expert opinion, seminars, workshops, public surveys, and surveys of elected officials. With care, any of these techniques can produce valid results, and selection of the particular method of measurement is left to the reader. The important consideration is that the relative priority assigned each of the parameters reflect the affected public's attitudes. A method which relies heavily on public input will have the added advantage of greater surface validity. At the conclusion of this assessment, each parameter should be paired with a priority score which reflects its importance relative to the other parameters. It is not necessary to have the scores add to any particular number or to be within a specific range because they will be normalized by the program which will perform the analysis. The priorities so developed will be area-dependent but not study- or plan-dependent.

Identification of Potential Impacts

As soon as conceptual plans are identified for consideration, the process of identifying potential impacts can begin. By examining the structural features and processes involved in each potential plan, the evaluator can begin identifying potential cause-effect linkages between the plan components and the parameters. Once this is accomplished, it will be necessary to: (1) select the indicator to be used; (2) determine which of these are to be quantified, the level of quantification required, and the measurement technique necessary to achieve this level of quantification; and (3) select a procedure for evaulating those indicators which will not be quantified.

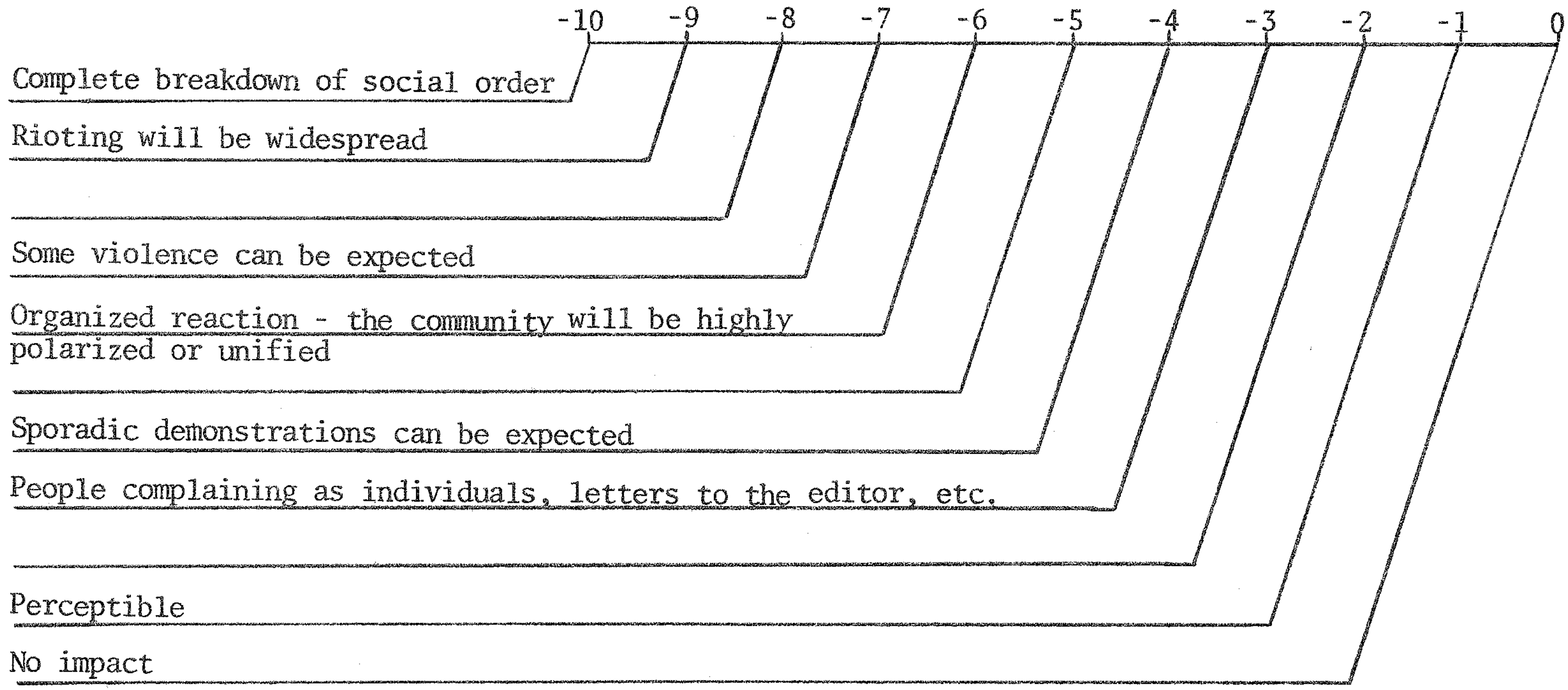
Assessment of Impact Magnitude

Predicted changes in the indicators are used to produce three estimates of the magnitude of the change each alternative plan will induce in each parameter. The change is estimated between the plan under consideration and a projected base line rather than between the plan and existing conditions. The estimates required are of the two limits of the interval which contains all probable impacts and the expected impact. The width of the range is an expression of data confidence. These estimates are converted to numeric scores by translating the appropriate subjective description to its numeric equivalent, using a scale similar to Figure 1.

The method selected for assessing impact magnitudes will depend on the resources available and the purpose of the assessment. The complexity of the process may range from one evaluator's expert opinion to a structured group evaluation. Several evaluations encompassing the full range of complexity may be employed during a single study.

A structured approach, which is recommended, employs the entire multidisciplinary study team augmented by outside expertise, if required. In addition to the active evaluators, an individual well versed in the method should act as moderator. The moderator's function is to manage the assessment, consolidate individual assessments, and insure that proper focus and perspective is maintained during discussions.

The team is assembled by the moderator, and the alternative plans are discussed; important linkages identified; and anticipated changes in the indicators described. After the team disperses, the members independently score each parameter for each alternative plan and give the scores to the moderator. The moderator identifies those areas of general agreement and disagreement. The team is reassembled and the moderator notes those areas of general agreement and proceeds to discuss individual parameters where there is disagreement. Team members explain their reasons for the score they assigned and attempt to determine if the disagreement results from lack of confidence in the input data or from differences in the treatment of the data. The team then disperses again and each member rescores the parameters. The monitor collects the second set of evaluations and examines it for convergence. It is not necessary that the convergence be on a single point; only that a range be identified which is acceptable to the team. The extremes of this range provide the high and low estimates, and the mode of the estimates is used to provide the expected value. This process is repeated until acceptable convergence is achieved. The moderator uses the results of the final evaulation to prepare the input data for the program.



NEGATIVE SOCIAL IMPACT SCALE

Sample Assessment Scale

Figure 1

Use of the Computer Program

Using an interactive, time-sharing program, the assessment information described above is loaded onto a computer file. This file is used as the input for the evaluation program. The following is a brief description of the simulation process:

- The parameter-importance factors are normalized to sum to one.

- Each alternative is evaluated independently:

  - The three impact scores are used to define a triangular-frequency distribution for each parameter.

  - The frequency distribution is expressed as a cumulative-distribution function (CDF).

  - One hundred random numbers are generated for each parameter. These are converted to trial impact scores by relating them to the CDF.

  - The trial impact scores are used to compute the trial parameter score using the function:

$$S_{jk} = I_j M_{jk}$$

where:

S_{jk} is the trial parameter score for parameter j and trial k.

I_j is the importance factor for parameter j.

M_{jk} is the magnitude of the change predicted in parameter j during trial k.

$$M_{jk} = 1.99546^X - 1 \quad \text{for } X \geq 0$$

$$M_{jk} = -(1.99546^{-X}) + 1 \quad \text{for } X < 0$$

X is the trial impact score provided by the simulation.

The exponential form of M_{jk} was chosen to correspond to the scale illustrated in Figure 1. On that scale, a score of -1 represented an impact which would be barely perceptible, while a score of -6 represents a situation where the community would become highly mobilized. Obviously, six parameters which had impacts estimated to be at level -1 would not have a net effect as intense as one parameter with a -6 impact. By using the scores as exponents instead of adding them directly, the problem of a series of minor impacts becoming equivalent to a major impact is avoided. The base of 1.99546 causes the expanded scale to have a range from -1,000 to +1,000, and the ± 1 causes the function to be continuous through 0. This form was derived during the initial testing and may require some adjustment as a result of more extensive use.

o The mean and upper and lower 95-percent confidence limits are computed for each parameter.

o One hundred trial impacts are computed according to:

$$N_k = \sum_{j=k}^{n} S_{jk}$$

where:

N_k is the net impact for trail k.

n is the total number of parameters under evaulation.

o The trial-net impacts are used to compute the mean or expected net impact and upper and lower 95-percent confidence limits.

o A sample of 15 of the trial net impacts is taken and saved for later use.

o After necessary sorting, the alternative evaluation is printed.

• After all the alternatives have been evaluated, they are sorted by expected net impact and the samples saved above are used to conduct a ranked-sum significance test (Snedecor, 1956, pg 117) to determine if discrimination is possible between the net impacts of the alternatives. This information is printed, completing the run.

Program Output

An example of the program output for one alternative is contained in Figure 2. The first line is the title of the run and the second line is the alternative under evaluation. The next three lines are self-explanatory, except to point out that they are on a scale extending from plus to minus 1,000. The numbers are useful for comparing the net effects of alternatives within a single computer run only. The numeric data are followed by a verbal interpretation.

EXAMPLE OF PROGRAM OUTPUT FOR ONE ALTERNATIVE

ALT A1

THE EXPECTED NET IMPACT OF THIS ALTERNATIVE 10.1
THE LOWER 95% CONFIDENCE LIMIT IS -.8
THE UPPER 95% CONFIDENCE LIMIT IS 25.9

THE EXPECTED NET IMPACT IS JUDGED TO BE MODERATELY BENEFICIAL
THE PROBABLE RANGE IS FROM SLIGHTLY ADVERSE
TO MODERATELY BENEFICIAL

PARAMETERS WITH POSITIVE SENSITIVITY INDEXES

PARAMETER NAME	SENSITIVITY INDEX
PUBLIC FAC. & SERV	1.7
EMPLOYMENT	19.6

SIGNIFICANT CONTRIBUTIONS TO THE EXPECTED NET IMPACT (WEIGHTED)

PARAMETER NAME	IMPACT	PARAMETER NAME	IMPACT
HIGHLY BENEFICIAL		HIGHLY ADVERSE	
NONE			
MODERATELY BENEFICIAL		MODERATELY ADVERSE	
EMPLOYMENT	10.9	PUBLIC FAC. & SERV	7.5
SLIGHTLY BENEFICIAL		SLIGHTLY ADVERSE	
INCOME	3.6	EDUCATION	0.7
DESIRABLE GROWTH	2.7	COMM. COEHESION	0.3
AIR QUALITY	0.8	AESTHETICS	0.1
COMM. STABILITY	0.3		
CULT. & RECREATION	0.3		

MODERATE AND HIGH IMPACTS ON PARAMETERS (UNWEIGHTED)

*** BENEFICIAL ***

```
PARAMETER NAME          MODERATE IMPACT          HIGH IMPACT
                       -------------------    -------------------
                       EXPECTED  POTENTIAL    EXPECTED  POTENTIAL

AIR QUALITY        .....X................................
EMPLOYMENT         .....X...............................X
COMM. STABILITY    ...............X......................
DESIRABLE GROWTH   .....X................................
INCOME             .....X................................
HOUSING            ...............X......................
CULT. & RECREATION...............X......................
```

*** ADVERSE ***

```
PARAMETER NAME          MODERATE IMPACT          HIGH IMPACT
                       -------------------    -------------------
                       EXPECTED  POTENTIAL    EXPECTED  POTENTIAL

AESTHETICS         ...............X......................
COMM. COEHESION    ...............X......................
PUBLIC FAC. & SERV.....X...............................X
HOUSING            ...............X......................
EDUCATION          ...............X......................
```

SAMPLE ALTERNATIVE EVALUATION

Figure 2

The discussion of the section on sensitivity indexes will be deferred until later.

The next section is a sorted parameter list grouped by category according to each parameter's contribution to the expected net impact. The figures displayed are weighted according to the relative importance of each parameter. The boundaries between the categories and the limits of the parameter scale are based on the input data. The shape of the scale is consistent with the net impact scale and is constant throughout a single run.

The scale limits are set by taking the highest normalized parameter weight and multiplying it by 1,000, which determines the highest value any parameter can achieve. A base is then computed by taking the tenth root of this value. The boundaries between slight and moderate and moderate and high are then computed according to the formulas previously given for M_{jk} by substituting the new base for the original 1.99546 and three and seven, respectively, for the exponents. Scores which fall below 0.05 are considered insignificant.

The final section of the output identifies those parameters which have expected or potential moderate or high impacts, regardless of the importance of the parameter.

Figure 3 shows the results of a discrimination test in an evaluation containing three alternatives. Most of the output is self-explanatory, except the area underlined on the right. The "3's" which appear next to Alternatives B and A indicate that their net impact is statistically indistinguishable, at the 95-percent confidence level, from the alternative in rank position three; in this case, Alternative C. They are, however, distinguishable from each other. What this means to the user is that no choice should be made between Alternatives B and C or A and C, based on their net impacts.

FIGURE 3

DISCRIMINATION TEST

DEMONSTRATION OF DISCRIMINATION TEST OUTPUT - 3 ALTERNATIVES

TENTATIVE RANK	NAME	EXPECTED IMPACT	INSUFFICIENT CONFIDENCE TO DISTINGUISH BETWEEN RANK #(S)
1	ALT B	7.2	3
2	ALT A	5.0	3
3	ALT C	4.4	

The lack of discrimination between two alternatives will result from one or both of the following conditions:

- The individual impacts of the two alternatives may be so similar that no degree of data refinement will allow discrimination. In this case, the selection between these alternatives should be based on some criterion other than the one used in this particular analysis.

- Lack of discrimination resulted from a lack of confidence in the individual assessment of impact magnitude for one or more parameters. The degree of confidence in the data is expressed by the range between the high and the low assessments. In this case, it may be possible to achieve discrimination by further data refinement. The purpose of the sensitivity index contained in the alternative analysis (Figure 2) is to identify the areas where data refinement will be most productive in achieving discrimination.

The sensitivity index is based on a comparison of the width of the 95-percent confidence interval for each of the parameters with that of the expected net impact score. Those parameters with confidence intervals which exceed 30 percent of the confidence interval for the total alternative are displayed. The sensitivity index is computed, using the formula:

$$SI_j = \frac{0.3(A_{ci}) - P_{ci}}{0.3(A_{ci})} \times 10$$

where:

SI_j is the sensitivity index for parameter j.

A_{ci} is the width of the 95-percent confidence interval for the alternative.

P_{ci} is the width of the 95-percent confidence interval for parameter j.

The use of 30 percent of A_{ci} as the cutoff point was established by trial and error, and the 10 is a scaling factor. The specific values are not critical, as the sensitivity index is only a measure of relative variability between parameters within a single alternative.

If a planner is faced with a situation where it is necessary for him to make a choice between alternatives that the analysis indicates are indistinguishable, he should first look at the two alternatives and determine if this condition is a result of similarity between the alternatives, or a lack of data confidence. If the lack of discrimination is a result of the similarity of the alternatives, then further data refinement and use of the program will not solve the problem. If, on the other hand, data confidence is the cause, the sensitivity index identifies the parameters for each alternative plan where further data refinement will be most productive. The higher the index, the more productive data refinement should be. The presence or absence of parameters displayed in this section should not be interpreted as an indication of the quality of the evaluation, and no attempt should be made to refine the data for the sole purpose of reducing or eliminating the list. The only way to insure that no parameters appear is to provide point estimates for all impacts, which will produce a deterministic analysis which defeats the purpose of the program.

Application in the Planning Process

Effects assessment is not new to the planning process; the benefit-cost ratio is a form of economic effects assessment. Traditionally, the benefit-cost ratio has been used throughout the planning process to aid the planner in forming his initial plans; modifying those plans; plan evaluation; and plan selection.

Expanding the scope of the effects assessment can be viewed in either of two ways: (1) it can be considered extra work for the planner who now has an extra subject to cover in his report, or, (2) it can be a valuable tool to augment the benefit-cost ratio and engineering expertise to streamline the process and broaden the planner's perspective.

To maximize the usefulness of the assessment process, it must begin in the early phases of a study and have an influence in determining the study's direction. The procedure just described is particularly suitable for early application because it allows the evaluator to express his confidence in, and then analyze, his data, taking the confidence level into consideration. In the earliest phases of the study, data confidence will be very low and the assessment process relatively informal; however, even at this level, the program is useful in determining data-collection priorities and some plan discrimination may take place. As economic and engineering data are refined, more precise assessment data can be developed. If serious adverse impacts are detected during the assessment process, this information can be used to modify the plans early in the study, or may even lead to early abandonment of unacceptable plans before a large amount of time and money have been invested in engineering.

Because the evaluator creates a permanent data file at the beginning of the assessment, it is not necessary to reenter all the data each time there is a change to be made. All that is required is that the appropriate changes be made to the data file and the program rerun.

The purpose of data refinement is to produce discrimination between alternatives. Once this has been accomplished, further refinement will not aid in the decision process and the time and money spent will be of little benefit. Because the output of the program indicates when discrimination is possible and where to direct additional data-collection efforts, it can also serve as a valuable management tool.

BIBLIOGRAPHY

Griffin, W. C., Introduction to Operations Engineering, Richard D. Irwin, Inc., 1971.

Snedecor, G. W., Statistical Methods, The Iowa State University Press, 1956.

Steel, R. G. D., and J. H. Torrie, Principles and Procedures of Statistics, McGraw-Hill, 1960.

ANALYSIS OF ALTERNATIVES FOR SAND AND TOLL GATE CREEKS, COLORADO USING THE FLOOD PLAIN MANAGEMENT SIMULATOR

By

John E. Velehradsky[1]
David Gjesdahl[2]

INTRODUCTION

Formulation of flood plain management plans in urban settings requires the analysis of numerous combinations of structural and non-structural measures. Selection of a plan for implementation from the myriad of alternatives that must be analyzed may be an almost impossible task. This is especially true if there is diversity of public attitudes regarding the "best use" of the flood plain. The Flood Plain Management Simulator can provide a useful analysis tool for simulating the economic effects of a particular flood plain management plan. By changing basic hydrologic and/or land use data and by changing assumptions about the planning horizon, alternative flood plain management strategies can be simulated for display.

Purpose

This paper is structured to present a brief description of the Flood Plain Management Simulator, a description of the planning setting, an analysis of selected alternative flood plain management strategies, and a discussion of the strengths and weaknesses of the analytical tool. The Flood Plain Management Simulator is currently being utilized in the Missouri River Division's three urban studies: Metropolitan Omaha, Nebraska-Council Bluffs Iowa; Metropolitan Kansas City, Missouri and Kansas; and Metropolitan Denver and South Platte River and Tributaries. In addition, data are being prepared for use in the analysis of alternatives for lower Big Sioux River flood plain at Sioux City, Iowa.

Sand and Toll Gate Creeks, Colorado pass through the eastern portion of metropolitan Denver, Colorado; an area currently undergoing rapid development. Alternative plans for managing the flood plains along these streams are currently being analyzed. This paper has a two-fold purpose: to provide information within the Corps of Engineers on the application of the Flood Plain Management Simulator to Corps' study activities; and to provide an analysis of the tool's applicability in the formulation of flood plain management plans for the metropolitan Denver area.

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[1] Chief, Regional Planning Branch, Omaha District
[2] Urban Planner, Planning Division, Missouri River Division

Much of the information utilized in this paper was developed with the assistance of William Drake and R. C. Hoff, Planning Division, MRD; Charles L. Hillerson and John Shobe, Planning Division, Omaha District; and Robert L. Musselman, formerly of the Planning Division, Omaha District. Without their assistance, this paper would not be possible. The authors gratefully acknowledge the contributions made by these persons.

FLOOD PLAIN MANAGEMENT SIMULATOR

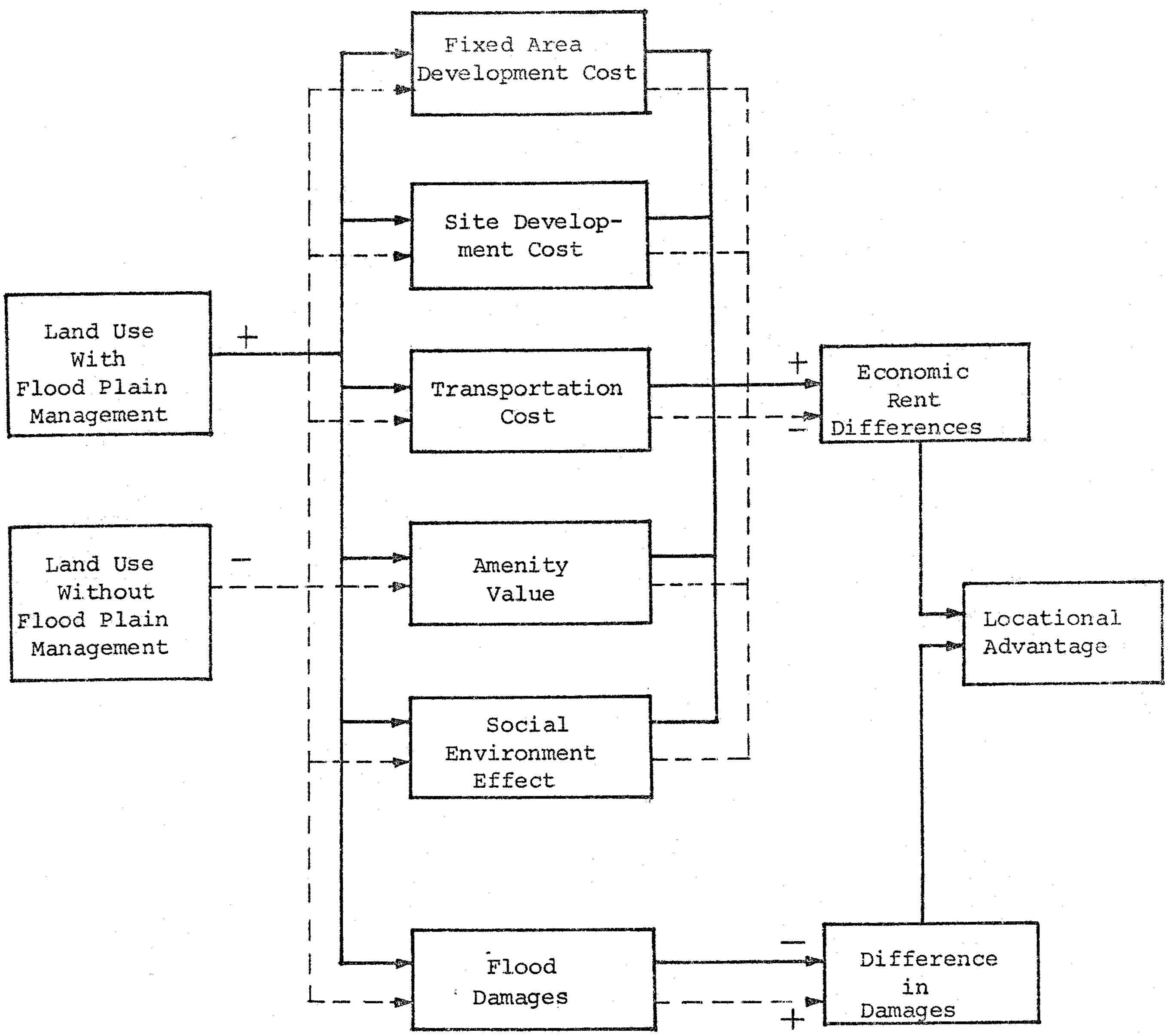
The basic SIMULATOR was developed for the Institute for Water Resources by INTASA of Menlo Park, California. Subsequent modifications and documentation were accomplished under contracts with the Office, Chief of Engineers, and with the Omaha District. Application of the model to Sand and Toll Gate Creeks, Colorado was essentially accomplished under a contract with the Omaha District, completed on 31 July 1973.

