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THE ALLOCATION OF WATER RESOURCES PROJECTS METHODOLOGY: A MODEL FOR THE ALLOCATION OF FUNDS FOR THE DEVELOPMENT OF WATER RESOURCES

Submitted to

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CHAPTER I

INTRODUCTION

Purpose of the Study

The purpose of the study to be outlined below was analyzing and evaluating the present methods used in the allocation of funds for all levels of water resource development and formulating a new, different and more suitable allocation methodology. Particular emphasis was placed on incorporating a goal-oriented model to provide predictions of future water resource demands and on utilizing systems analysis techniques for determining the allocation of funds for development of water resources. The goal was full resource development. If one can state one's future goals quantitatively, the model can formulate an efficient program of water resource development which will enable one to meet the water resource needs necessary to achieve those goals.

Survey of Methods for Allocation Of Funds for Water Resources Development

Scope of the Survey

The initial effort of the survey involved becoming familiar with the procedures widely used in the allocation of funds for water resources projects, outlined in "Policies, Standards, and Procedures in the Formulation, Evaluation, and Review of Plans for Use and Development of Water and Related Land Resources" (1962), which will, hereafter, be referred to as Print 97. The available literature on the Planning-Programming-Budgeting System (PPBS) was reviewed. The procedures proposed by the Water Resources Council and outlined in "Procedures for Evaluation of Water and Related Land Resource Projects" (1969) were also studied in detail.

Meetings were then held with individuals from each of the three main water resource agencies: The Corps of Engineers, the Soil Conservation Service, and the Bureau of Reclamation. The purpose of these meetings was to become more familiar with the procedures used in actual practice by each agency in the development of water resources. Visits were made to the offices of the Bureau of Reclamation in Oklahoma City, Oklahoma, the offices of the Soil Conservation Service in Stillwater, Oklahoma, and the offices of the Corps of Engineers in Tulsa, Oklahoma, and Dallas, Texas. It was felt that the Corps of Engineers afforded the most general view of current methodology. The Corps has the largest water resource development program; it encompasses the greatest variety of projects; and it had pioneered the present rules for water resource development. For these reasons, their system was studied in greater detail than the others. Early in the development of the model for allocating of water resource funds, J. J. Tozzi, Operations Research Specialist for the Secretary of the Army, came to the University of Oklahoma campus and outlined the development of PPBS in water resource systems. In addition, some investigators also participated in the

Water Resources Council's test of its proposed procedures for the evaluation of water and related land resource projects. The procedures used in the formulation of a water resource project of the Soil Conservation Service were examined, and the project was evaluated using the proposed procedures.

Findings of the Survey

Two major areas where the methods currently being used in the planning and evaluating of water resources are inadequate were found. The first area involves being unable to measure all of the effects of water resource projects. The second area of difficulty arises from viewing projects as isolated events and not parts of a total system.

Measurement of Project Effects

Currently, the effects of water resources projects are evaluated in a national income account by means of their B/C ratios (the ratio of benefits produced by a project to the cost of construction). In theory, the benefits of a project are increases in value of goods and services to the nation which result from conditions created by the project. Induced costs (all uncompensated, adverse effects caused by the construction and the operation of a project) and associated costs (the value of goods and services over and above those included in project costs needed to make the immediate products or services of the project available) must be subtracted from benefits.

The actual method of measuring benefits of a project varies with the type of benefit being considered. Water supply and water quality benefits are expressed in terms of the cost of construction and operation of the next expensive alternative. Irrigation and navigation benefits are the net increases in income to those persons directly benefiting from the project. Flood control benefits are the reductions in property damage due to flooding. Recreation and fish and wildlife benefits are the values of the improvements as measured by the number of users of the project times some unit value of the recreation. In general, the validity of measures of benefits is highly questionable and limited to a narrow range of project effects.

Project costs are taken into account in two ways. In some cases, such as in projects involving irrigation, associated costs are deducted from the corresponding benefit. The second way involves considering costs which are more directly related to the project (the costs of construction, operation, loss of mineral production due to inundation, and relocation of transportation facilities). These costs are added to the cost of construction of the project. All project costs are expressed in monetary terms.

Basically, B/C analysis seeks to overcome the previous reliance on profits (net benefits) in public enterprises as the criteria for comparison of alternatives. It attempts to approximate the results of an analysis using true benefits and costs more closely by using a ratio as opposed to a difference.

Recently, the Water Resources Council has attempted to rectify some of the inadequacies inherent in the current procedures of B/C analysis, as a result, and has suggested the formulation of the following additional accounts: a regional development account, an environmental account and a well-being account.

These new accounts were proposed in response to a need to "beef up" benefits. The Bureau of the Budget wanted to increase the discount rate used in B/C analysis by calculating it on an opportunity cost basis which would, in effect, increase project costs.

The new regional income account would be similar to the national income account except the B/C ratio would be net for the region instead of net for the nation. The environmental and well-being accounts would account for impacts of the project on the environment and on the well-being of the nation respectively; however, no methodology has been developed for the implementation of these two accounts. The three additional accounts would presumably have the same relative importance as the national income account has.

As opposed to the use of the B/C ratio for evaluation, net benefits (benefits minus costs) are used in the formulation of individual projects. In general, the goal of a planner is to maximize a project's net benefits while meeting whatever constraints he deems appropriate.

The Viewpoint of Plan Formulation

The conception and formulation of plans for water resource projects are usually made on an individual basis. Projects are considered in isolation and as having no relationship to each other or to an overall plan or program for development. This viewpoint is inherent in the present system of planning used by water resource agencies.

Most projects are the result of local or regional interest groups requesting that one of the water resource agencies solve a particular problem. In some cases, the agency can study the problem and do a limited amount of planning; these are usually rather small, limited projects. In other cases, the U.S. Congress must appropriate funds to study a particular problem. Once funds are appropriated, the problem is studied and a plan formulated to solve the immediate problem.

The California Water Plan (1960) was an attempt to look at the entire state's water situation at one time and, therefore, achieve an all-encompassing plan. The plan did offer an efficient solution to the stated problem of getting the water to the people but did not deal with other problems.

Recently, the Corps of Engineers and others have been trying to change the approach to water resources planning by using PPBS. This system is presently used as a mechanism for assigning priorities to proposed Corps projects. The priority a project receives is a function of a basin's needs and an equity term for a given area. The equity term is a function of several things including the amount of money for new