The Flood Plain Management Simulator is divided into input data and three main parts:

- Input Data. Basic data are required for calculating flood damages, land values, and economic rent. Economic rent includes fixed area development cost, site development cost, transportation cost, amenity values, and social environment affects. Additional data includes ultimate land use plans with and without flood plain management and land use requirements over time. A flow diagram showing the data requirements is shown on exhibit "A".

- Economic Rent, Flood Damage and Land Value Computations. Economic rent differences and flood damages are computed for aggregate activities and subarea combinations. For benefit evaluation, the same computation is performed for detailed activity/subarea combinations, where the land use over time is used to account for the social environmental effect of neighboring land uses.

- Land Use Allocation. The land use allocation model is the main portion of the Flood Plain Management Simulator. Before the benefits of a specific plan can be evaluated, the land use over time with and without the plan must be forecasted. The allocation of land use is performed at two levels. The first level is used to arrive at land utilization over time and locates aggregate activities in subareas. This allocation is, in general, based on the ultimate land use plans at some future point in time within or beyond the social planning horizon, and on present values of net economic rents using a private discount rate and market horizon. It accounts for interdependencies between activity types; need to reserve land for future uses with higher productivity; availability of land outside the study areas; social and political constraints on land uses; and irrational behavior of land users. The second level locates detailed activities to parcels and provides the detail required to obtain accuracies in benefit evaluation.



ESTIMATING LOCATIONAL ADVANTAGE USING
ECONOMIC RENT FORMULA

EXHIBIT A

. Benefits Evaluation. Using the detailed land use allocation, the economic benefits accruing to the flood plain management plan are determined at each evaluation period by reduction in flood damages and locational advantage. For activities that locate the same with and without flood plain management, benefits are measured by locational advantage, and three different methods can be used for its measurement. The first is based on economic rent differences and flood damages; the second on land values and flood damages; and the third in a combination of the two previous methods. Finally, present value of benefits is computed using the social discount rate and planning horizon.

COMPUTER SYSTEM REQUIREMENTS

The Flood Plain Management Simulator is written in CDC FORTRAN IV. Control Data Corporation Models 6400, 6500, 6600, and 7600 can be used to run the program. If program changes are to be made, a standard CDC RUN computer is required. The program can be operated either via over-the-counter submission or on a batch process terminal such as the CDC 200 USER TERMINAL. The maximum number of cards which can be read in one run is 1,000. Compilation of the program requires 100 K_8 of core memory and program execution required 150 K_8 of core storage.

THE PLANNING SETTING

The Study Area

Sand Creek is a right-bank plains tributary of the South Platte River. Sand Creek and its principal tributary, Toll Gate Creek, pass through the eastern portions of the metropolitan Denver area. The Sand Creek basin is a 189-square mile area, with a major portion of the basin lying upstream from the metropolitan Denver area. Sand Creek flows through the northern portions of Aurora and joins the South Platte River at Commerce City. Prior to World War II, nearly all of the Sand Creek basin was devoted to agricultural production. A few industrial buildings and oil refineries situated near the mouth of Sand Creek had encroached on the flood plain. By the mid-1950's, Aurora had expanded eastward to the vicinity of Toll Gate Creek. By 1969, the downstream 10 miles of Sand Creek and the downstream 4 miles of Toll Gate Creek had experienced the effects of urban development. In the past five years, additional areas along Sand Creek and Toll Gate Creeks experienced the effects of development. This trend is expected to continue due to Aurora's abundant water supply. Portions of the Sand Creek basin are experiencing the highest rate of growth in the metropolitan Denver area. The study area is shown on plate 1.

Land Use Data Used in the Analysis

The following assumptions and data were used in the analysis:

. Economic Growth Areas. Economic growth areas are geographic areas encompassing all alternative development sites considered in the analysis. A study area can have up to five economic growth areas. For the analysis on Sand and Toll Gate Creeks, the study area was assumed to represent the economic growth area.

. Dummy Locations. A dummy location is defined to account for locations that cannot be included in the study area, either because they cannot be identified, or because their inclusion complicates the study to an unwarranted extent. The analyses on Sand and Toll Gate Creeks did not require the identification of a dummy location.

. Available Land. Identification of the land available for urban development is one of the initial steps in the definition of the study area. U.S.G.S. Quadrangle maps are useful in identifying available vacant lands by topographic features, such as slope and by proximity to highways and existing development. Local land use plans can also be used to augment the information provided on the quadrangle maps. Areas outside the flood plain that will develop the same with and without the flood plain management are blocked out, since these areas will not be alternatives for flood plain development. Areas reserved for open space and those areas which have a high development cost are also blocked out. The remaining land forms are available for urban development. The available land areas are shown on plate 2.

. Flood Damage Zones. Flood damage zones are areas where the flood characteristics, such as depth, velocity, and debris can be assumed to be uniform. To achieve this uniformity, the flood plain along Sand and Toll Gate Creeks was divided into 13 reaches. The locations of the reaches used in this analysis are shown on plate 3. Each reach was divided into three damage zones, representing the area affected by floods having a 2 percent, a 1 percent, and 0.2 percent chance of annual occurrence. The model can accomodate up to ten damage zones.

. Site Development Zones. Site development zones are located on the basis of relative uniformity of site development and construction costs within each zone. Factors affecting the location of these zones include differences in site preparation, road construction, and transportation costs. Terrain, general slope, soil composition, and soil bearing characteristics are considered in the selection of site development zones. The site development zones used in this analysis are shown on plate 4.

. Transportation Zones. Transportation zones are located on the basis of the approximate uniformity of cost for commuting and transporting goods. Factors that determine the transportation cost of a site are its distance from business activities, employment centers, and proximity to main arteries. Table 1 shows the distances and travel times from the subareas to the employment centers used in the analysis.

Table 1

TRAVEL DISTANCES AND TIMES

Subarea	Distance in Miles	Time in Minutes
1	8	20
2	7	17
3	9	22
4	7	11
5	11	24
6	9	22
7	11	23
8	12	26
9	14	28
10	20	33
11	19	31
12	10	22
13	10	23
14	11	24
15	9	22
16	13	24
17	12	26
18	11	23
19	12	24
20	16	30

Based on the regional transportation plan for the metropolitan Denver area, it was assumed that the transportation network would change twice during the 50-year planning horizon: at 10 years and at 20 years. Table 2 shows the revisions in travel times and distances during the planning horizon.

Table 2

TRANSPORTATION REVISIONS

Subarea Affected	Change 10-years		Change 20-years	
	Distance	Time	Distance	Time
6	8	17	6	13
7	9	19	6	11
8	10	21	7	16
9	11	23	9	18
10	16	28	13	23
11	15	26	12	21
12	8	17	5	11
13	8	17	5	10
14	8	18	5	11
15	8	17	6	13
16	13	24	13	24
17	8	18	5	11
18	8	17	5	12
19	9	18	8	15
20	14	27	12	24

For commercial and industrial activities, a similar analysis is used, except the distance and travel time area computed from the subarea to the access point of the nearest transportation network. The number of tons transported per annum per acre is used to determine the transportation cost.

. Social Environmental Effect. Social environment effects are considered when defining subareas and the subareas are used to define social environment effect zones. The effects of social environment are an estimation of the influences of neighboring activities on the economic rent of a residential activity. For example, neighboring activities such as industries, low income housing, or other detrimental activities can have a negative effect. The proximity of recreation activities can have a positive effect.

. Parcels and Subareas. Parcels are the smallest land use units used in the model. Their selection is based on the uniformity of flood damages, site development costs, and amenity values over the area under consideration. The total number of parcels in the study area is limited to 100. Groups of parcels may be combined to form subareas. A subarea is that part of the study area that can be assumed to develop as a unit. A planned unit development would be an example of subarea. The relationship between the various levels of geographic definition is shown on plate 5.

The following constraints and considerations are used in combining parcels into subareas:

- The total number of parcels must be kept to 20 or less. The maximum number of parcels within a subarea is limited to 18.

- If the number of parcels is equal to or less than 20, the parcels can be considered as subareas.

- Subareas considered to develop early in the planning horizon should contain more parcels than those expected to develop later in the planning horizon.

- The direction of growth from a developed area to an undeveloped area should be considered.

- Subareas are used as social-environmental effect zones where it is assumed that no differences exist between subareas.

For the analysis on Sand and Toll Gate Creeks, the subareas and study reaches were chosen so that no study reach would be in two adjacent subareas. Subareas 1 through 13 correspond to reaches 1 through 13. Subareas 14 through 20, shown on plate 3, represent the alternative non-flood plain sites used in the analysis. For the analysis, the land use plan was assumed to be the same with and without the flood plain management plan.

- Activity Types. Aggregate activity types are high, middle, and low income housing communities; industrial groups; and agriculture groups. Housing community types are related to income or housing type. The aggregate activity types for industrial land use distinguish between two industrial groups; one group would be those land uses serving retail, wholesale, and distribution; and the second group would be those land uses serving special purposes. For agriculture, the aggregate activity types include those agricultural uses having the same yield per acre.

Community land use types can be subdivided into detailed activities such as residences, commercial enterprises, public buildings, open space, streets, highways, and utilities. The activity types for industrial types can be subdivided into more specific industry types. For agriculture, no detailed activity types are used.

Land Use Allocation

Allocation of land use activities over time with and without the plan is developed from land use requirements and from the ultimate land use plan for the area. The allocation is performed in two levels: level 1 is the land use over time; and level 2 is the detailed allocation of activities over time. Input data required for level 1 follows:

- Allocation periods during which increase in land use is assumed constant.

- Cumulative requirements for each aggregate activity at the end of each allocation period.

- Ultimate land use plans giving the ultimate land use in acres for each subarea by aggregate activity type.

- Sequence in which area with a fixed development cost will be used.

- Private discount rate and planning horizon.

The following input data is required for level 2:

- Sequence in which parcels will develop in each area.

- Preference order of each aggregate activity type.

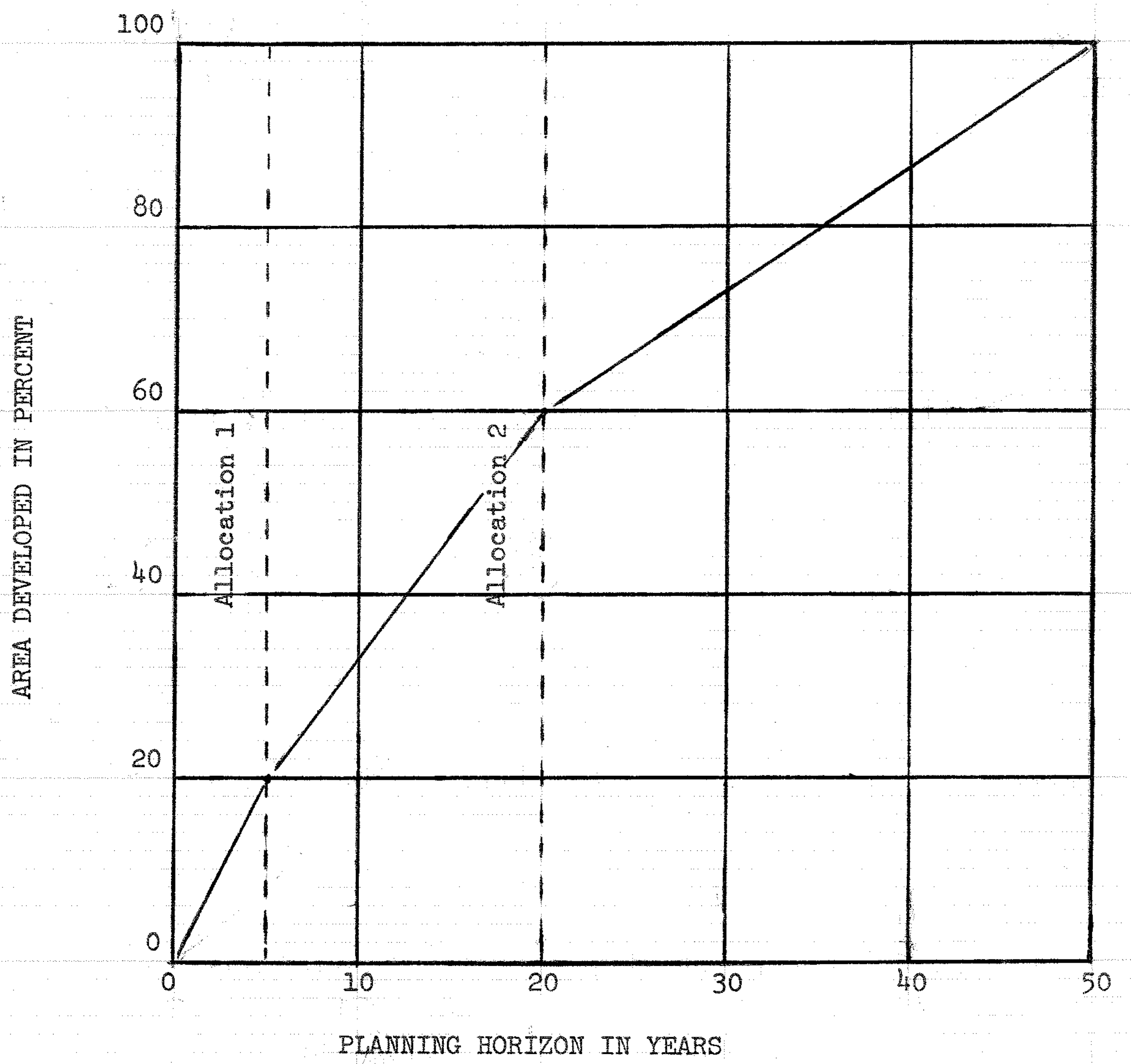
- Sequence in which aggregate activities locate in a subarea.

LAND USE REQUIREMENTS OVER TIME

Land use requirements over time for each activity type are given by the total requirement from the beginning to the end of the planning period, and by the percentage of this total required from beginning to end of the planning period. Figure 1 illustrates the allocation of land use requirements over time.

FIGURE 1

LAND USE ALLOCATION OVER TIME



Community Type	Allocation 1	Allocation 2	Total Acres
1. Residential A	20	60	391
2. Residential B	20	60	855
3. Residential C	19	60	7,268
4. Retail I	19	60	525
5. Retail II	20	62	1,000
6. Warehousing	21	60	1,725
7. Industrial I	20	60	2,059
8. Industrial II	--	--	0
9. Industrial III	19	60	271
10. Special I	20	60	133
11. Special II	20	60	1,121
12. Special III	--	--	0

Hydrologic Data Used in the Analysis

Descriptions of the hydrologic and hydraulic data required in the model and assumptions used in the Sand and Toll Gate Creek analysis follow:

- Depth-Frequency Curves. Average annual flood damages are computed using depth (stage)-damage and depth (stage)-frequency relationships for the damage zones. For the Sand and Toll Gate Creek analysis, stage-discharge and frequency-discharge relationships were converted to stage-frequency-relationships. The stage-discharge and the frequency-discharge relationships are computed exogenous to the model. Since the Flood Plain Management Simulator (FPMS) uses the same computer equipment as HEC-1 and HEC-2, an office using these models could also use the FPMS. For Sand and Toll Gate Creeks, these relationships were developed from data computed by Omaha District hydrology and hydraulic models.

The methodology used for converting stage-discharge and frequency-discharge relationships to stage-frequency relationships is shown on plate 6.

A reference location, representative of the hydraulic characteristics within a reach, was selected for each of the 13 reaches previously identified. The flood having a 1 percent change of annual occurrence was selected as the reference flood for each reach. A total of 10 sample floods were selected to represent the depth-frequency relationship for the reach. Table 3 shows the frequency of sample floods used for all reaches.

Table 3

FREQUENCY OF SAMPLE FLOODS

	Sample Flood									
	1	2	3	4	5	6	7	8	9	10
Frequency	.10	.08	.07	.06	.05	.04	.03	.02	.01	.20

For the analysis, three flood plain management alternatives were selected in addition to the existing situation. The illustrations on plate 7 demonstrate the delineation of the reference and sample floods and damage zones. The distances between the reference flood and the sample floods are shown in table 4.

Table 4

DISTANCE OF SAMPLE FLOOD TO
REFERENCE FLOOD W/O FPM PLAN

Reach	.10	.08	.07	.06	.05	.04	.03	.02	.01	.002
1	-4.80	-4.50	-4.30	-4.05	-3.70	-3.30	-2.70	-1.70	0.00	2.50
2	-8.60	-8.10	-7.80	-7.40	-6.90	-6.30	-5.20	-3.55	0.00	6.90
3	-6.80	-6.30	-6.00	-5.70	-5.30	-4.80	-4.00	-2.60	0.00	6.50
4	-10.70	-10.00	-9.50	-8.95	-8.20	-7.50	-6.10	-4.10	0.00	8.80
5	-7.40	-6.80	-6.50	-6.00	-5.50	-4.80	-3.80	-2.40	0.00	4.90
6	-8.00	-7.40	-7.00	-6.50	-5.90	-5.10	-4.00	-2.40	0.00	4.60
7	-7.90	-7.30	-7.00	-6.65	-6.00	-5.50	-4.55	-3.00	0.00	4.80
8	-5.50	-5.90	-5.60	-5.20	-4.70	-4.20	-3.40	-2.20	0.00	4.30
9	-4.40	-4.10	-3.90	-3.60	-3.30	-3.00	-2.30	-1.60	0.00	3.30
10	-4.90	-4.50	-4.20	-3.90	-3.60	-3.20	-2.50	-1.60	0.00	3.10
11	-9.70	-8.70	-8.10	-7.45	-6.50	-5.50	-4.10	-2.65	0.00	2.70
12	-9.90	-9.30	-8.90	-8.40	-7.70	-6.90	-5.50	-3.15	0.00	2.00
13	-12.40	-11.60	-11.10	-10.45	-9.60	-8.20	-6.30	-3.55	0.00	2.38

. Depth-Damage Relationships. Depth-damage characteristics are given by depth-damage curves and value of damageable components for each activity or structure type that locates in the flood plain. The damageable components are structure, contents, and fixtures. The damages for each damageable component are expressed as a fraction of its value. The same depth-frequency curve applies to all land uses of the same type regardless of value.

For some activities, separate depth-damage curves may be required for structures, contents, and fixtures. For other activities, depth-damage relationships are required for only the structure and contents or the structure. Zero damage in the depth-damage can refer to ground level or first floor elevation, whichever is appropriate for the analysis.

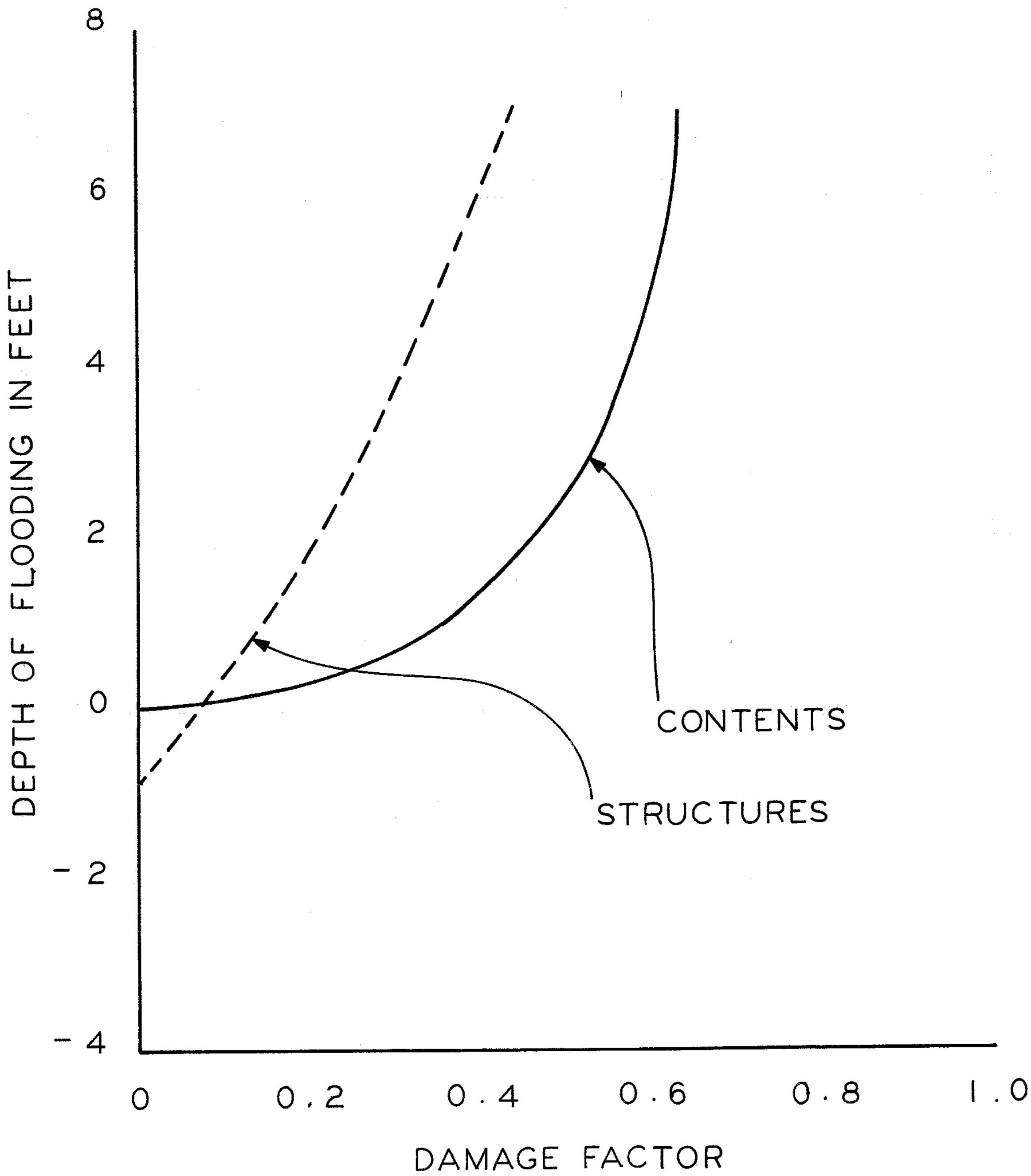
Up to three time periods can be used to determine the effects of an increase in value of damageable components over time. The age of the structure can also be used to determine the effects of depreciation over time. Three time periods are also used in the depreciation calculation.

Figure 2 shows the depth-damage relationships for structures and contents used in reach 4.

FIGURE 2

DEPTH - DAMAGE RELATIONSHIPS

REACH - 4



ANALYSIS OF ALTERNATIVES

For the purposes of illustration, four alternative flood damage reduction techniques were chosen: the first, a dam on Sand Creek and a dam on Toll Gate Creek; the second, channel enlargement on Sand and Toll Gate Creeks; the third, a levee along Sand and Toll Gate Creeks; and the fourth, a combination of dams and channel enlargement. Other techniques such as flood proofing, zoning, and evacuation in selected reaches and combinations of these measures will be evaluated.

Dams on Sand Creek and Toll Gate Creek

Previous studies of potential flood control measures on Sand and Toll Gate Creeks identified potential dam sites on Sand Creek and Toll Gate Creek. The potential dam site on Sand Creek is located about two miles southeast of Buckley Field shown on plate 1. The potential dam site on Toll Gate Creek is located at the confluence of East and West Toll Gate Creeks. The latter site is currently being encroached upon by residential development. Both dam sites would be capable of impounding the standard project flood. Discharge-probability relationships for the without project condition were based on the assumption that no releases would be made from the dams during a flood event.

It was assumed that land use in the flood plain was essentially the same with and without the potential dams. However, the Flood Plain Management Simulator is capable of analyzing a changed land use over time with the project in operation. For the analysis, thirteen cards, representing the depths between the reference flood and the sample flood for the controlled conditions, were inserted in the data deck. The model has the flexibility of changing the distance between the reference flood and the sample flood over five time periods during the planning horizon to represent the hydrologic effects of urban development.

Channel Enlargement on Sand and Toll Gate Creeks

For this analysis, it was assumed that the Sand and Toll Gate Creek channels would be enlarged to contain a flood having a 1 percent chance of annual occurrence. Again, the major change in the data set was the insertion of cards with data representing the changes in depth between the reference flood and the sample flood. Alternative channel sizes can be evaluated by simply changing the depth relationships. Development of these relationships requires the exogenous computation of depth-probability relationships for each condition to be simulated.

Levees along Sand Toll Gate Creeks

It was assumed that levees, capable of providing protection against a flood having a 1 percent chance of annual occurrence, would be constructed along Sand and Toll Gate Creeks. Analysis of this alternative requires a minor modification in the input data.

Combination of Dams and Channel Enlargement

This analysis assumed the combination of the two dams described under the first alternative with the channel enlargement in the second case. This combination would provide control of the standard project flood. As in the previous simulations, the major change in the data set was the difference in depth between the reference flood and the sample for each of the 13 reaches.

Analysis of Simulation Results

Selected results of the four simulation runs analyzed are shown in table 5. Column 1 shows the annual reduction in flood damages to existing development in the flood plain. The reduction in damages to future activities that would locate in the flood plain with or without protection are shown in column 2. Certain activities would locate in the flood plain if protection were provided; column 3 shows the reduction in damages to these activities. Column 4 shows the economic advantage of locating development in the flood plain in lieu of locating in an alternative non-flood plain area.

Table 5
COMPARISON OF ALTERNATIVE
FLOOD DAMAGE REDUCTION MEASURES

	Benefits in $1,000				
Alternative	Existing Activities	Future Act Before Proj	Future Act After Proj	Loc Adv	Total Benefits
Dams on Sand & Toll Gate Crks	$1,196.9	$1,193.5	$662.5	$ 750.8	$3,803.2
Channel Enlargement	1,127.2	1,124.0	284.7	1,131.7	3,667.6
Levees	378.4	220.6	359.8	11.7	970.5
Dams and Channel Enlargement	1,315.3	1,278.9	321.4	1,300.3	4,215.9

An obvious conclusion from the comparison is that levees are the least effective method and a combination of measures consisting of dams and channel enlargement is the most effective method of reducing flood damages in the study area. Based on a comparison of costs, which are not shown, channel enlargement would be the most efficient method of damage reduction considering existing levels of development in the flood plain.

The combination of dams and channel enlargement would provide essentially complete flood protection. The other alternatives provide a high degree of protection; however, by completely eliminating flood damages, a savings in site development and transportation costs amounting to over $1,300,000 annually could be realized. Dams alone would produce a savings of about half the amount realized by adding channels to the dams.

Theoretically, the plan providing essentially complete flood control should be the most efficient land use allocation. This thesis is predicated on the supposition that in the absence of flood damages, land uses would allocate solely on the basis of the economic rent calculation. Table 6 shows a comparison of land use allocations for aggregate activity - Retail I. Without flood protection, initial development in subarea 1 would occur in 46.3 years. With complete protection, initial development of this activity would occur in 31.3 years. Subarea 7 is a dramatic example of a location that is extremely attractive for development. However, the flood threat is such that the land users will not find it feasible to take advantage of this desirable site until the flood damages are reduced.

Table 6

LAND USE ALLOCATION
AGGREGATE ACTIVITY
RETAIL I

Subarea	Year of Initial Development: Without Flood Protection	With Project: Dams	Channel	Levee	Combination
1	46.3	49.1	31.9	33.1	31.3
2	NA	NA	NA	NA	NA
3	37.6	40.6	37.0	38.4	33.6
4	NA	NA	NA	NA	NA
5	47.1	46.3	29.0	47.1	12.4
6	31.0	28.4	27.1	30.1	32.1
7	30.1	5.1	33.1	31.6	5.1
8	43.3	29.9	34.0	44.1	39.3
9	32.4	33.3	42.7	34.0	42.7
10	26.4	37.7	47.1	27.3	47.1
11	29.7	32.9	32.7	26.9	42.3
12	29.3	12.4	28.6	26.4	13.8
13	36.9	12.6	12.0	32.4	14.0
14	0.0	0.0	0.0	0.0	0.0
15	2.5	2.5	2.5	2.5	2.5
16	12.0	13.0	12.4	12.0	14.4
17	5.1	5.5	5.1	5.1	5.5
18	16.2	17.2	16.5	16.2	18.5
19	NA	NA	NA	NA	NA
20	19.7	21.3	20.0	19.7	24.1

EVALUATION

The Flood Plain Management Simulator calculates the benefits of a plan in two categories: (1) Damage reduction, and (2) Locational advantage. Damage reduction is the appropriate benefit measure for existing activities and for projected land uses where the influence of the flood control plan does not affect the locational decision. Locational advantage is the appropriate benefit measure where the effect of the plan results in a change of location. While the ultimate location for each activity is fixed by the final land use plan which is direct input, the model derives the most efficient land use plans over time based on economic rent calculations. The Omaha District has found that the simulator can be applied beneficially in two ways:

(1) As a damage reduction model only.

(2) As a comprehensive flood plain land use analysis model. The strengths and weaknesses of each approach will be discussed below.

As the name "Simulator" implies, the model was built to analyze land use over time. This compromises the detail with which existing land use information can be used as input. Specifically:

(1) The user must specify the same basic land use types for both existing and future activities.

(2) A residential community must have the same structure type mix and density both over time and throughout the study area.

(3) A limit of 45 land use/value categories must suffice for both existing and future.

Work is now underway in the Omaha District to remedy some of these problems by expanding the detail at which existing land use can be input. It will then be possible to calculate damages in considerable detail for existing uses while at the same time estimating damages at the aggregate level for future activities.

Limitations have also been imposed on the detail with which hydrologic information can be input. Only 15 reaches can be specified and all flood profiles are assumed to be parallel throughout the length of each reach. If this limitation is unacceptable and would cause significant error, the stream profile may be segmented into the number of reaches desired and then introduced into the Simulator in groups of 15 reaches.

Despite these problems, the Omaha District has found the INTASA model to be useful when applied as a damage reduction and potential benefit model. There are two significant reasons for this:

(1) The model requires that all pertinent hydrologic and economic data be precisely specified. Often, much of this important information is never clearly defined.

(2) Alternative management plans and sensitivity analysis can be accomplished with a minimum of additional effort. The effect of uncertainty in flood frequency, valuation, depth damage, flooded area-frequency, discount rate, density, and land use information can be readily evaluated.

It is also prudent to weigh these advantages of the flood damage model against the theoretical deficiencies of the Simulator. It is quite probable that in almost all cases, the uncertainty in such data as area-flooded vs. frequency, and depth of inundation vs. damage is a source of greater probable error than the defects in the methodology used by the Simulator.

When the Simulator is used as a comprehensive flood plain land use analysis model, the applicability of economic rent and its components, in addition to flood damages, must be evaluated. Due to the complex data required and the scope of investigations to date, the Omaha District uses the INTASA model as a flood benefit evaluation tool. If we assume that efficient use of land is a reasonable criteria for evaluating the potential for occupation and development of the flood and for evaluating the benefits of a land use plan, then we should consider the method used to accomplish this goal as defined by the INTASA Simulator:

A. The flood plain under study is typically a very small part of the area in an urban economic system. It is from this larger area that an activity can choose its location. Therefore, when using this Simulator, we are faced with a problem in geographic scale. We must detect the subtle economic rent differences in alternative flood plain locations with economic rent component routine attuned to a large complex economic system such as a metropolitan area.

B. There is another problem of scale with this model as well as many other complex computer models. The Simulator as a whole was kept to a manageable size in terms of computer storage, input required, and running cost. These specifications meant that some of the subroutines were generalized to a point where their output has limited credibility. For example, the social and environmental models are virtually direct input/output procedures. The transportation model cannot accommodate multiple destinations and the zones of constant cost tent to become overly large.

C. Applying the concept of differential economic rent (the differential earnings to activity/site combinations as a result of occupying or developing alternative parcels of land) as modeled by INTASA to simulate land use decisions requires that the user and planner exercise care when interpreting the output. It is inherent in this model that:

(1) Decisionmakers have perfect knowledge of potential costs. We assume, for instance, that the flood damage threat and its costs are known by the economic system.

(2) All decisions are made in economic terms and all alternatives can be displayed by economic cost. Social and environmental effects, for instance, must be reduced to dollar costs and benefits.

(3) The risks are equal and uniform. It is questionable, for instance, that for purposes of simulating economic decisions, whether the risk of incurring a site development or transportation cost is equal to that of incurring flood damage cost. Furthermore various political units may incur varying amounts of the risk through a wide array of taxing and compensation arrangements at the local, regional, and national scale.

(4) Each person in the decision matrix has the same time horizon.

(5) We impose existing values and technological interdependencies on future land use decisions. There is no provision for the introduction of new urban forms. We assume the same social and environmental values will be relevant decision criteria throughout the study period. No change in transportation technology and its effect can be quantified in this model nor in any other model of this type. In other words, the quantification of situational interdependencies is virtually impossible.

Despite these theoretical and practical difficulties with the Flood Plain Management Simulator, it does have value when used as a tool in the development of a flood plain management plan. Most importantly, it at least creates an environment where the right questions can be addressed. With this model, the use of the flood plain is considered in conjunction with the use of land <u>throughout</u> the study area. Also, since the ultimate land use plan is given as input, we are not required to develop <u>a</u> land use plan, rather we can evaluate alternative plans developed by local or regional agencies. This model is therefore not an optimization model; rather the allocation of activities to land is restricted by the zoning maps (ultimate land use plans). It is the responsibility of the planner to prepare an ultimate land use plan that reflects the values of the people and accounts for the social, environmental, economic, and political considerations that are not modeled. The Simulator will then derive the most economically efficient use of land over time within these limitations. The output then is a consistent rationale for future growth and flood plain development with the benefits measured by the increased earnings through locational advantage and damage reduction that result from the flood plain management plan.

A common concern is that the benefit category of locational advantage opens the door to indiscreminate boosting of benefits. This is not the case. Rather, the Simulator's economic comparison of alternative locations provides a more rational basis for benefit accumulation than an arbitrary assumption of flood plain development regardless of the cost in flood damages. Since some of the economic rent components cannot be accurately quantified with a high degree of certainty, the Simulator calculates an "upper bound" for locational advantage benefits to prevent the planner from deriving unrealistically high benefits. The upper bound calculation is based on the assumption that the economic rent benefit cannot exceed the flood damage reduction if the activity had located the same both without and with the project. This is based on the fact that an activity would have located in the flood plain even without the project if the economic rent advantage of the flood plain location is greater than the flood damage.

This model is more amenable to user interaction than many comprehensive land use models. In no sense is it a "black box"; changed in data produce logical and predictable variation in the economic rents and activity allocation.

Data collection for the flood benefit and economic rent analysis can be a major task. Assuming the stage-discharge and discharge probability data are available, a minimum of about 2 man-months are required to gather the remaining land use and flood damage data required to complete the basic data packate. Debugging and analysis of the basic data requires several computer runs. When the basic data requirements are satisfied, sensitivity simulations will range from about \$10 to \$70 depending on the computer facilities used.

Finally, INTASA has remedied some of the technical deficiencies of the Simulator with the development of a new model called the Land Program. The Land model consists of the Simulator plus more detailed transportation analysis, a routine capable of allocating population and employment projection alternatives, and map display capability. A resource demand subroutine has also been added to calculate the water supply, wastewater output, etc. required for each land use plan derived.

REFERENCES

Computer Model

INTASA; Menlo Park, California; "Planner's Mannual", February 1973; Contract DACW07-72-C-0012.

INTASA; Menlo Park, California; "Input Data Collection Guide", February 1973; Contract DACW07-72-C-0012.

INTASA; Menlo Park, California, "User's Manual", February 1973; Contract DACW07-72-C-0012.

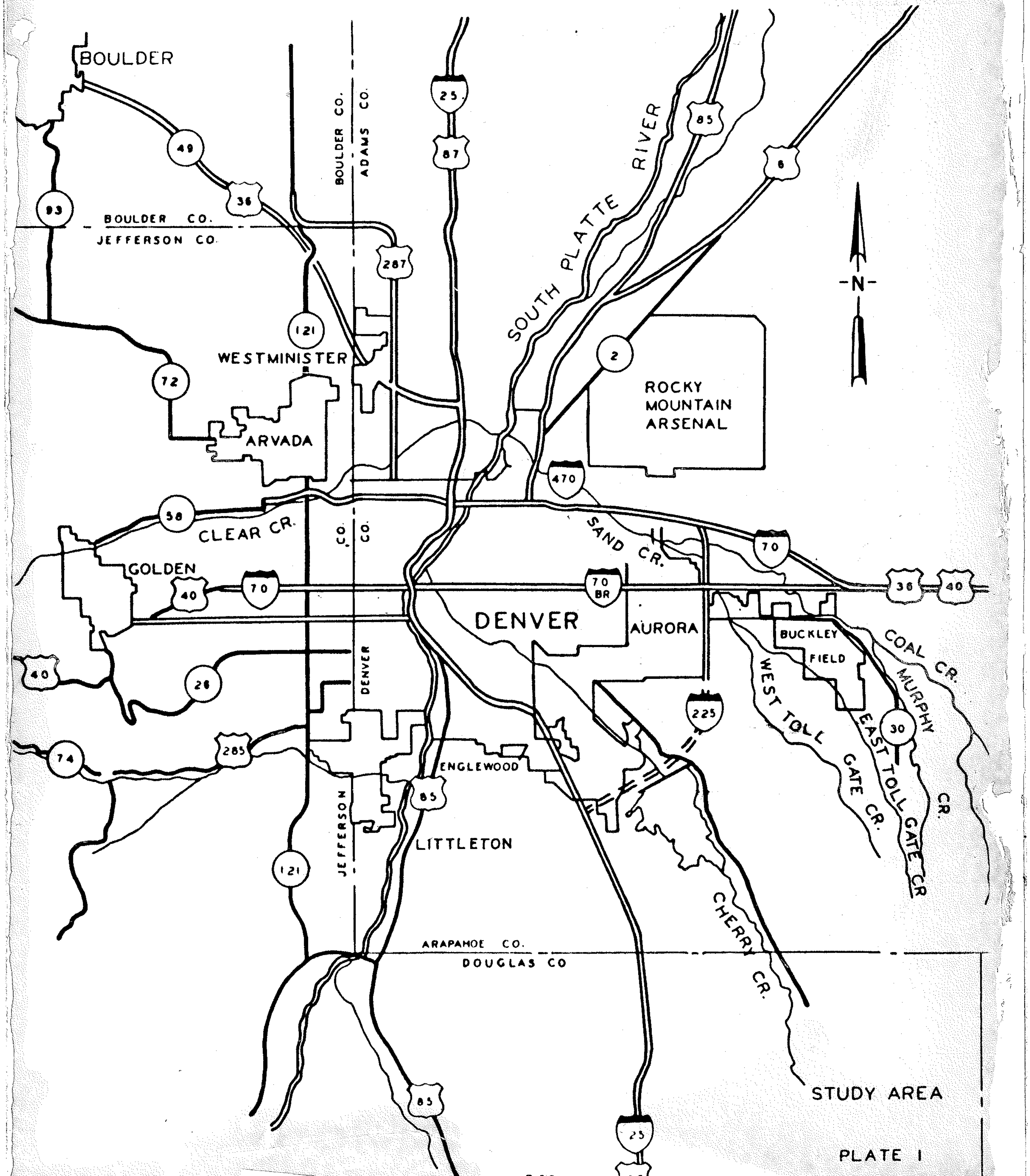
Flood Plain Data

CE, Omaha District, "South Platte River and Tributaries, Colorado, Wyoming, and Nebraska; Interim Report on Sand and Toll Gate Creeks, Colorado", August 1969 (Revised January 1972).

Land Use

Regional Transportation District, Denver, Colorado; "Regional Transportation Plan"; 1972.

Denver Regional Council of Governments; "Land Use Plan"; date unknown.


BOULDER
WESTMINISTER
ARVADA
GOLDEN
DENVER
AURORA
ENGLEWOOD
LITTLETON
ROCKY MOUNTAIN ARSENAL
BUCKLEY FIELD
SOUTH PLATTE RIVER
CLEAR CR.
SAND CR.
COAL CR.
MURPHY CR.
WEST TOLL GATE CR.
EAST TOLL GATE CR
CHERRY CR.
BOULDER CO.
JEFFERSON CO.
ADAMS CO.
DENVER
ARAPAHOE CO.
DOUGLAS CO
N
STUDY AREA
PLATE I

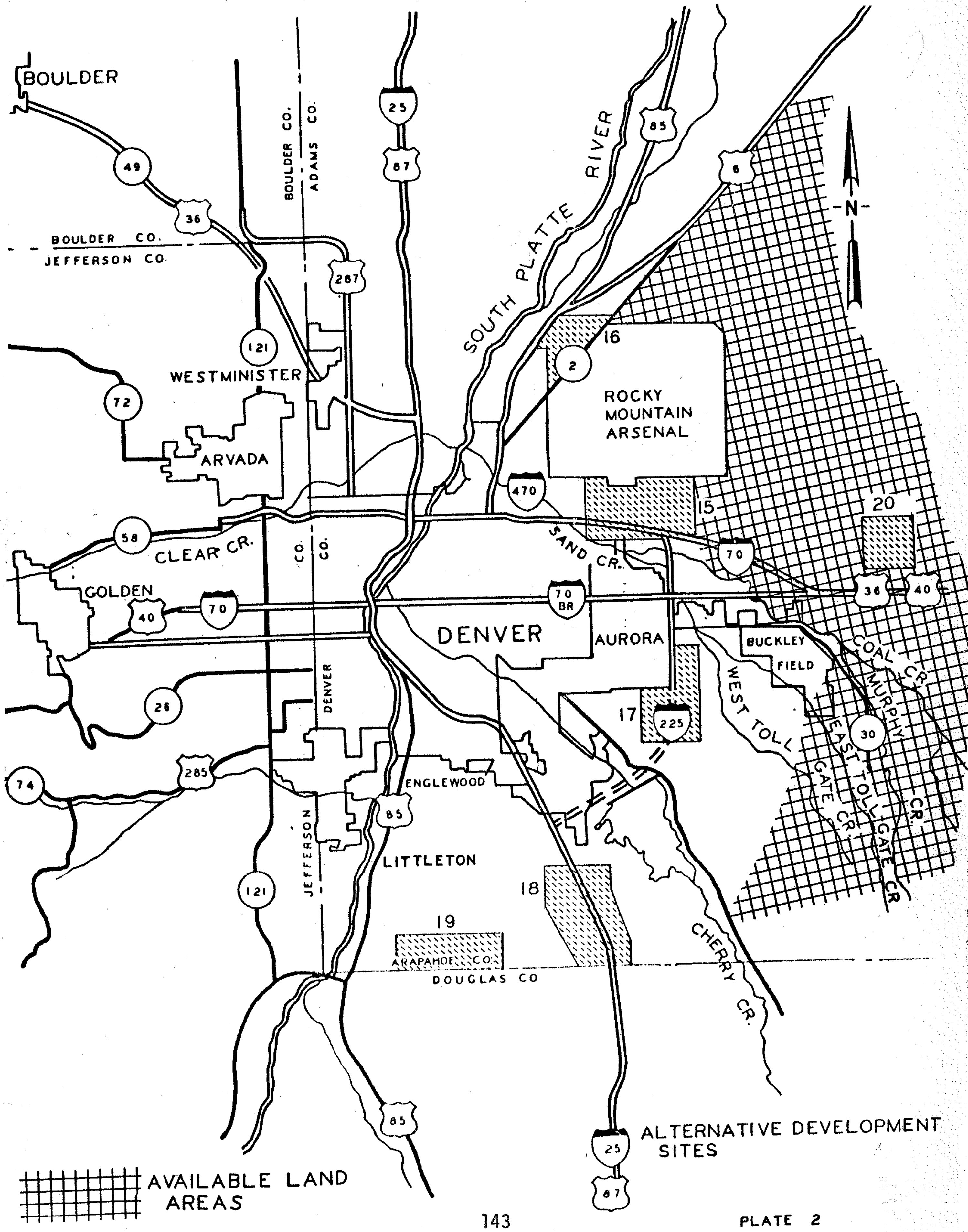

BOULDER
49
36
BOULDER CO.
JEFFERSON CO.
BOULDER CO.
ADAMS CO.
25
87
287
121
WESTMINISTER
72
ARVADA
SOUTH PLATTE RIVER
85
6
N
16
2
ROCKY MOUNTAIN ARSENAL
470
15
20
58
CLEAR CR.
SAND CR.
70
36
40
GOLDEN
40
70
70 BR
DENVER
AURORA
BUCKLEY FIELD
COAL CR.
MURPHY CR.
WEST TOLL GATE CR.
EAST TOLL GATE CR.
26
17
225
30
74
285
ENGLEWOOD
85
JEFFERSON
DENVER
LITTLETON
121
18
19
ARAPAHOE CO.
DOUGLAS CO
CHERRY CR.
85
25
87
ALTERNATIVE DEVELOPMENT SITES
AVAILABLE LAND AREAS

PLATE 2

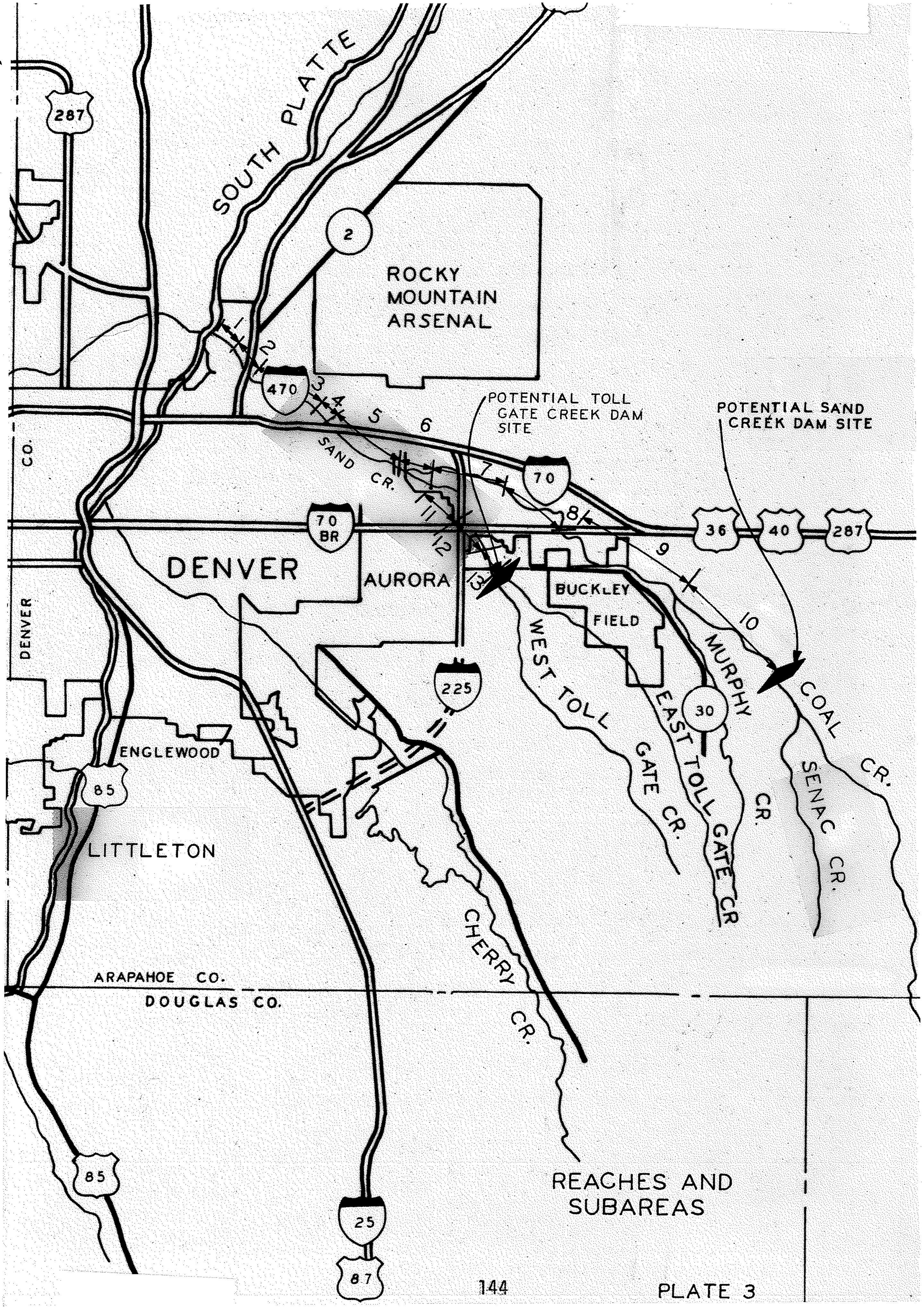

SOUTH PLATTE
ROCKY MOUNTAIN ARSENAL
POTENTIAL TOLL GATE CREEK DAM SITE
POTENTIAL SAND CREEK DAM SITE
SAND CR.
DENVER
AURORA
BUCKLEY FIELD
WEST TOLL GATE CR.
EAST TOLL GATE CR
MURPHY CR.
COAL CR.
SENAC CR.
CHERRY CR.
ENGLEWOOD
LITTLETON
DENVER CO.
ARAPAHOE CO.
DOUGLAS CO.
287
2
470
70
70 BR
36
40
225
30
85
25
87
1
2
3
4
5
6
7
8
9
10
11
12
13
REACHES AND SUBAREAS

PLATE 3

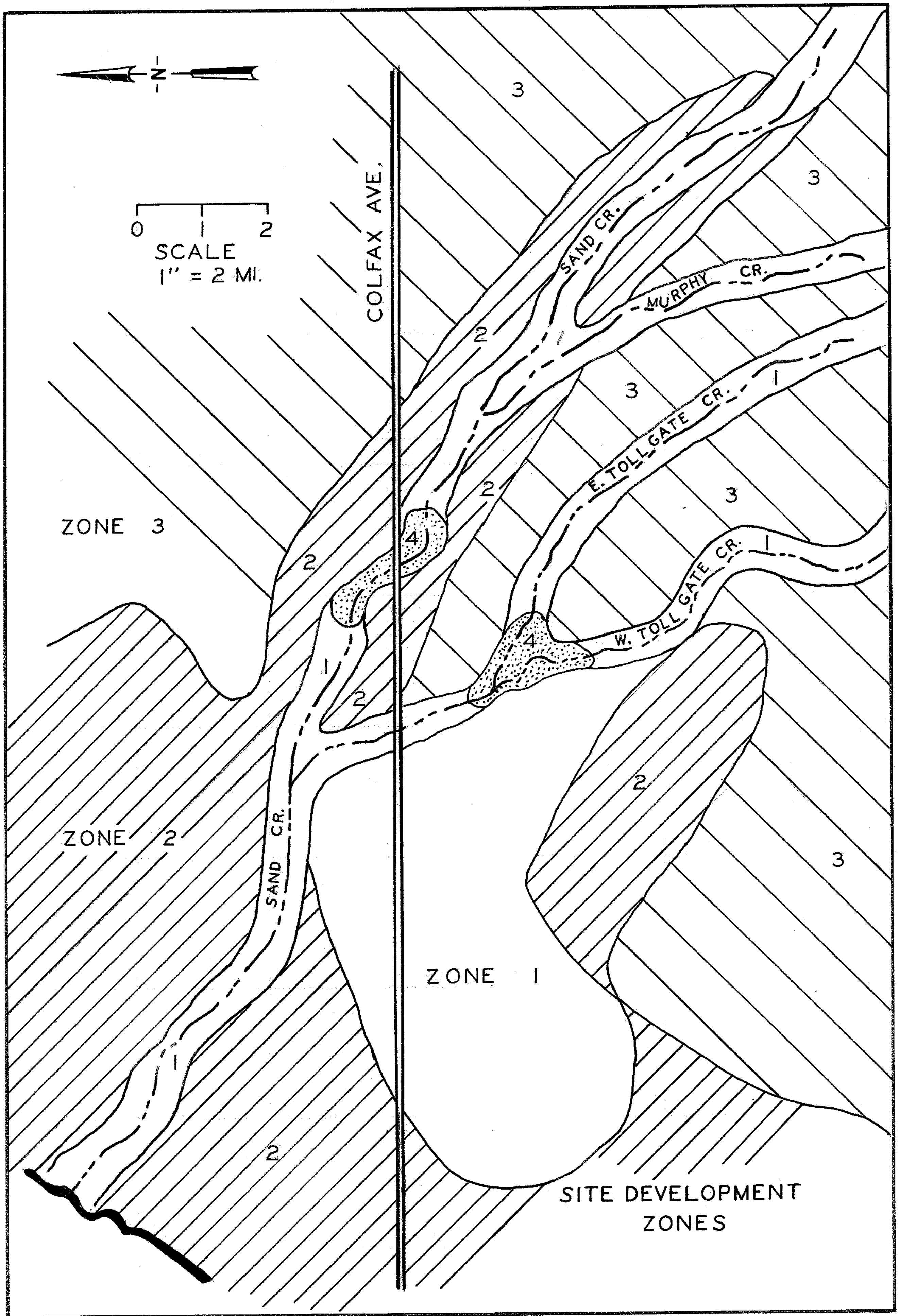
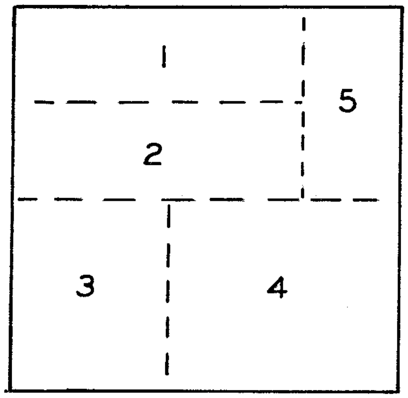
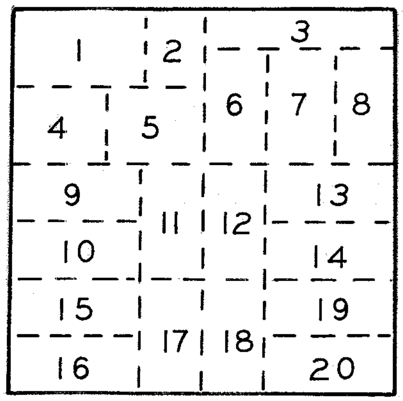

N
0 1 2
SCALE
1" = 2 MI.
COLFAX AVE.
ZONE 3
ZONE 2
ZONE 1
SAND CR.
MURPHY CR.
E. TOLLGATE CR.
W. TOLL GATE CR.
SAND CR.
1
2
3
4
SITE DEVELOPMENT
ZONES

PLATE 4



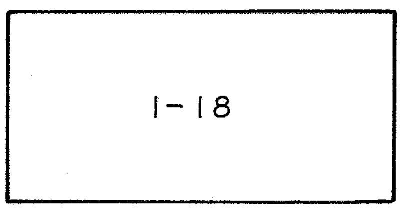
STUDY AREA

STUDY AREA = 1-5 ECONOMIC GROWTH AREAS



ECONOMIC GROWTH AREA

ECONOMIC GROWTH AREA = 1-20 SUBAREAS

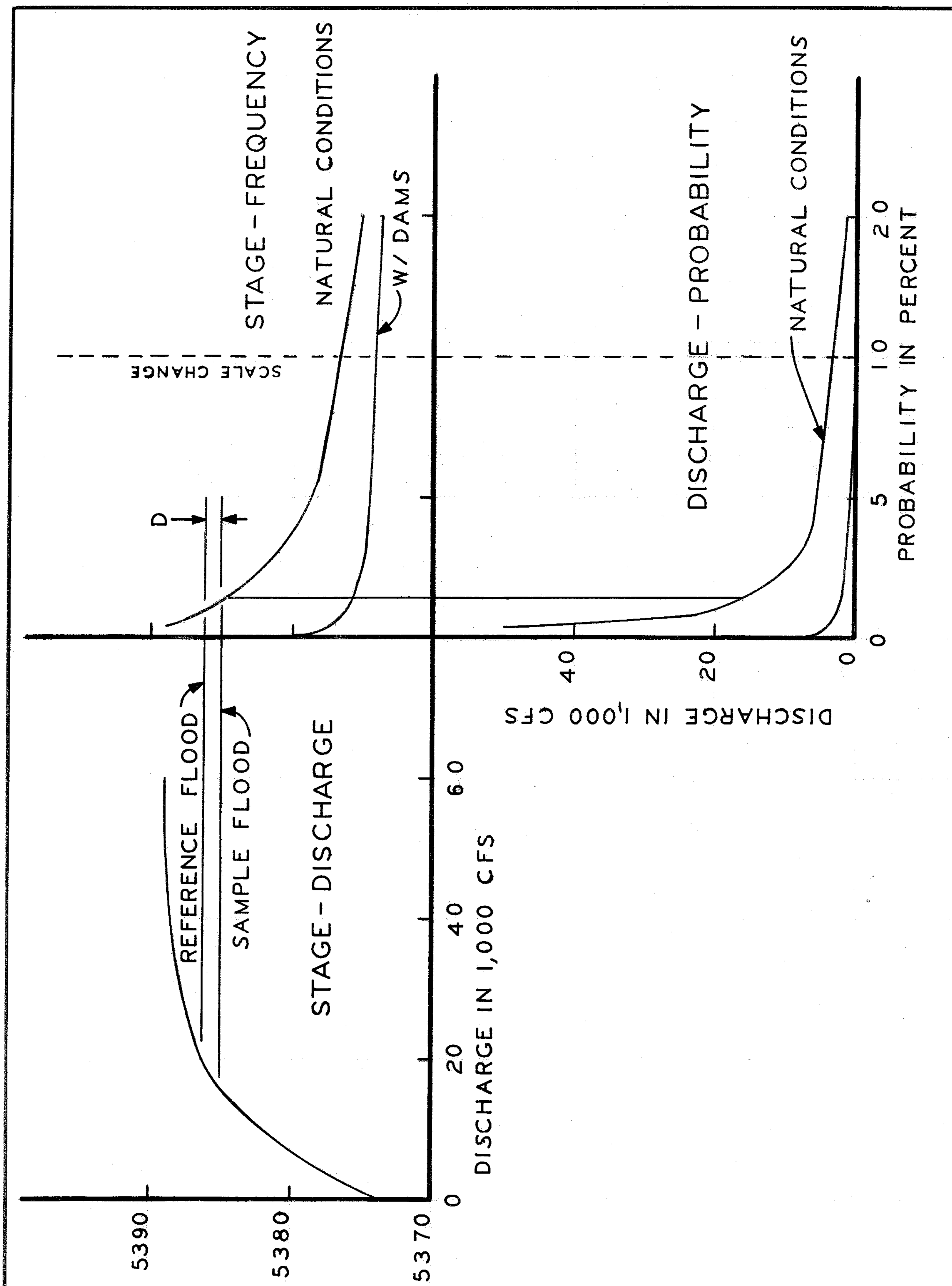


SUBAREA

SUBAREA = 1-18 PARCELS

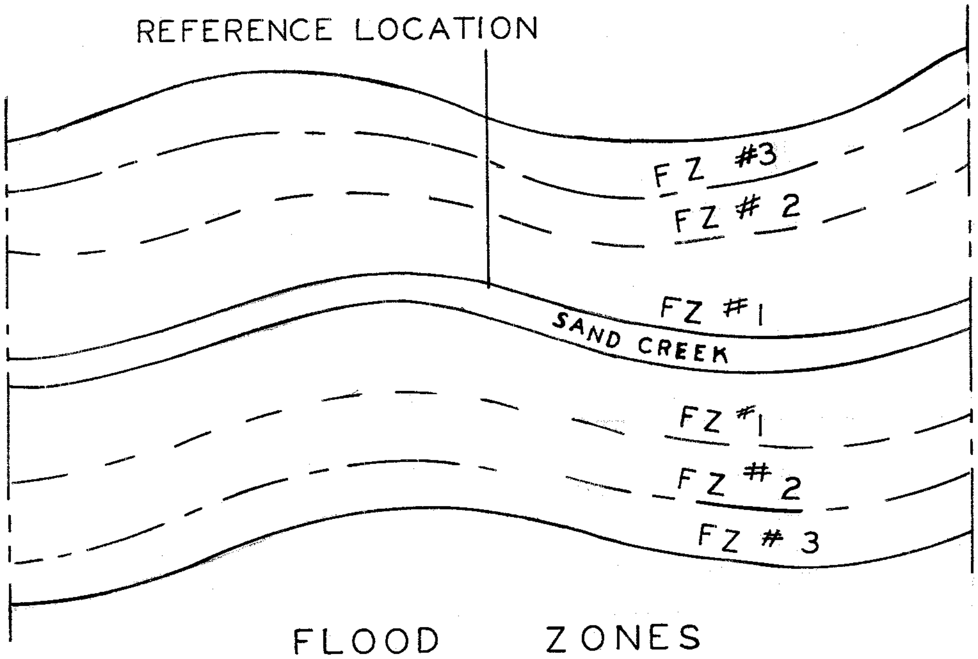
GEOGRAPHIC DEFINITION OF STUDY AREA COMDONENTS

PLATE 5

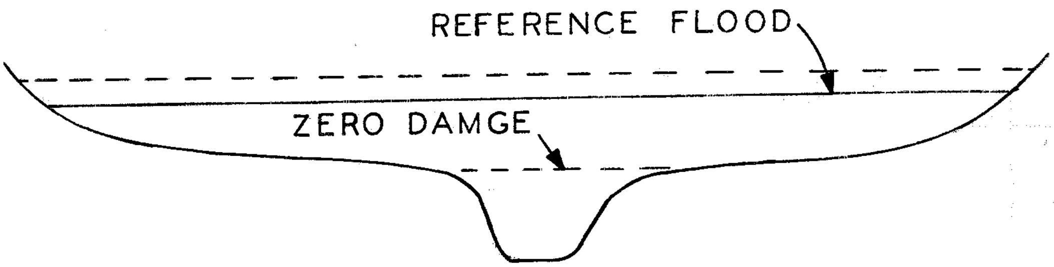


DEVELOPMENT OF
STAGE - FREQUENCY
RELATIONSHIPS

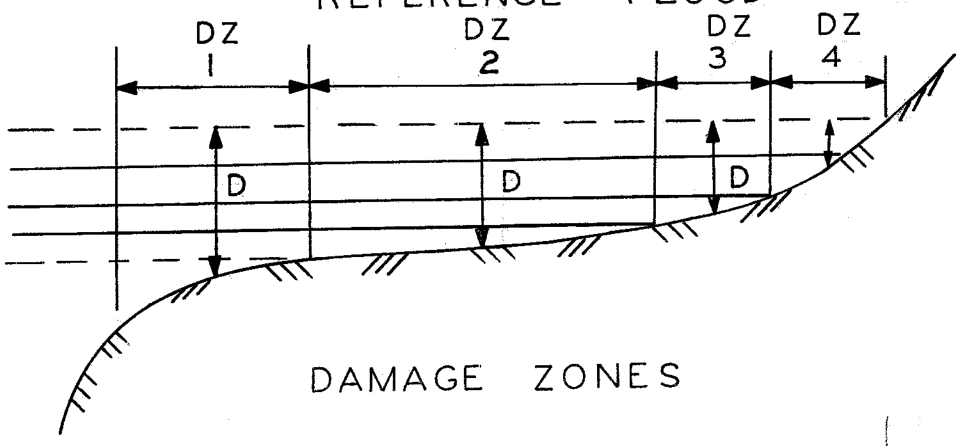
PLATE 6



FLOOD ZONES



REFERENCE FLOOD



DAMAGE ZONES

FLOOD & DAMAGE ZONES

DESIGN FUNCTION AND APPLICATION OF THE ST. LOUIS SMSA LAND USE MODEL

by

Richard Rodakowski[1]

I. Introduction

a. This study is an effort on the part of the St. Louis District, U. S. Army Corps of Engineers to develop a methodology that will assist in analyzing project impacts and evaluate alternatives for optimal plan formulation. The model is essentially a land use simulator which attempts to incorporate and imitate real world land use development. It is an urban land-use tool developed by the University of Missouri, St. Louis, and was designed to allocate land-use activities based upon an initial (1970) data base and internal ranking criteria.

b. Basic input consists of three essential and interacting elements. An initial 1970 data base is required. Data must be collected for each and every grid in a county by the size grid the planner desires. The data forms the variables and platform for simulator land-use forecasting. The second component of input varies with the user's general understanding of the area under investigation. Population forecasts for each decade and all land use types must be provided for the counties involved in the study. Further, the user must be cognizant of the density constraints by decade and land-use type. An elementary understanding of economic principles and spatial relationships would be helpful in forming the exogenous population and density parameters.

c. Two basic types of output are provided. One is a printout of land-use allocation results consisting of real numbers such as population, employment, acres, and density. The other is a grid-map printout which provides a visual illustration of the modeling process. All output is provided on a decade basis from 1970 to 2030. Five land-use activities are evaluated each decade: (1) heavy industrial, (2) light industrial, (3) residential, (4) commercial, and (5) public.

d. The output is grid oriented. Each of the eight counties in the St. Louis SMSA is segregated into 5000-foot units called grids. The large counties may be composed of as many as 1000 such units, whereas the smaller counties are composed of 400 to 500. The 5000-foot unit is not mandatory. For example, a 10,000-foot or even a 20,000-foot grid pattern may be used depending on data availability and needs. Each county must have the same size grids, but grid sizes can vary between counties. Each cell is identified by a row and column number, designated by R and C respectively, corresponding to the Y and X axis of the Cartesian Coordinate System. The St. Louis model has 32 variables for each land unit, eight of which may be used simultaneously during the ranking process. Grid maps A and B provide a visual example of the mapping process. In the actual simulator, there are ten shade variations each representing a different level of land-use development. Two size maps, one small and the other large, are producible.

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[1]Economics Branch, St. Louis District, Corps of Engineers

II. The Model

a. Figure 1 illustrates in schematic form the sequential flow of computer operations in the distribution process. At the top of the schematic is a list of counties to which the computer distributes exogenously forecasted employment or population to land-use types. It is important to recognize that each of the eight counties is functionally independent in terms of computer algorithms. The land-use types to which the distribution process takes place are also indicated in the schematic, and are in order of desirability. All industrial land use is first completed followed by residential land use, commercial land use, and public land use. This process is repeated from 1970 to 2030 at decade intervals. The arrows indicate the general direction of computer logic. Steps one through five are repeated for each county and each decade. A detailed discussion of the internal operations will facilitate understanding of what actually takes place within each modularized land-use type. It should be noted that the entire area could be run all at once or on a county by county basis.

b. Figure 2 exhibits a detailed internal view of the distribution mechanism within a particular module, namely heavy industrial land use. This example is typical of what occurs in the other four land-use types during the allocating process. Frame 1 shows a hypothetical example consisting of County X. The heavy industrial employment forecast for County X is 1,000 industrial employees for 1990 and was exogenously determined. This 1,000 industrial employment figure must be distributed among the grids which make up the county. The typical land unit to which employment or population is distributed is the grid (sometimes referred to as a cell). The decision as to how much employment is distributed to each land unit is directly related to the ranking matrix (Frame II) which is essentially the heart of the model. The matrix consists of a minimum of one and a maximum of eight rules or independent variables per land use type, which are the relative weights by which one cell is distinguished from another in terms of the number of employees it receives. These rules, which will be discussed in more detail later, algebraically interact to rank each cell in a county. The resulting rank is in the form of a percentage of total exogenously forecasted employment that is distributed to each grid. Notice that the sum of all industrial employment allocated in a particular county must total 100 percent of the forecasted employment. In essence, those land units which are ranked more desirable receive the greatest percentage allocation, whereas those ranking lower because of a less desirable variable constituent receive the least allocation. Frame III shows grid 1 ranks first in County X in terms of relative desirability. Grids 2 and 3 on the other hand, rank second and third, respectively. Although a land unit ranks first for industrial use, it may rank two-hundredth for residential use, fiftieth for public use, and twentieth for commercial use. Hence, ranks are invarient to each other, and the computer responds accordingly. This order priority ceases when all grids in a county receive their weighted share of employment and when all projected employment is accounted for. Frame IV is a distribution process which each and every grid must pass. Within this frame, each grid's allocation is distributed to a land-use type. Continuing with the hypothetical structure, if grid 1 is to receive 5 percent of total industrial employment (50 workers) then those workers must be distributed on industrial acres in some ordered fashion. The key to this distribution is another set of exogenously determined parameters, namely, density or employees per acre of land-use type. If land unit 1 must absorb 50 workers and the 1990 County X density is 10 workers per acre, then clearly it will require 5 acres of industrial land to satisfy the land-use requirements. The computer will allocate those workers on 5 acres of land. The density threshhold of 10 workers per acre acts as a constraint which may change each decade depending upon population forecasts. In the case where there are more employees to allocate than current industrial acres available, the computer proceeds to acquire whatever vacant acres it needs in that unit and distributes the residential or unallocated employees to vacant land. Similarly, if suitable vacant acres prove insufficient to satisfy the process, computer logic then proceeds to agricultural land within a grid and initializes the same process. If undistributed population still exists after this phase, another phase begins which accumulates all undistributed population and deposits it to the most desirable grids that are not already saturated. It is doubtful any residual exists after this stage, but if one does persist, an error message will be printed informing the user that such a state of affairs has arisen. More will be said about this point later in the discussion of model phases.

c. Frame V represents a repetition of the entire process for the light industrial land use module (Figure 1). No change of county or decade takes place until all land use modules of all counties are appropriately processed for a particular decade. At this point, the decade is incremented and the allocation process is repeated.

d. Reference was made earlier to the ranking matrix (Frame II, Fig. 2) in terms of a more detailed analysis. The analysis is somewhat complex, but important to a full understanding of the model. A hypothetical example will again serve to illustrate the fundamental principles involved during the distribution process. A discussion of the ranking process must be done in two essential and interrelated stages: (1) the ranking of independent variables, and (2) the manipulation of these variables to form the final percentage distribution. Table 1a and 1b will serve as key references. Suppose there are five grids in a particular county and three variables, X_1, X_2, X_3, which are the weighting parameters. These independent variables can represent any economic, demographic, or ecological measurement desired. For example, X_1 can be a measure of commercial employment, distance to a railroad terminal, or the number of firms in a grid. Similarly, X_2 and X_3 can represent some indicator of sewage and water accessibility, the percentage of that grid in a flood plain, or population. Almost any parameter can be used as a weighting element in the ranking matrix. The only constraint on this is that of consistency, i.e. same units. As many as eight ranking variables can be employed for each county and land-use type, representing a variety of proxies of economic base performance and measurements. The actual ranking process goes as follows: Suppose we let X_1 be acres in heavy industrial usage, X_2 a measure of accessibility to a railroad terminal, and X_3 industrial employment (Table 1a). The values of these variables are placed adjacent to their respective land units. For example, grid (100R, 50C) has $X_1 = 50$, $X_2 = 8$, and $X_3 = 800$. In this simplified example, only three variables were used for ranking five land units. In actuality, we could have used eight variables and there may have been 700 land units. Note also that the X's are real world numbers. Table 1b shows what the simulator does. Each real number in Table 1a is converted to an integer value. To illustrate, column X_1 (Table 1a) shows land unit (100R, 50C) as ranking fourth in numerical value out of a maximum of five units. Cell (105R, 50C) ranks fifth out of five--the highest ranking value for that cell and that variable. A similar conversion process takes place for all cells and variables. The next operation horizontally sums the X values. The overall highest ranking unit sums the greatest, and after conversion, receives the highest number of employees. In reality, modeling does not stop here, but the simplification provided portrays the basic algorithmic processing.

III. Model Phases

a. In order to present a comprehensive description of model functions and processes, a non-mathematical approach will be utilized. The mathematics and statistics are not difficult to comprehend but would require a detailed example too lengthy for general description purposes. The model functions on a three-phase basis as described below.

b. In Phase I, population and employment are distributed to developed land based upon the ranking process heretofore described. Each grid receives a relative percentage share of use depending upon its calculated desirability. If a land unit is not fully saturated during this phase, it may receive additional use during subsequent passes. Alternatively, if the unit becomes fully utilized and the cutoff density constraint is reached, a residual of unallocated population or employment will exist. This is to say that developed land within a grid cannot absorb further allocation.

c. Phase II is designed to allocate the residual of population and employment that could not be distributed during pass one. It accomplishes this task in two steps. Step 1 distributes the residual to vacant acres in that land unit. Population is allocated to vacant land at a density which is less than the density of the previously developed land. This corresponds to reality in that newly developing land usually does not produce high density land units. The partial density is functionally dependent on three principle factors: (1) the level of development already existing, (2) the relative desirability of contiguous units, and (3) a random number generator. All three factors are given consideration when the partial cutoff density is calculated. Ordinarily, Phase II will allocate all remaining residuals. However, a few land units may rank sufficiently high that a residual still persists. Under these conditions, Phase II, Step 2, allocates any remaining population to agricultural land in the grid--at the same weighted partial cutoff density, as was the case with the vacant use. In a few cases, more allocation is required. Phase III is designed to rectify the problem.

d. Phase III is a last effort to remedy the problem. Like Phase II, Phase III has two steps. Step 1 directs the allocation effort back to vacant land which, as you recall, is partially developed. This time, vacant land is brought to the same maximum density as highly developed land. Greater allocation takes place further decrementing the residuals of population and employment. Finally, as a last resort, Phase III, Step 2, increments the density of agricultural land and attempts to distribute population. If a residual persists, an error message is printed indicating that an adverse condition is in effect. The entire three phase process is repeated each decade. It should be realized that what has been described is illustrative of general sequential flows.

IV. Control Cards and Input

a. The input section of the model consists of two major sources: the decade 1970 data base, and user-supplied input and control cards. Within the context of the subdivision, there exists a set of primary control cards, a set of secondary control cards, and a set of auxiliary output specification cards.

b. The primary control cards are required for the allocation algorithms to take place. These cards include the following: (1) the population projections or "POP" cards, (2) the terminating decade card or "TO" card, (3) the ranking input variable cards, "FILL," (4) the limiting density factor, "DEN," and (5) the initiating control, "DO." All five cards are mandatory for the distribution process to function, as each of these cards contains vital information. For example, the "POP" card contains the exogenously forecasted population and employment by land use type and county from which distribution takes place. The "TO" card controls the decade that the model forecasts to, i.e., 1980, 1990, 2000, 2010, 2020, or 2030. The "FILL" card, on the other hand, contains the variables by which land units are ranked (a maximum of eight variables per use). The "DEN" card limits allocation by land use density constraints which are exogenous to the model per se. The "DO" control card instructs the computer to perform all indicated processes to all counties and land use types where the letters "DO" are placed. If a "DO" card is omitted, that land use type for that county will not be processed.

c. Secondary control cards are used primarily for "fine tuning" the allocation process by specifying action to be taken under specific conditions. Seven different cards are used for this purpose. None are required, but in using them, certain desired economic activities can be constrained or facilitated by known contingency developments. These cards include (1) a dispersion or "DISP" card, (2) a ranking or "RANK" card, (3) a "XDEN" card, (4) an exception or "EXCP" card, (5) a special statistics or "STAT" control factor, (6) a "ZONE" control, and (7) a "HOLD" command, and (8) a "Cell" card.

(1) The "DISP" card allows the model user to interrupt the main sequence flow process in order to store a percentage of exogenously fore-casted population or employment for a reallocation procedure. For example, 5 percent of a given county's industrial employment can be set aside and the remaining 95 percent distributed according to plan. The 5 percent will then be distributed to, say, the top ranking three grids. In effect, this can represent a proxy of redevelopment of more established urban areas, if desired.

(2) The "ZONE" and "HOLD" commands permit control over the utilization of land. The "HOLD" commands permit control over the utilization of land by withholding vacant or agricultural land from development. Ordinarily, the computer would absorb both when needed, as explained above. The "HOLD" control specifies a land unit number, the type of land, and the acreage to be withheld from development. Each acreage specified on a card applies to one decade in the forecast. Similarly, the "ZONE" command increases flexi-bility by allowing the model user to set a maximum on the number of acres which can be developed on a specific land use ostensibly for zoning regula-tions. Each "ZONE" card specifies a land unit, a land use, and the maximum acreage that can be developed in the land unit.

(3) The "RANK," "XDEN," "EXCP," and "STAT" cards require special attention because of a set of algebraic rules. The rules within a land use type take the form of a series of "IF" statements" If A is LE (GT, EQ, LT, NE, GE) B, then action D is taken. The three symbols in the "IF" statement represent the input specification of a rule: the "A" symbol is the variable number in the data base to be used, the "B" symbol represents the value of this variable to be satisfied, and the "X" symbol represents the algebraic operation to be performed: less than or equals, greater than or equals, or equals. For example: If 31 is LE 25, where "31" is the variable number of the percent of land subject to flooding, "LE" means less than or equal to, and "25" is the value of the flood plain percentage which must not be exceeded.

(4) Specifically, the "RANK" control card provides the capability to alter the ranking of land units within a county for land use. For example, the "RANK" card alters the result of a ranking by allowing an increase, decrease, or specification of rank for a land unit or units. A logical expression similar to the one above is required for the ranking change to take place. In addition, the ranking can be altered for a certain decade if desired, rather than all decades.

(5) The "EXCP" command provides the capability to alter the maximum population (employment) density for a land unit(s) in a particular land use after the initial (DEN) allocation process has taken place. The "EXCP" control card alters the maximum density by allowing an increase, decrease,

or specification of maximum population density for a land unit(s). As before, a logical expression is constructed to achieve an alteration of density. This flexibility can be applied to reflect unusual or atypical circumstances not identifiable during the normal flow process.

(6) The "STAT" control card is unique in providing for the capability to alter the population density at which agriculture and vacant land is developed. In other words, the density at which vacant and agricultural land is used can be changed to reflect realism. For example, vacant land in relatively rural areas generally does not develop at the same density as does vacant land in the older, more established urban areas. This can be reflected by use of the "STAT" card and the proper logical expression.

(7) The "XDEN" control card allows the model user to modify the maximum population (employment) density for a land unit(s) in a specific land use, prior to the initial allocation. This control element alters the maximum density by allowing an increase, decrease, or specification of minimum population density for a land unit(s). In addition, the densities can be altered for a certain decade by specifying that decade.

(8) A "Cell" control card is also provided. This permits the user to specify processing on a land unit for a particular purpose. In this way, control over one land unit is possible without directly interfering with other units.

d. The last eight control cards discussed are basically used to "fine tune" and solve unusual problems not covered in the normal flow sequence. The user is constrained to 1000 cards by the memory complexities of the computer.

V. Output Specifications

The output specification cards allow for suppression of parts of printouts which are unnecessary or undesirable for applied analysis. These include a "Base" card, "RPT" control, "UCALC" function, "MAP" card, and a "DIAG" card.

(1) The "Base" card permits the planner the flexibility of dumping specified decade data base variables for purposes of statistical analysis.

(2) The "UCALC" function is an access point where a statistical analysis package can be placed, such as a regression, correlation, factor analysis, or Chi-Square program.

(3) A mapping "MAP" suppression is also incorporated. If the planner wishes to use only 1990 and 2010 maps, all others can be suppressed (1970, 1980, 2000, 2020, and 2030). In this way, he is not bothered by massive printouts of maps.

(4) Finally, a "DIAG" card allows for suppression of extraneous printout. Some of the simulator's output is non-functional for a planner's purpose. This is auxiliary data used ordinarily for checking model processing. These reports are often called diagnostic reports.

VI. Data Base

a. Most of the data utilized in the model was collected by the East-West Gateway Coordinating Council, the St. Louis area's council of governments. This data consists of a host of information pertaining to area-wide economic, demographic, and geographic attributes of potential use in terms of ranking variables. A list of these variables is contained in Table 2.

b. Those variables chosen as economically useful are known to be theoretically important. For example, accessibility to transportation modes such as railroad and truck terminals, barge facilities, and highway intersections, are all valuable for determining the potential development of a particular land unit. All four types of transportation are important to commercial development. There is a number of large retail establishments in the metro area that require input to warehouses via rail, truck shipments to the retail outlet, and extensive highway development for customer delivery and business.

c. Another important economic variable is that of a measure of distance from a central business district (CBD). The data base also provides this. A grid within a county is chosen as a CBD because of known economic attributes and all other cells in that county can be ranked by the distance from that centrally important unit. Since there are eight counties (including the City of St. Louis), eight CBDs can be chosen upon which to rank their respective units. The principle behind using distance from a CBD lies in the research conducted on "central place theory." Briefly, "central place theory" asserts that as one moves away from a dense urban center, density, business activity, and utilities decrease in quantity. In other words, development is functionally dependent upon distance from a central business center. Thus, land units farthest from a CBD will be given less weight in terms of rank as compared with those adjacent to the hub of activity. The model also has the ability to modify this process for atypical situations. There are many more variables that may be regarded as economically deterministic and the two indicated above are examples.

d. Demographic variables are also available as ranking parameters. Population of each cell is in the data base and can serve to "weight" units in terms of residential development. If the assumption is made that those units containing high residential population at a particular time will also contain high populations in the future, then it is reasonable to believe that those same units will be residentially oriented in the future. A second related ranking variable is that of population and employment densities (people per acre). An already dense population center could prove to be attractive to further residential development via high rise in the future.

e. Examples of geographic parameters would include soil types (severe, moderate, slight), the percentage of a land unit in a flood plain, and total acre size of a particular unit. These types of variables allow the modeler to take into consideration topography, inundation, and a number of other "physical" features of the unit under consideration.

VII. Planned Applications

a. The St. Louis District's Land Use Forecast Model was designed to measure project impacts and to assist planners and economists in formulating alternative solutions to water resource problems. The model can best be applied to projects which are regional in scope. For example, in formulating alternatives to wastewater treatment projects, a variety of solutions can be evaluated and tested for the eight-county area. Another potential use which shows promise is the application of the simulator to interior drainage problems. By using flood plain data and altering input variables, a quantitative output can be analyzed. It would be useful to more vividly describe how the model could be used and how the output is interpreted for a wastewater project and an interior drainage problem.

b. The St. Louis District is developing the foundations for a regional wastewater treatment complex to meet the growing needs of the St. Louis SMSA. There are essentially three basic problems which must be thoroughly analyzed before final plans can be implemented. They include the questions of: (1) where to locate the treatment sites in terms of a comprehensive regional coverage, (2) how many and what size facilities to provide, and (3) what kind of treatment should be used. The model can be applied as a supplemental tool in evaluating this maze of problems. Each alternative can be tested by a separate run and compared to the no-project condition. In this way, land use impacts can be analyzed. As a formulation tool, it can show how alternative plans respond to meeting some predetermined and desired end--such as local land use plans. Output will include, but not be limited to, such factors as population and employment shifts, land use density configurations, acreage requirements, variances in land-use spread, and area needs. This information will be provided for each grid in every county within the SMSA from 1970 to 2030, by decade. In addition, all principle land-use types will be evaluated numerically and on grid maps.

c. A second promising application of the simulator focuses on analyzing numerous solutions to interior flood control problems. The traditional remedy frequently involves the installation of pumping stations, the addition of levee protection or ditching, reservoir construction, or some integration of these types of projects. The land use simulator has the capacity to test the alternatives and their varying impacts. For each designated alternative, a separate run can be made and the difference in land use could then be compared and contrasted. It gives the planner a variety of choices from which a single plan can be formulated. As before, the output will be in terms of population, employment, densities, and acreages. It is possible to incorporate the addition of water supply, hydroelectric power, recreation, and environmental aspects of project implementation. A great deal can be done provided that data base variables are made available.

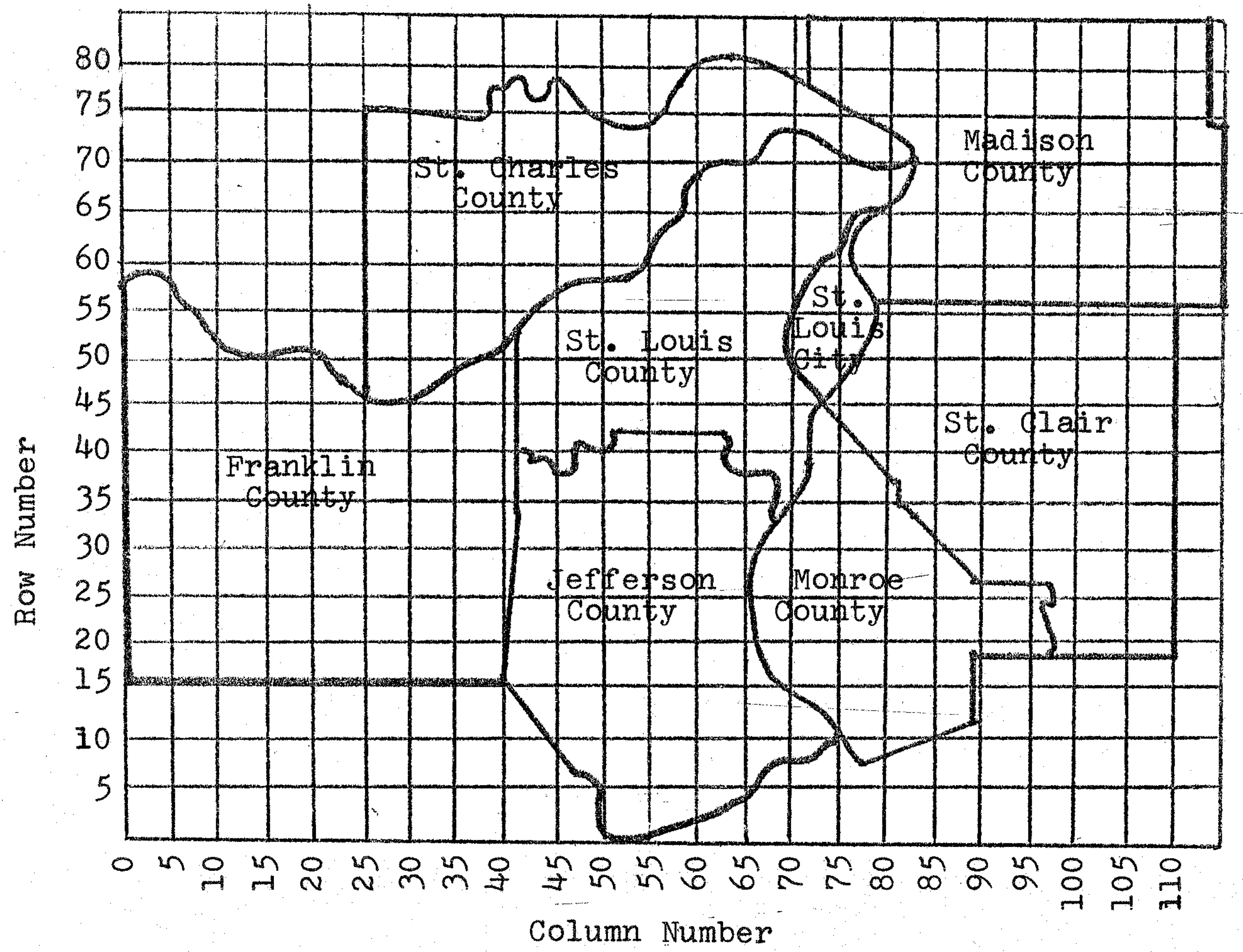
d. The two types of projects discussed are amenable to modeling. The model can also be of assistance in evaluating airport development, industrial park impacts, recreation projects, and possibly other uses not yet thought about. It is an excellent supplemental tool.

VIII. Technical Configuration

The minimum core requirements to run the land use simulator is 850K. A memory capacity greater than this is frequently needed. It was developed on an IBM 370/165, O.S. Version 21.6 Hasp Version 3.1. Fortran is the principle language used, but a large "U" matrix is written in PL-1. One direct access device is required to accommodate the nine files used (IBM 2314 diskdrive or Model 3330 drive) during processing and compiling. In addition, a Grid mapping program is needed for printing map output.

IX. Summary

As a regional impact tool, the St. Louis District's Land Use Forecast Model fulfills many of the functional needs of planners and economists alike It can be applied to many areas and is not uniquely attached to the St. Louis area in any technical sense. It is not designed to be an all inclusive tool and should not supplant all other methods, but rather serve to supplement existing analytical techniques. The two sources of output (real numbers and mapped results) provide for both a quantitative and visual inspection of impacts and facilitate plan formulation. Modeled results are as detailed as desired with the only principal constraint being the quality of the initial input data base.

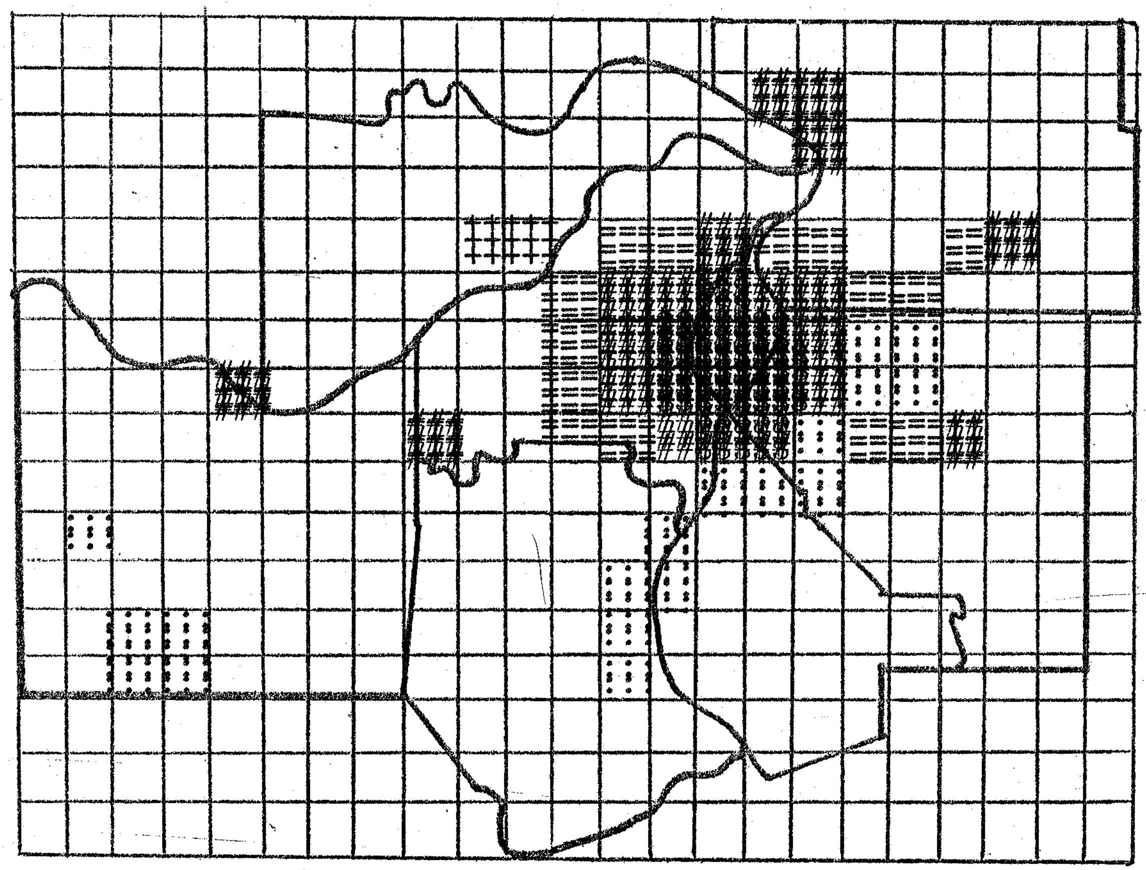


GRID MAP A

St. Louis SMSA

This represents an illustration of how grid mapping looks. Actually, smaller or even larger grids may be formed depending upon data availability and needs of the planner.

GRID MAP B



3,000-3,999	Hvy. Employment
2,000-2,999	Hvy. Employment
1,000-1,999	Hvy. Employment
500- 999	Hvy. Employment
100- 499	Hvy. Employment

etc. There are ten shades

Grid Map B represents how the mapping effort looks. Maps are produced for each decade and each land-use type. The planner has a tool to examine land activities over time and under varying conditions.

FIGURE 1

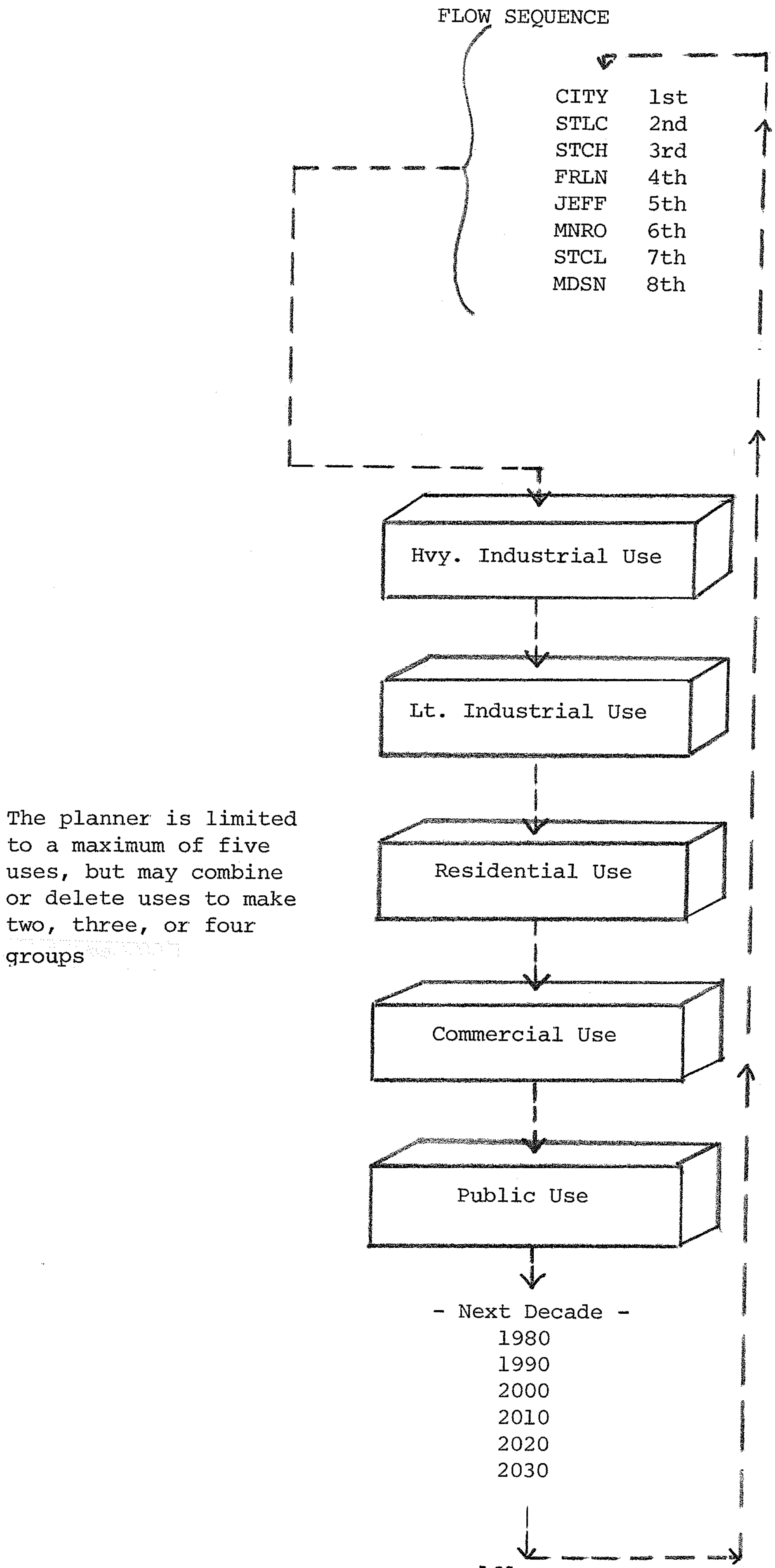
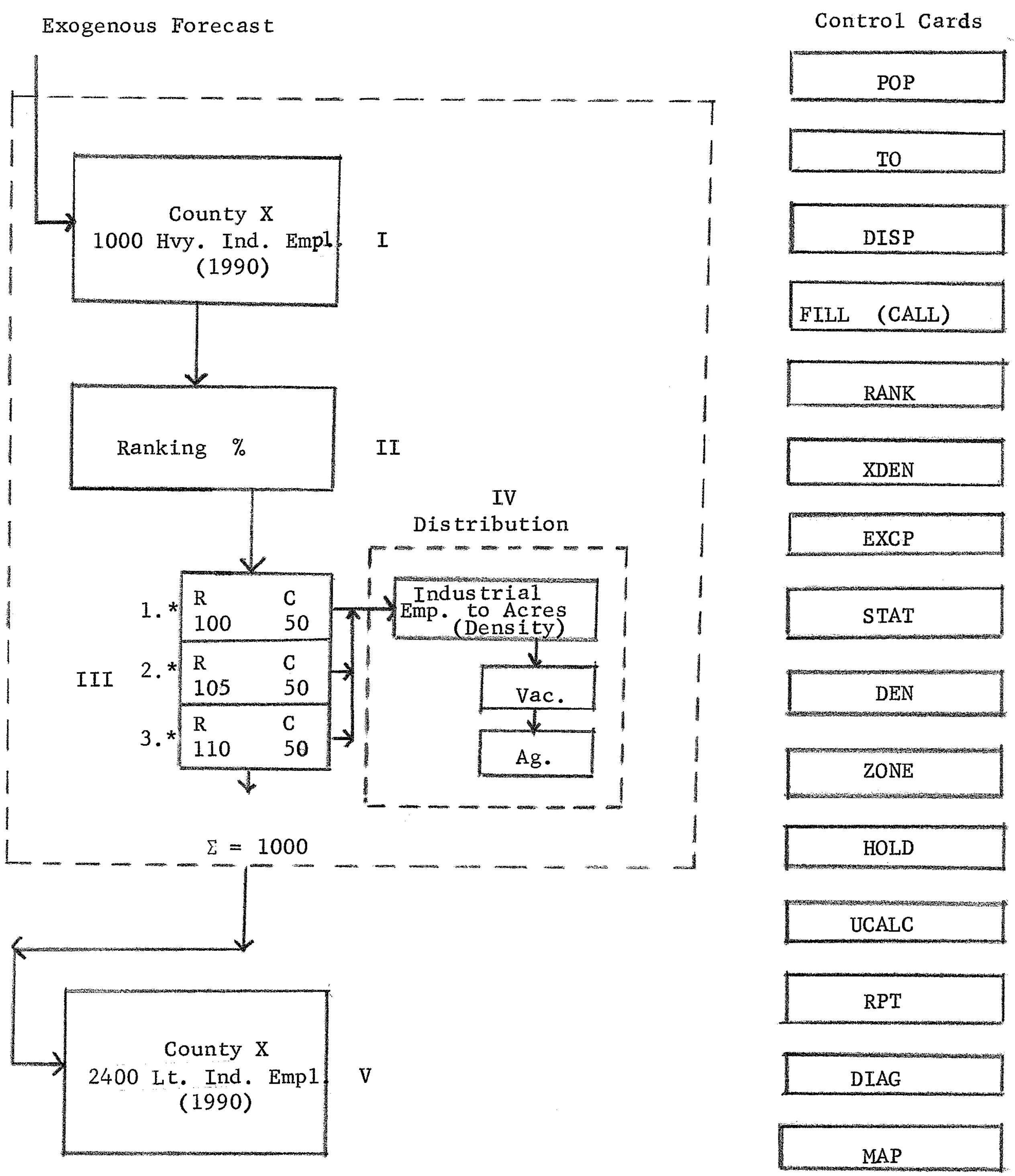

FLOW SEQUENCE
CITY 1st
STLC 2nd
STCH 3rd
FRLN 4th
JEFF 5th
MNRO 6th
STCL 7th
MDSN 8th
Hvy. Industrial Use
Lt. Industrial Use
Residential Use
Commercial Use
Public Use
- Next Decade -
1980
1990
2000
2010
2020
2030
The planner is limited to a maximum of five uses, but may combine or delete uses to make two, three, or four groups

FIGURE 2

Internal Structure



* The numbers 1, 2, and 3 are hypothetical ranks as would be calculated by the simulator

TABLE 1a

County X

Ranking Process

Grid Row	Grid Col	Acres in Hvy. Ind. X_1	Access to RR X_2	Ind. Empl. X_3
100	50	50	8	800
105	50	150	10	1000
110	50	30	3	800
115	50	0	1	500
120	50	20	2	77

TABLE 1b

County X

Grid Row	Grid Col	Rank Values X_1	Rank Values X_2	Rank Values X_3	ΣX_i**	%	Population Allocated*
100	50	4	4	4	12	27	270
105	50	5	5	5	15	33	330
110	50	3	3	2	8	18	180
115	50	1	1	3	5	11	110
120	50	2	2	1	5	11	110
					45	100	1000

*Assume 1,000 as exogenously forecasted employment for County X.
**In case of a tie between sums, numerical order presides.

TABLE 2

INITIAL INPUT VARIABLES COLLECTED FOR EACH LAND UNIT

Variable Number	Information
2	Acres in heavy industry
3	Acres in light industry
4	Acres in residential
5	Acres in commercial
6	Acres in public
7	Acres in agricultural
8	Acres in vacant
9	Heavy industrial employment
10	Light industrial employment
11	Residential population
12	Commercial employment
13	Public employment
14	Recreational acreage
15	Airports
16	Soils
17	Slope
18	Retail
19	Industrial parks
20	Office center
21	Free-standing
22	Institution
23	Rail terminal
24	Barge terminal
25	Truck terminal
26	Sewer
27	Mining
28	Acres water
29	Ground water
30	Highway: summation 1970
31	Highway: summation 1990
32	Distance from a specified unit

ALTERNATIVE SYSTEMS FOR COMPUTER MAPPING AND AUTOMATING GEOGRAPHIC INFORMATION

by

Jack Dangermond, Director

Environmental Systems Research Institute
14 North Fifth Street
Redlands, California 92373

I. Introduction

This paper provides a classification of spatial identification techniques for automated geographic information, and describes some of the advantages and disadvantages of alternative technical approaches as they relate to planning applications. For background, historical methods for satisfying information problems and current methodologies being utilized are discussed. The grid, polygon, and single point techniques are examined in detail. In addition, various computer mapping and analysis programs are examined in terms of their usability in association with spatial identification techniques.

II. Origins of a Geographic Data System

During the past 15 years, many professionals involved in geographic analysis have been working on the development of automated systems for efficient collection, storage, analysis, and presentation of geographic data. Apparently, these efforts have been the result of an increased need for quantitatively arrayed spatial data for use in planning and decision making.

There are two basic justifications for the development of these systems. First, they typically increase the technological capability for manipulating and analyzing large quantities of data. Second, they reduce the per unit cost for acquisition of necessary information.

Recent development of various automated techniques for spatially identifying geographic data has evolved from historical methods of geographic data storage. These methods consisted primarily of maps or statistics related to aerial units described on maps. Examples are maps of natural resources (e.g., soils, vegetation, mineral resources, etc.) and cultural geography (e.g., land use, transportation, etc.). Polygons, lines, points, and surfaces of geographic variation are typically depicted on these maps.

Polygon maps define the borders of homogeneous features as well as the characteristics associated with those features (e.g., a soils map describing the boundary characteristics of soil types).

Line maps define linear elements of geography such as roads, hydrologic networks, railroad lines, etc.

Point maps articulate the geographic position of events or phenomena located at specific points (e.g., historic landmarks, wells, topographic elevation, or traffic intersections).

Surface maps which describe continuously varying quantitative spatial data are a sub-set of both line and point maps. Topographic lines and elevation points are typically used to display this data.

The basic problem associated with developing a geographic data base is transferring the aforementioned map features into a computer readable data file describing the spatial location of these features. A series of techniques have been developed for conducting this map to automated data file conversion.

In general terms, an automated geographic information system can provide many of the same qualities provided by an integrated mapping system. In addition, a well structured automated system can provide many advantages associated with complex information studies involving massive amounts of data. Specifically, an automated system can provide a quantitative framework for rapid analysis and retrieval of information in a manner easily understandable, highly accurate, and cost effective.

The overlay and analysis of several geographic data maps of the same location provides a good example of how such a system can be beneficial. A traditional technique used for this type of analysis involves the manual overlay of acetate maps. Using this technique, the analyst loses sense of comparison after the second or third overlay; any form of quantitative weighting is impossible.

The recognition of these problems has led to the development of retrieval techniques that facilitate various forms of mathematical modeling and computer graphics.

In preliminary research efforts, as well as those presently ongoing into geographic data base design, there exist a great many common attributes which are seemingly applicable to most systems. One of the most important of these is techniques for spatial identification of geographic data. This paper addresses the subject of spatial identification techniques in detail.

III. A Classification of Spatial Identification Techniques

Three generalized spatial reference systems have been developed and operationally tested for digitally recording geographic data. They are the grid system, the polygon system, and the single point system.

The grid system is a technique whereby variables of data are associated with a uniform gridded matrix superimposed on the landscape. The polygon system is a technique for collecting information by polygon areal units. The point system is a technique using single points for sampling of continuous surface data or referencing some phenomena or event on geography. These three main classifications will be discussed in detail in the following sub-sections.

A. Grid Cell Identification System

The grid cell technique employs a grid matrix, or lattice, uniformly inscribed and referenced on geography. Having established a grid cell system for collection of data, qualitative and quantitative data associated with each cell can be encoded or digitized. This data can be collected by manual digitizing, whereby each cell receives a manually recorded code denoting the data and classification value identified within that cell, or automatic digitizing wherein polygons or points are measured in terms of x,y coordinates and subsequently converted into a grid format automatically. The resulting matrix of data can be used for a variety of purposes. Some examples are:

- computer mapping of basic data according to original scale or in rescaled values

- merging maps for varying sources and scales into a unified data file

- selecting small geographic areas (windowing) from a larger geographic area file (e.g., watershed planning units)

- "overlaying" map data files of two or more variables for the same geographic area (this can involve a variety of weighting techniques)

- searching and calculating distances to or from a specific grid cell location or phenomenon.

Examples of computer printer and plotter maps produced from the grid referencing system are displayed in Figures 1 and 2.

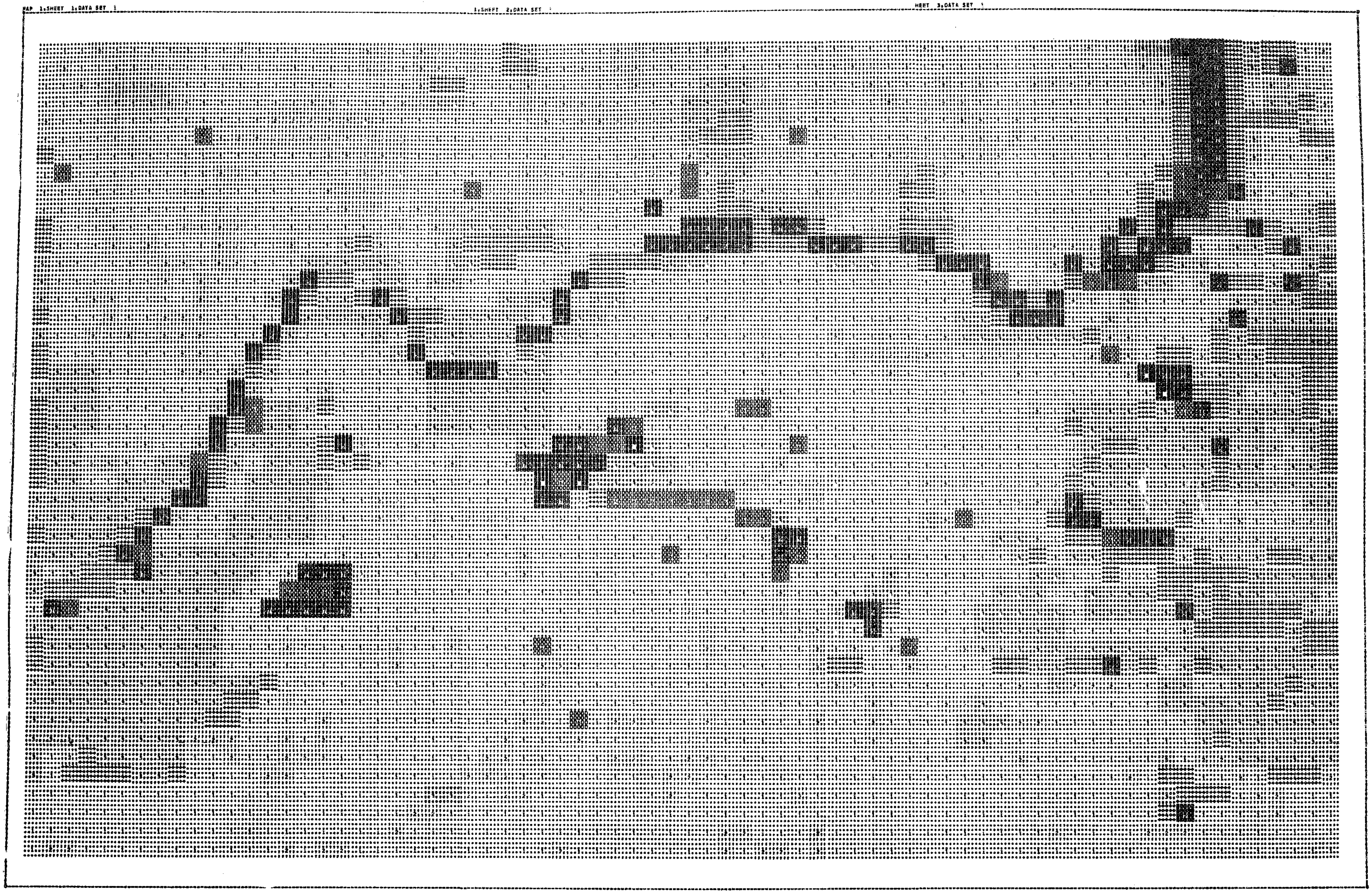
Some of the basic advantages of using the grid cell system, as opposed to other techniques, are listed below:

1. The grid cell provides an easy way to collect data. A plastic overlay of grid cells is laid on top of air photos or maps. Spatial information is recorded on encoding forms to be placed into the data bank.

2. The computer storage and subsequent access to this matrix of information is made relatively easy by using a simple row and column method (matrix array); thus, the data file is extremely straightforward in accessing and computation. No coordinate digitizing is necessary.

3. Air pollution dispersion models, gravity models, and other urban system models use, as a basis, the matrix of information stored in a grid cell data bank. Technically speaking, the technique is very strong; in fact, the basis for FORTRAN has its roots in matrix methodology, making a quick and easy interface with many other types of programming technologies that have been developed.

4. The nature of the grid cell makes it useful for discrete as well as continuous types of data analysis. By using simple programs, multitudes of point x,y location data can be aggregated into the grid cell for different types of display. The GRIDS program, developed by the U.S. Department of the Census, is a



ECOLOGICAL SENSITIVITY MODEL

GUAJOME RANCHO REGIONAL RESOURCE STUDY

ECKBO, DEAN AUSTIN, WILLIAMS AND ENVIRONMENTAL SYSTEMS RESEARCH

THIS MODEL UTILIZES INFORMATION GENERATED BY A DEPENDENCY MATRIX THAT EXAMINED THE QUALITATIVE ASSOCIATIONS AMONG SELECTED BIOLOGICAL, PHYSIOGRAPHIC, AND HYDROLOGICAL VARIABLES COMPOSING THE ECOLOGICAL INFRASTRUCTURE OF THE REGION.

DATA MAPPED IN 10 LEVELS BETWEEN EXTREME VALUES OF 0.0 AND 36.00

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

MINIMUM	0.0	3.60	7.20	10.80	14.40	18.00	21.60	25.20	28.80	32.40
MAXIMUM	3.60	7.20	10.80	14.40	18.00	21.60	25.20	28.80	32.40	36.00

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00

FIGURE 1

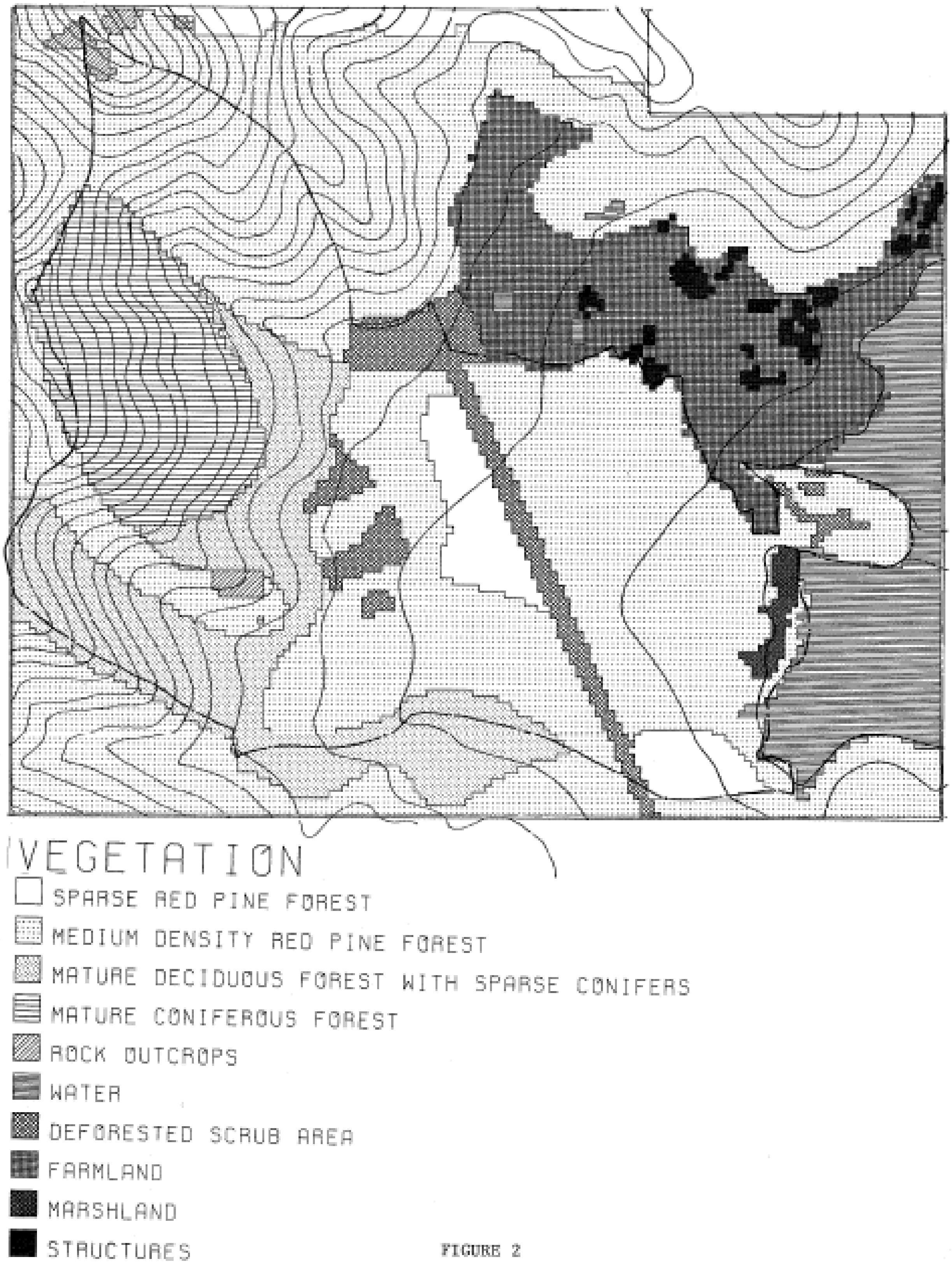

VEGETATION
SPARSE RED PINE FOREST
MEDIUM DENSITY RED PINE FOREST
MATURE DECIDUOUS FOREST WITH SPARSE CONIFERS
MATURE CONIFEROUS FOREST
ROCK OUTCROPS
WATER
DEFORESTED SCRUB AREA
FARMLAND
MARSHLAND
STRUCTURES

FIGURE 2

perfect example of a program having the potential for aggregating information into grid cells and then displaying it.

5. Many forms of geographic projection have initially used either consistent or warped grid cells. Using the grid approach, one can tie in very quickly to the other forms of geographic projection and can easily relate to other types of information that have been collected historically or are to be collected in the future.

6. Because of its uniform size and consistency, the grid cell provides a good framework for understanding information. In contrast to the very complex types of polygons (to be discussed later), the grid cell provides a clean and easily communicated form for simplification of data.

7. A grid cell system provides a very fast and efficient processing mechanism; when compared to the polygon approach, it is computationally more efficient.

The disadvantages of the grid approach are quite obvious and can be summarized in the following.

By aggregating certain types of information to the grid level, one loses a certain percentage of accuracy. This might best be illustrated by pointing out the difficulties in encoding a soils map by grid cell. Soil types change quite often and quite drastically and can be thought of as distinct qualitative data, as opposed to spatially continuous unchanging data. Problems exist when three, four, or a dozen soil types occur within a single grid cell. Two options are available for handling the problem:

a) the most dominant type of soil within a grid cell can be encoded

b) one can encode the relative amounts of each soil type within the grid cell; this, of course, takes a good deal of effort because each soil type must be hand digitized from a map and calculated by each grid cell.

If "a" is used, a certain degree of error and constraint is inherent in the assumption that he makes. If such error is acceptable, the resulting information system provides only a "broad brush" approach for analysis and planning.

One of the better grid overlay mapping systems was originally produced at Harvard University and is now being used with various modifications at different places around the country. The program name is GRID. It basically uses any number of characters to define a rectilinear grid system. GRID displays one variable or one combination of variables at a single time and is, in this sense, limited. A second disadvantage of the system is that the maximum number of symbols presented at a single time is 12, although many more can be stored and drawn out in scale forms. GRID uses character overprinting to create relative shading relating to a frequency distribution similar to the one originally developed in the

SYMAP program.

The GRID program can be used to compare various matrices of information and produce maps of grid data. The program also has the capability of calling out many variables from a data bank, overlaying them, and applying statistical coefficients to selected variables. One of the subroutines in the program is called Subroutine Flexin-obviously named because it is an attempt to give flexibility to the reading in of data inputs. Using this routine, any program can be compiled for computation and graphics.

B. Polygon Identification Systems

The second system to be discussed involves the use of an irregular polygon areal unit for spatial identification. This system requires geographic data to be digitized, stored, and retrieved in its basic polygon form (not relating to any specific system of geometric configuration). The perimeters of each polygon areal unit containing the data desired for use are digitally encoded. Having stored these polygons, they can be called individually and used in a variety of information analysis and display procedures.

This paper will present a discussion of various graphic techniques for computer mapping of polygon data, followed by a detailed explanation of polygon overlay techniques with brief narration of other analytic applications of polygon data.

1. Computer Mapping Programs

The most basic use for polygon data is computer mapping display. There are numerous computer graphic programs available for polygon mapping. One of the first printer computer graphic packages developed was the SYMAP program, developed under the direction of Howard Fisher at the Harvard Laboratory for Computer Graphics and Spatial Analysis.

One of the options of SYMAP is choropleth, or polygon, mapping of thematic data. This system provided an initial breakthrough, and although it was cumbersome and in some ways inefficient, it pointed out the usefulness of basic data as a tool for communication as well as spatial analysis.

The basic program is designed to operate and produce graphics on a standard chain line printer device; as such, it has a great deal of transferability. It is written in Fortran IV, but has a complete user language associated with it, enabling people with little computer background to use the system.

Its shortcomings are that it was designed as an overall graphics system; as such, it has characteristics which limit its application for many users. Because it is written to handle almost every conceivable exception, the program (6000 cards) is very large and requires a sizeable partition of core on a computer (128K on an IBM 360 with overlays), putting it out of range for many users. In addition, it has many options for an ever increasing number of mapping problems. The learning time required for developing an "experienced user" is evidence that the program is both confusing and expensive for the user.

SYMAP's inefficiencies and shortcomings have prompted research and development of several newer mapping packages. One of the first programs was C-map, a very small printer choropleth mapping package designed to run efficiently on IBM 1130 machines. This program used no coordinates, but instead adopted a grid cell concept for the identification of zones or polygons. Although the program can be modified, the original version produced only single page maps which, for many applications, did not provide enough graphic display. The grid cell digitizing scheme caused many users to complain that the encoding for a complex areal unit map involved too much effort. Because of its very efficient scheme, the C-map program also seems to have stripped the user of any flexibility (e.g., scaling, legends, etc.), and as a result probably went too far for efficiency's sake.

Another program, AUTOMAP I, represented an attempt to strip the original SYMAP program of many of its options, thereby making it easier for the user to operate, and also making it capable of running on small machines. The approach, although meeting some of the desired objectives, retained many of the original SYMAP problems. It still required a substantial amount of user specifications (70% of SYMAP). The minimum core requirement was still 82K on an IBM 360, and the computation time for choropleth maps remained excessive. Clearly, this program did not go far enough.

The experience from both of these extremes has given insight into how the design and programming of computer mapping systems should be approached. Modular programs which address specific mapping requirements and applications are, no doubt, the most efficient. Several mapping programs taking this approach have been written.

The most significant of these new programs is AUTOMAP II, which has the capability of producing several types of printer maps on a small computer. The AUTOMAP II system is made up of three small modular programs designed for separate but interrelated activities. The programs are Basemap, Areamap, and Contourmap. The structure of these three programs was designed around a grouping of the main procedural steps necessary for automated cartography.

One of the most important efficient concepts of AUTOMAP II is the development of a permanent and reusable Base Map Image File (BMIF). The file is a large grid matrix similar in concept to C-map; however, it is generated from coordinate input data rather than by grid cell. This file is an in-between computational step that traditionally, in SYMAP, was required for each map produced. This BMIF also includes all legend and associated map cosmetic data used on every map.

The Base Map program initially creates the Base Map Image File which subsequently becomes a permanent file for re-use by the other programs, saving an enormous amount of computer time because the grid matrix is made only once.

The Area Map program is designed to read in the Base Map Image File. This program, however, produces contour and proximal maps and, as such, has additional options that can be employed for specific applications.

The AUTOMAP II programs are written in Fortran IV and require a Level G Fortran compiler. Once the programs are compiled, the largest program requires a minimum of 42K on an IBM 360. This includes storage for compilation of various Fortran system library routines (i.e., input, output, error recovery) used in the program. Program decks are available for both OS and DOS configurations from ESRI.

In addition to printer graphics, there have been several significant developments in the area of plotter programs. The most significant of these is a program called Calform, developed at Harvard Laboratory for Computer Graphics and Spatial Analysis. This program generates two-dimensional choropleth maps on a Calcomp plotter. The program has a user language associated with it, enabling non-technical people to produce graphics with little difficulty (see Figure 3).

In summary, it can be observed that present developments in the area of computer mapping are directed toward producing programs which are more efficient, more user oriented, less costly, and require smaller hardware.

2. Polygon Overlay and Related Analysis Applications

The second application of polygon data involves overlay analysis wherein data can be compared or overlayed statistically. Overlaying two or more maps is a technique commonly used to display or investigate the spatial association between various geographical aspects of the same locality. More specifically, the polygons are sorted and compared using a dominant polygon variable as the summarizer of a subordinate polygon variable file. The particular advantage of this approach is the great degree of accuracy that occurs by exact polygon overlay. Usually, the computational structure of polygon overlay requires only two sets of polygons to be overlayed at a single point in time.

A number of program systems for polygon overlay have been developed. These are discussed briefly below.

The polygon overlay system called Map/Models was developed by Samuel Arms at the University of Oregon. The Map/Models technique has been under improvement for the past five years and includes an extensive "exception" vocabulary, whereby many of the errors that potentially occur in encoding are checked and re-checked as part of the computational process. This system is well tested and seems to be operating successfully in a number of cases. The most serious problem reported with the program is that the computational time is very great, resulting in expensive processing costs.

The second type of polygon information processing system is entitled PIOS (Polygon Information Overlay System). PIOS was originally developed by ESRI for the Comprehensive Planning Organization in San Diego. This program is extremely simple in logic and ties together an efficient sorting and overlay system with a variety of additional computation and analysis programs. The system relies primarily on pre-checked data coming from a digitally plotted output. This pre-check involves pen plotter computer graphics and visual editing. The editing, together with a stripping concept of polygons, reduces some of the high computational costs of map models.

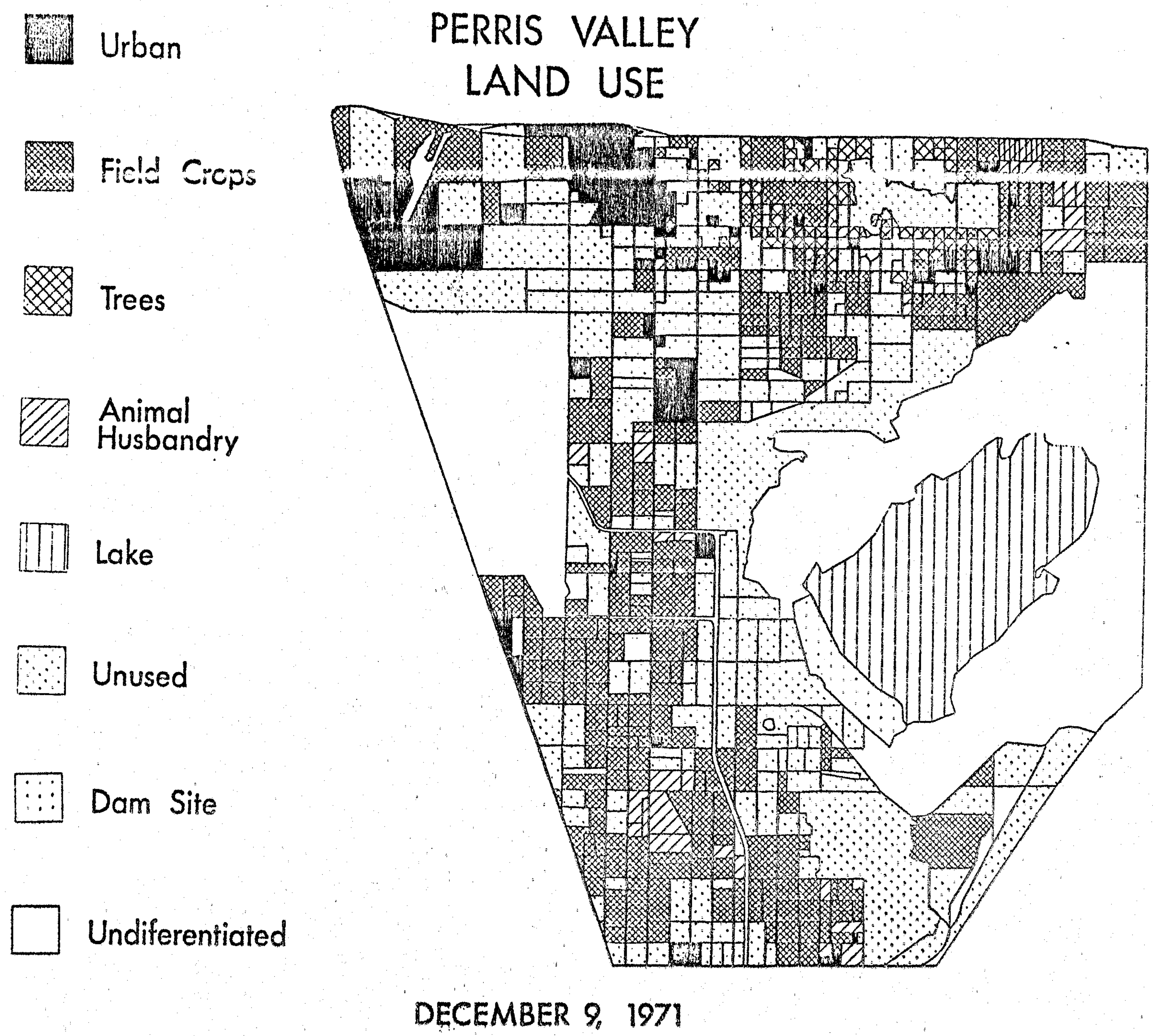

PERRIS VALLEY
LAND USE
Urban
Field Crops
Trees
Animal Husbandry
Lake
Unused
Dam Site
Undiferentiated
DECEMBER 9, 1971

FIGURE 3

Additional polygon systems reviewed by ESRI include the Canadian Land Use Survey; Boeing Polygon Overlay (a version of Map/Models); a system developed by Lockheed Electronics Company; and the FRIS system developed in Sweden by the Central Board for Real Estate Data. A review of available literature on these systems suggests that the basic concept of file structure in all of them is similar. The two greatest areas for improvement relate to encoding or digitizing of input maps and improvements in techniques for overlay computation. Although automated scanning devices promise a future for increased efficiency, the recent international conference at Ottawa suggests that a gap remains between required and available technology. The PIOS, Lockheed, and FRIS systems all have efficient sorting routines as part of their overlay structure. Beyond this improvement, we are unsure of how to increase polygon overlay efficiency.

It should be noted that a number of inherent problems exist in the general procedure of polygon overlay. The most important of these deals with the statistical significance of overlay from any two sets of "assumed" homogeneous polygon sets. While the literature concerning this applied technique is substantial, there have been very few investigations into the basic validity or reliability of the overlay approach. This has significance, not only in the realm of hand cartography, but particularly in the arena of automated resource data banks.

The production of reliable results from polygon overlay is intrinsicly linked to the basic assumption that each polygon is spatially homogeneous in terms of its descriptive attributes. If one dismisses maps of data polygons such as census tracts, traffic zones, or other arbitrary areal units wherein the polygon attribute descriptions are homogeneous by definition, then the map which contains truly homogeneous descriptions is very rare.

Furthermore, if initial polygon maps such as soils or geology are not homogeneous, then the map polygons computed from overlay are likewise not homogeneous summations of the input polygons.

This problem of non-homogeneity stems from a basic generalization of all maps, resulting from inability to unwillingness of the map maker to allow enough complexity of line in the definition of the polygon.

Research by the CSIRO in Australia indicates that when overlaying polygons of three maps having the same geographic aspects, only 38 percent of the time could it be predicted that all of the variables said to be present at a single point were actually there. The substantial error is caused by assuming homogeneity within the zone classifications. This should make the casual user of polygon data beware of assuming absolute information.

The results of the Australian experience places a great deal of the so called "natural resource planning methods" in suspect. Certainly one might question approaches such as those advocated by McHarg, Lewis, or Hills when analyzed in the context of non-homogeneous zones.

Although this information makes the universal application of the polygon overlay technique questionable, the problems are not severe for many applications such as the summary of a single variable (soils) into a set of areal unit polygons (traffic zones). However, the analyst should examine each project application carefully to avoid creating invalid interpretations.

A third application for polygon data systems involves the capability to derive a multitude of grid cell data banks. As previously illustrated in the section discussing the GRID system, various agencies and research planning groups have found that although grid cell data banks are useful, they do require a good deal of typically manual data collection. In addition to the large job of initial data collection, the grid cell data banks are frequently developed for a single application; therefore, the cell sizes differ in a range from 1/4 of an acre to one kilometer. The data collected for one type application may be virtually useless for a study demanding greater or lesser detail.

Usually polygon data is collected in the lowest common denominator (i.e., the complete polygon) and can, therefore, be aggregated and averaged into any areal unit desired. Data collected in this form can be used for many types and scales of information requirements. ESRI has recently written a program entitled GRIPS which, with a single pass of a polygon data file, creates a grid cell data bank of any cell size. This technique should prove useful for a host of environmental and planning studies that involve the smaller scale grid techniques.

The fourth and most obvious use of polygon data is the calculation of area and centroid information for the polygon.

C. Single Point Description

The point identification technique involves the use of an x,y coordinate point to represent the spatial location of various types of phenomena.

The following is a discussion of major classifications of use for the single point: area representation, sample point location, and specific facility event or statistic location.

1. Area representation is the referencing of a polygon such as a land parcel, city block, or census tract with a single x,y coordinate. This reference point might be the visual centroid, the mathematical centroid, a weighted centroid or any other logical location which could meaningfully represent an area. These coordinates are frequently used for thematic computer maps (contour or proximal). An example is the mapping of census data. This technique is based on the theoretical assumption that data attributes collected in polygon areas can be represented by a single point in space.

   In the design of parcel information systems, a point is frequently used to identify each parcel. This procedure allows for the aggregation of parcels into a coordinate specified areal unit such as census tracts, health planning districts, etc.

2. Sample Point Location - A second use for single coordinate points is the geographic location of sample observation points. This technique is based on the assumption that single point observations of the environment can provide patterns of data which, when observed in total, provide a meaningful picture of geographic phenomena. An example of this is air pollution monitoring stations wherein air contamination is periodically measured using various devices. The air pollution data collected from these stations can be mapped using a contour mapping technique for producing representations of a continuous data surface. If the geographic coordinates for monitoring stations are calculated, a user can input the measurement data into a standard computer mapping program such as SYMAP and very easily produce thematic displays which depict the geographic distribution of air contamination. This sampling technique is essentially the same as that used by the field surveyor who, with the use of various instruments, samples topographic elevations for the purpose of interpolating a computer map.

3. Specific Location of Facilities, Events, or Statistics - The third use for single point identifiers involves the detailed or specific location of some geographic phenomena (e.g., facility, event, or statistics). An example of this might be the reasonably accurate location of a fire hydrant or of an automobile accident. Aggregation of point information is another valuable use of point data. Incidents occurring at specific geographical point locations can be easily aggregated, using a point-in-polygon algorithm, into polygon zones (i.e., traffic zones). This data can then be used for comparative statistical or single variable analysis. This analysis requires the digitizing of the x,y coordinates of each point incident, then running the point-in-polygon program to calculate the position of those points relative to the various polygons in the data bank. The proper point information is then allocated to each respective polygon. The summarized polygon data is then usable for statistical analysis or computer graphics.

Computer Mapping of Point Data

There exist a host of software programs for the manipulation and graphic production of point coordinate data. The following discussion reviews those systems that can produce maps of proximal and contour data.

SYMAP, Autogen, and AUTOMAP II are three programs that generate thematic displays on a standard chain line printer. (For a more detailed discussion of these programs, refer to the previous section on Polygon Identification.)

The following is a review of several important points that should be understood when attempting thematic displays from single point data.

The user must be sensitive to the theoretical basis of contour mapping. This form of display is designed to depict phenomena having properties of a continuous surface (e.g., temperature, topography, air pollution, etc.). The properties of qualitative data such as land use or housing data (and even many quantitative demographic variables) are typically associated with discrete areas and should not be interpolated onto a continuous surface.

Proximal mapping is a method whereby non-continuous data can be mapped using a single data point as the spatial identification technique. This mapping type (available in SYMAP and AUTOMAP II) involves the formation of polygons based on the nearest distance of any grid cell to an identified x,y coordinate. Technically, this is done by using an interpolation routine with only a single data point used for calculating the value of any given grid cell. The computer program searches the area surrounding each grid on a printer map until it finds the nearest coordinate and then assumes for that grid the value associated with that point.

Although the proximal mapping technique is useful in gaining insight into the generalized pattern of data, it does not have the accuracy properties that are available when polygon definitions have been specified. Proximal mapping falls under particular criticism when there is a wide range in the size of polygons that are being approximated by the single point.

In addition to the above mentioned mapping types, there are several other programs in existence which display contour or surface data on a pen plotter. An example of output from a surface display program is presented in Figure 4. One of the distinct features of this program is that it is capable of deciding which parts of a surface being viewed can be seen, and which are hidden from view. This program uses as input a grid matrix of absolute data generated by SYMAP, AUTOMAP II, or hand grid cell coding. These three-dimensional views provide the framework for certain intuitive understandings of data that are not entirely possible with a two-dimensional map.

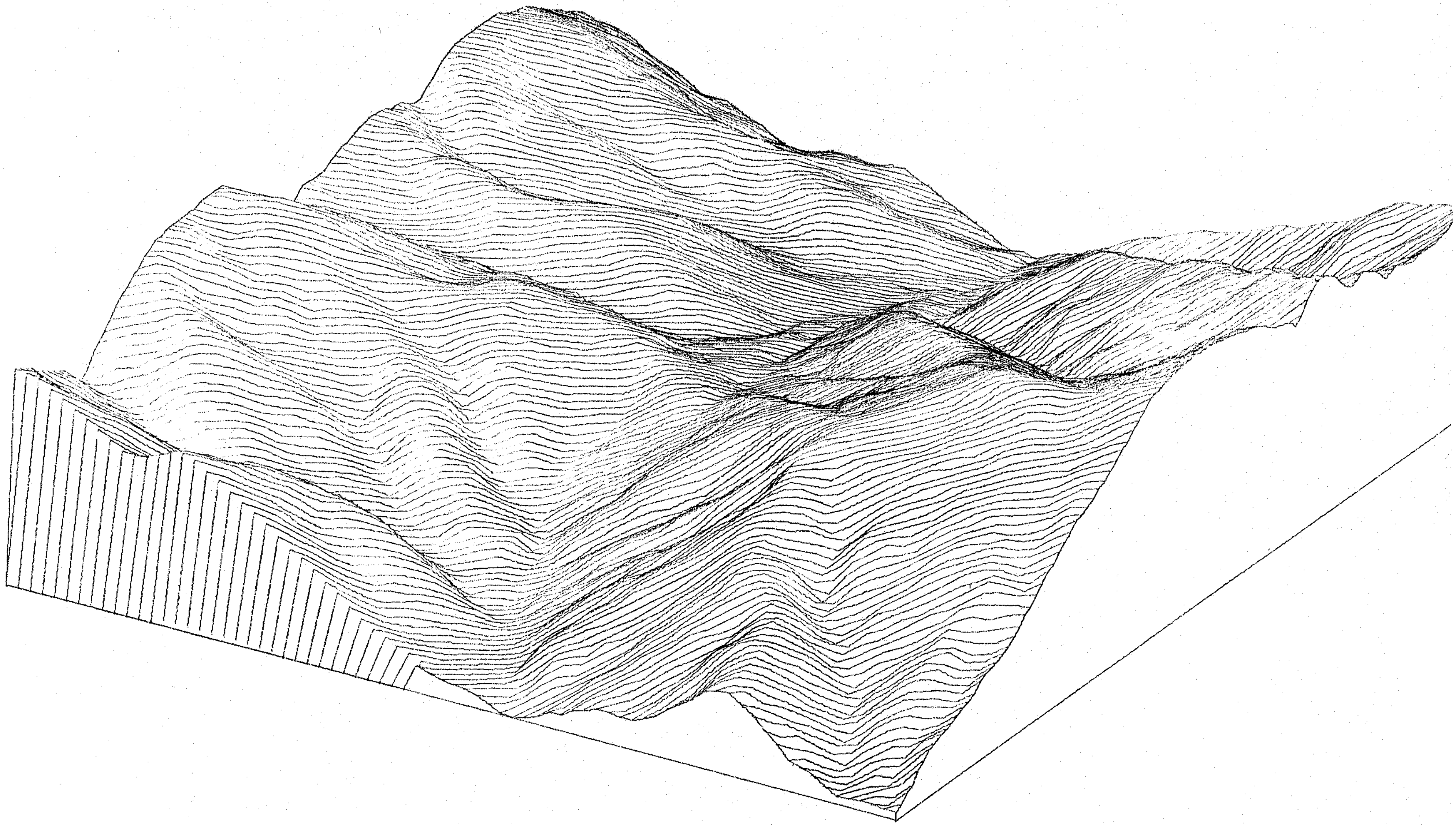
A second plotter program is called TOPO. This program generates two-dimensional pen drawn contour maps on a standard pen plotter. Like SYMVU, TOPO also requires a grid data base file such as generated by SYMAP, AUTOMAP II, or any other similar surface interpolation routines which produce a grid matrix of data. TOPO runs in small core (32K) and has numerous options for scale, legend, line suppression , etc., available. TOPO was developed by and is available from ESRI.

IV. Summary and Conclusions

The previous review of alternative techniques focused on many issues, techniques, applications, and costs. Its objective is not to define the "best" or "worst" system, but rather to classify the actual experience associated with the use of each system.

When looking at any type of spatial identification technique, it is important to consider the desired objectives. Experience has demonstrated that the application of the previously presented techniques should be carefully reviewed prior to any system design. One can, however, make several general comments about the attributes of each spatial identification system. These comments are summarized below.

The polygon system provides extremely accurate data (depending on accurate digitizing). For various types of analysis procedures such as map overlay, the results can be calculated with great accuracy. On the other



HIRAYU TØGE VIEWED FRØM THE NØRTHEAST

FIGURE 4

hand, the grid cell method, although not as accurate as the polygon approach, has many efficiency advantages from the computational and modeling standpoint, resulting in a very useful technique for "broad brush" modeling of activities and systems. The joint system, in a thematic sense, provides for a very generalized and interpolated framework for analysis.

In many cases the three systems can be used together; that is, the complete polygon can be encoded and stored as a unit having the grid cell and point information computed from the polygon storage. In this way, the original polygon data can be kept complete in its original form (lowest common denominator). This is a truly meaningful framework for long range multi-disciplinary data bank design efforts.

The justifications for developing an automated geographic information system are many, but they are normally based upon one or both of two general parameters: cost effectiveness and increased analysis capability. The decision by an agency to move ahead with a polygon approach is usually motivated by the desire to develop the long range capability that this system can provide. The use of grid cell data focuses on applications where data generalization to the size of the grid cell is acceptable. Typically, this is allowable for quick "one shot" studies that do not require long term data bank flexibility in scale and application.

Previous discussions on aggregation and computer mapping make clear that single point data is particularly useful in the identification of relatively small geographic phenomena such as parcels. When using point data, the larger the scale, the greater amount of data interpolation and, as such, greater amounts of generalization must be accepted.

DEVELOPING REGIONAL WATER SUPPLIES -- A CASE STUDY OF SOME ANALYTICAL PLANNING METHODS

By

Paul E. Pronovost [1]

INTRODUCTION

Water resource planning and analysis in the last few years has undergone a dramatic shift in complexity, emphasis and priorities. Whereas, in the past, study efforts were directed toward technical engineering design features of the "plan," today, the majority of effort is expended in determining alternatives with an assessment and evaluation of their impacts. The reasons for this shift in direction can be found in the planning requirements of the National Environmental Policy Act of 1969, Section 122 of the Rivers and Harbors Act of 1970, and the "Principles and Standards" of the Water Resources Council.

All of the water resource planning performed by the Corps of Engineers is undertaken to provide information so that decisions can be made in an informed and rational manner. The continuation of this Corps role coupled with the necessity of examining a wide range of alternatives and their associated impacts, therefore, requires the development of techniques which allow for rapid and accurate analysis. In addition, display techniques which allow review and evaluation of the alternatives and impacts are needed so that meaningful public participation may be gained.

Purpose

The purpose of this paper is to present as a "case study" a recently completed regional water supply study which was conducted within the New England Division. The study, a pre-authorization detail effort, was undertaken from July 1970 to July 1972. Neither Section 122 nor the Principles and Standards had been adopted formally at this time. However, since it was anticipated that both requirements would be in force prior to completion of the study, they, together with NEPA, were included in the study efforts.

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[1] Supervisory Civil Engineer, Northeastern United States Water Supply Study, New England Division.

The case study method is used in the paper to provide the seminar participants the types of issues together with necessary impact analysis and evaluation which water resource planners must respond to in today's environment. Examples of analytical methods applied in the "case study" are discussed and shortcomings of some methods described. Possible areas which appear to be candidates for further development of analytical methods are discussed using experience gained in the case study.

CASE STUDY - DEVELOPING REGIONAL WATER SUPPLIES

Planning Process

Historically, the planning process for water resources development was essentially a linear function. Generally, a need was considered a "given," alternative plans to meet the need were evaluated by the agency staff, a plan was then selected and presented to the public.

The advent of NEPA, Section 122 and the Principles and Standards has required a reworking of this traditional planning process. In particular, the restructuring had to accomodate the increasing emphasis that is being placed on public involvement and non-monetary impacts.

One process[1] which appears to respond to the current planning needs consists of four planning activities as shown in Figure 1; namely, Problem Definition, Formulation of Alternatives, Impact Analysis, and Evaluation. In the case study, this type of iterative planning process was utilized with some degree of success.

Background for the Case Study

The recent sixties' drought in the Northeastern United States was the most intense in the region's recorded climatological history. The 89th Congress, in response to the possible economic damage which the drought could create, enacted the Northeastern United States Water Supply Study (NEWS) on 27 October 1965.

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[1] Impact Assessment in the Water Resources Planning Process, June 1973, unpublished, by Leonard Ortolando, Assistant Professor, Department of Civil Engineering, Stanford University.

A series of investigations revealed a limited number of regions within the northeast faced almost immediate shortages. One of these regions was southeastern New England, a plan of which is shown on Figure 2.

Within southeastern New England, a large percentage (30%) of the population is serviced by the Boston Metropolitan District Commission (MDC). The MDC maintains three major reservoirs and a connecting tunnel aqueduct as its supply sources. This system of reservoirs, as shown on Figure 2, includes as its backbone a reservoir in the Connecticut River Basin. This reservoir (Quabbin) provided grist for a 1930's interstate water dispute between Massachusetts and Connecticut which was finally resolved by the Supreme Court.

A feasibility detail of alternatives for supplementing the existing supplies of the regional supply system was carried out in 1969. Following review by Federal, State and regional agencies, together with local and environmental interest groups, a consensus was reached on some projects which should undergo survey detail investigation. Included in these projects were two which would involve interbasin transfers of water from the Connecticut River Basin to the metropolitan Boston region (see Figure 2).

As discussed earlier, the planning process which was used consisted of four tasks; namely, Problem Definition, Formulation of Alternatives, Impact Analysis, and Impact Evaluation. The four planning activities were carried out simultaneously, not sequentially. Thus, the planning was, in essence, an iterative process in which the four activities are carried out continuously, but with increasing degrees of refinement. For example, in early stages of planning, problem definition receives a high proportion of effort, while in later stages, the impact assessment and evaluation phases provide the major tasks.

Some of the elements which surfaced during the investigations are shown in Table 1. Many of these elements were garnered from meetings, discussions, correspondence, etc., from the public and various interest groups. In some cases, the problems, as perceived by these groups, go well beyond those technical questions which would have been addressed in a traditional water supply study; e.g., need for water-based recreation,[1] termination of natural flooding cycle, regulation of demand.

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[1] Water supply reservoirs are rarely used for recreational activities in New England.

TABLE 1

Problem Definition	Alternatives	Impact Assessment	Impact Evaluation
1. Water supply demand is in excess of yield	1. Diversion from Connecticut River	1. Estuarine ecology	1. Private Citizen
2. Misuse of available supplies	2. Ground-water	2. Reservoir ecological investigations	2. Ad hoc organizations
3. New supplies create unwanted growth	3. Watershed Management	3. Economic costs	3. Environmental interest group
4. Economy will suffer without new supplies	4. Wastewater Reuse	4. Socio-economic impacts	4. Basin action group
5. Additional recreation opportunities needed	5. Pricing to reduce demand	5. Effect of groundwater on cranberry bogs	5. Town and city governments
6. Reservoir ecosystem will be destroyed	6. Desalting	6. Downstream supply needs	6. Regional planning agencies
7. Groundwater will be depleted by river diversions	7. Weather Modification	7. Riverine ecosystem	7. State officials
8. Natural flood cycle will be terminated	8. Other river sources	8. Anadromous fish restoration	8. State Governors
9. Supplies necessary for downstream needs will be diverted	9. Restrictions		9. Regional commission
			10. Federal agencies
			11. Corps staff
			12. State legislators

As illustrated by the case study experience, the problems (or issues) which the planner had to address ranged from physical means of providing new supply to insuring future generations of downstream users that their supply needs would be provided for. Some of the alternatives considered for dealing with the issues included structural measures, such as developing to groundwater supplies to regulatory actions which would restrict or limit supplies made available to the consumer.

Impact assessments of the alternatives required skills from a variety of technical disciplines such as marine biologists and social scientists, geologists and economist, engineer and environmentalist. Each of these skills even while working on a team effort generally has a favorable bias toward their field or specialty, and care is required that this bias does not influence the assessment. For example, marine biologists working on the staff were extremely interested in gathering data on euryhaline species in the estuary, while other areas of concern such as adjacent salt marshes received less attention. Similar professional leanings were also evident in other disciplines.

Evaluation of the impacts associated with the alternatives proved to be particularly difficult. As shown in Table 1, public participation encourages project evaluation from a wide variety of interests and viewpoints. Whether an impact was considered positive or negative depended upon the interests of those affected by it.

Analytical Methods Used

As the case study demonstrates, the planning process followed today leads to a large number of problems to be addressed, alternatives to be investigated, impacts to be assessed and evaluations to be made. In order to perform these tasks, use of various analytical models which would allow rapid and accurate analysis of each alternative and its impact is highly desirable. Unfortunately, no such single panacea method exists today. Instead, the water resource planner, much like a carpenter or other tradesman, calls upon specific tools to perform specific tasks. Once the individual pieces have been completed, careful assemblage allows the process to be viewed as a whole.

In the case study, both simulation models and physical models were utilized as analytical techniques. A description of some of the models employed follows:

COHART

A computer program[1] for estimating costs of hard rock tunnels. The program is designed to duplicate the thought and reasoning processes that take place in the detailed planning, design, quantity take-off and estimate of cost of an actual tunnel - shaft system. A number of cost components (such as excavation) are selected together with factors (such as tunnel design, methods of construction and geologic conditions) that affect the magnitude of each of the cost sub-components. The resulting relationships are then drawn upon to yield cost estimates for construction.

Utilization of COHART was used extensively in the case study in the formulation of alternatives and impact assessment tasks. Alternative alignments and diameters using both conventional and mole excavation techniques were investigated. Since extensive tunnelling was a major cost item in several alternatives, this model proved extremely useful in providing reliable cost data for economic impact assessment of alternatives.

Input requirements for the model include physical factors such as tunnel size, rock strength, water inflow and rock quality and construction methods factors such as muck transport, excavation methods and advance rate. Output from the model included calculated tunnel and shaft data, tunnel - shaft segment and reach costs, and cost summaries. All input data necessary can be furnished by technical skills present in District and Division level Corps offices.

NEWSX

A computer simulation program for analyzing complex integrated water supply systems for a historical flow record. Given historical streamflows and prescribed operating rules as input, the program computes transfers, downstream releases and changes in storages up to 20 points of interest in a system. The program was written by New England Division personnel for an IBM 1130 computer. Because of limited core storage, the program was written as several sub-programs and routines.

Operation of the systems analyzed was based on a daily time increment. Output from this program was then fed into a second model which simulated major existing reservoir storage on a

[1] Developed by Harza Engineering Company for the U. S. Department of Transportation.

monthly time increment. The basic steps performed in the program: (1) determine downstream flow releases; (2) adjust storages for downstream releases; (3) determine transfers based on transfer capacity, water availability and respective priorities at receiving storage sites; (4) adjust storage for transfer and spillage, if any. Since the system to be simulated included two large existing reservoirs, real life operational considerations had to be included in the model. A priority routine was used to determine the amount of water to be transferred between reservoirs.

Output from the simulation program included "safe yield" estimates for the alternatives considered. Marriage of output from COHART and NEWSX allowed rapid economic analyses as part of the alternatives impact assessment.

In addition to COHART and NEWSX, the case study also used two other computer simulation models to aid in the analysis of alternatives. These are SOCIO and ESTUEN.

SOCIO is a computer simulation model which analyzes the adjustments in a metropolitan region necessary to equate available water supply to water demands which exceed the supply. Downward adjustments in demand through restrictions are translated to economic losses for the region. Output from this model thus allowed the establishment of a "market value" for water supplied from any of the alternatives.

ESTUEN is a computer model which analyzed riverine water temperature differentials which might occur if upstream diversion alternatives were implemented. Output from the model was then used by marine and freshwater biologists to determine environmental impacts which might occur.

SUMMARY AND CONCLUSIONS

The time has passed when a decision to provide flood control, water supply or other resource developments involves a project formulation and an evaluation of available hydrologic data, project benefits and economic costs. Today, water resource planning and analysis is a complex inter-disciplinary process. Certain of the tasks in the planning process such as impact assessment and evaluation are more an art than a science.

As discussed in the case study, problem definition with the aid of public participation often goes well beyond what traditionally would have been considered "fair game" in a water supply study. In turn, this broadening of the issues which are addressed by a study also is reflected in the formulation of alternatives, impact assessment and evaluation tasks. As a result, the planner today is required to identify, assess and evaluate a multitude of alternatives.

Alternative actions, for example, considered in the case study vary from such non-structural measures as pricing to reduce demands and regulatory restrictions to structural yet less traditional techniques such as wastewater reuse and desalting. Impact assessment required to forecast changes associated with the alternatives varied from traditional economic considerations to environmental and socio-economic costs (both direct and indirect). Impact evaluation was made by a spectrum of interests from the local citizen whose land would be taken by the alternative to state governors who must concern themselves with the interests of the entire state. Each of these interests views must be included in the ranking of the various alternatives.

As indicated by the case study, the planning process now under way in Corps studies requires a new generation of thinking regarding approaches which can be used to sort out and order the myriad of physical, social, economic and environmental parameters in a study.

Four of the models used in the case study were described. Use of both COHART and NEWSX proved to be most valuable in the alternative and impact assessment tasks of the study. It would be less than frank to indicate that equal confidence levels were enjoyed while using SOCIO and ESTUEN. Both of the latter models were based on a number of assumptions which were forced to rely upon limited data bases. This data base shortcoming was not occasioned by general lack of data (e.g., population, income, river temperature, etc.). Rather, the shortcoming was caused by the scarcity of information regarding the relationships (or cause and effect) between an action and, for example, a socio-economic response. The lack of hard data on such relationships was not unexpected, but nevertheless it did impair the analysis.

Future needs in water resource planning which analytical methods may serve can be viewed in two general ways. First, an improvement in the techniques used in the analysis of alternatives in kind as well as alternatives in scale. Second, physical and social scientists working closely with system engineers should develop those cause and effect relationships upon which future analytical models may build.

REFERENCES

1. Northeastern United States Water Supply Study, Millers River Basin Water Supply Project, March 1973, by the New England Division, Corps of Engineers.

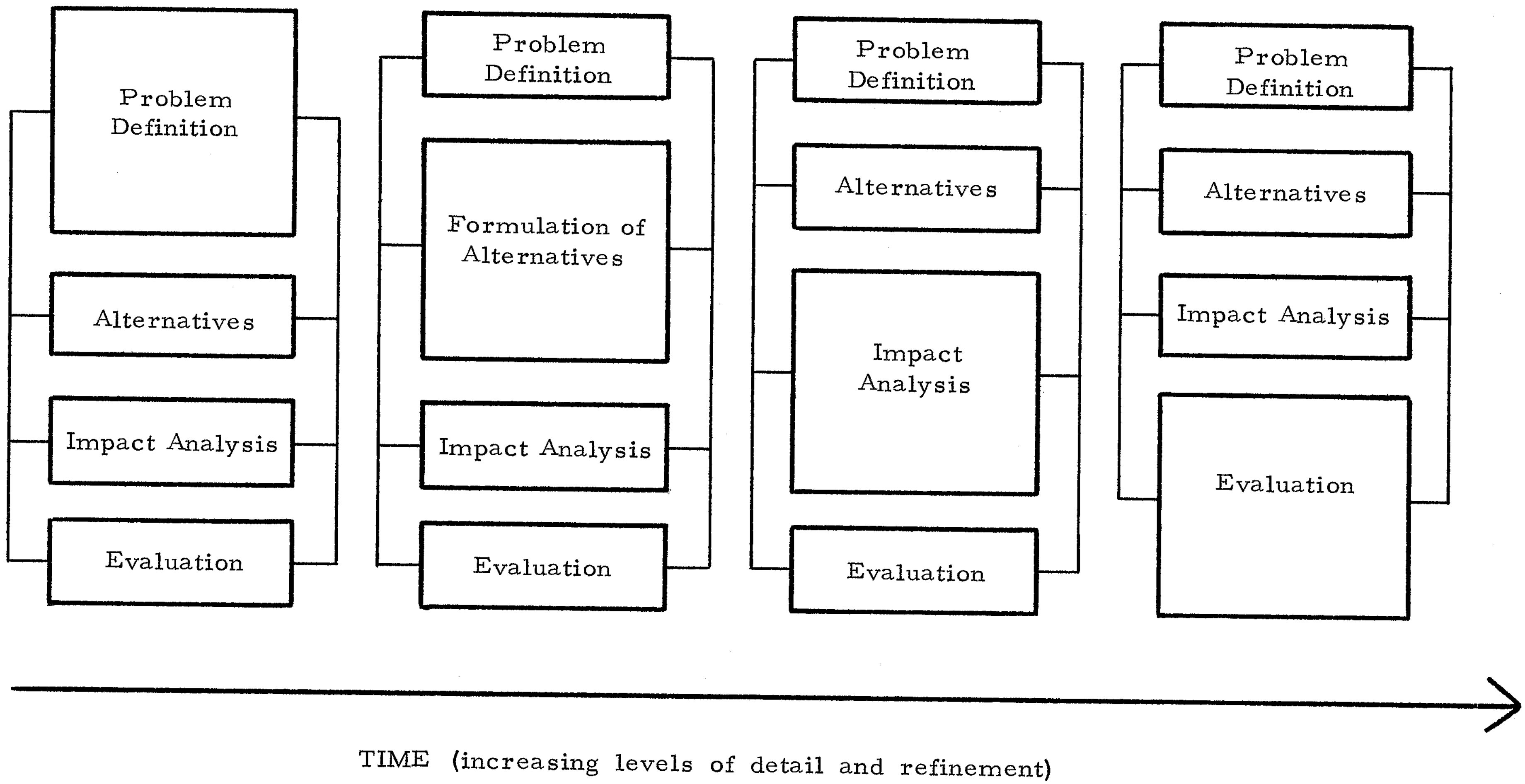
2. Identification and Assessment of Social and Economic Impacts -- Connecticut and Millers River Basin Diversions, Abt Associates, Inc., June 1972, Prepared for the New England Division, Corps of Engineers.

3. Possible Effects of Various Diversions from the Connecticut River Estuary, Essex Marine Laboratory, Inc., May 1972, Prepared for the New England Division, Corps of Engineers.

4. A Computer Program for Estimating Costs of Hard Rock Tunnelling (COHART), Harza Engineering Company, May 1970, Prepared for Office of High Speed Ground Transportation and Urban Mass Transportation Administration, Department of Transportation.

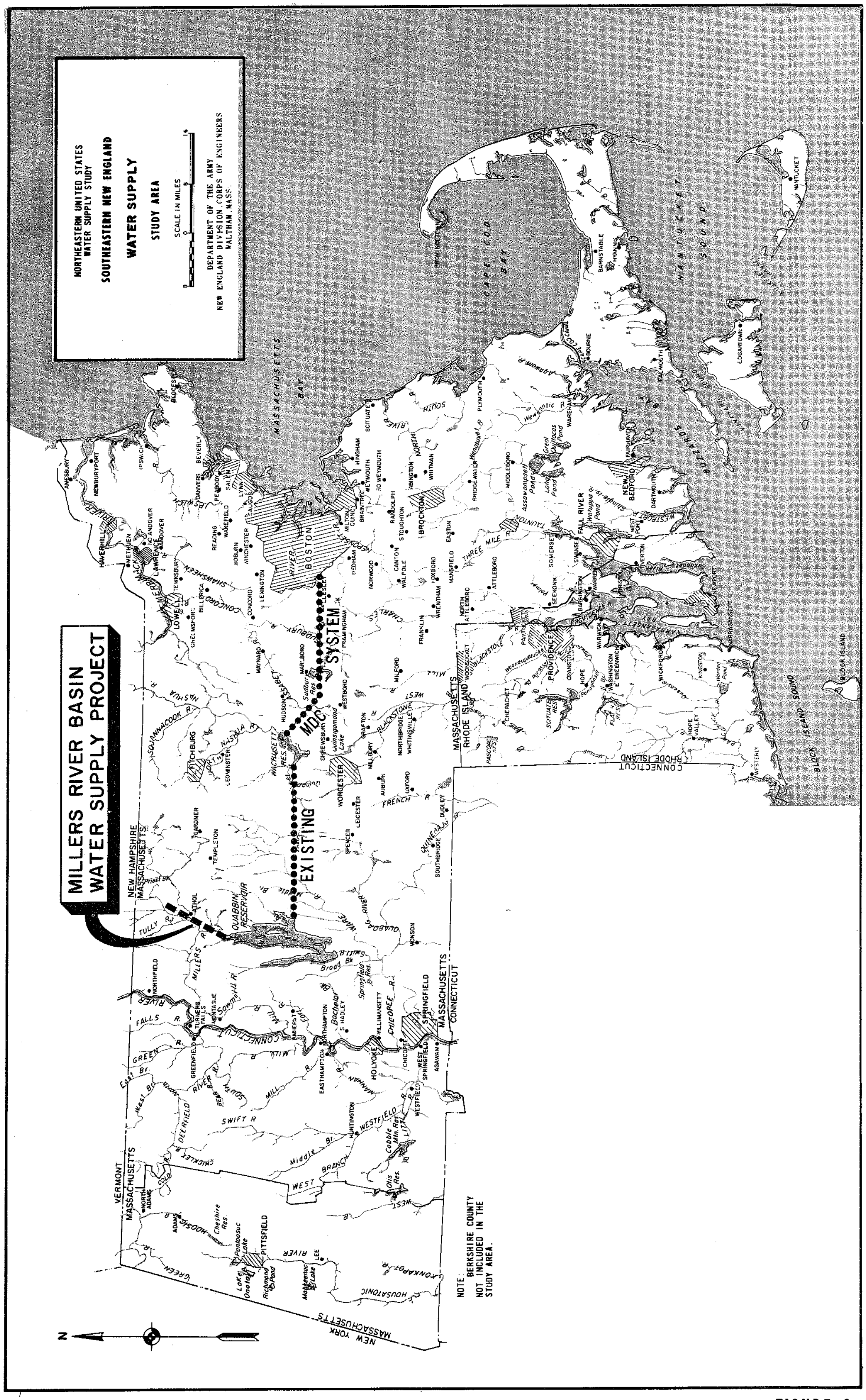
5. Ecological Study -- Merrimack River Estuary, Massachusetts, Normandeau Associates, Inc., November 1971, Prepared for the New England Division, Corps of Engineers.

6. Impact Assessment in the Water Resources Planning Process, June 1973, by Leonard Ortolando, Assistant Professor, Department of Civil Engineering, Stanford University, Stanford, California, Unpublished.



A Suggestive Representation of the Planning Process Over Time (by Ortolando)

FIGURE 1



NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY
SOUTHEASTERN NEW ENGLAND
WATER SUPPLY
STUDY AREA
SCALE IN MILES
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
WALTHAM, MASS.
MILLERS RIVER BASIN
WATER SUPPLY PROJECT
EXISTING MDC SYSTEM
QUABBIN RESERVOIR
WACHUSETT RES.
BOSTON
PROVIDENCE
SPRINGFIELD
WORCESTER
MASSACHUSETTS BAY
CAPE COD BAY
NANTUCKET SOUND
BUZZARDS BAY
BLOCK ISLAND SOUND
NOTE: BERKSHIRE COUNTY NOT INCLUDED IN THE STUDY AREA.

FIGURE 2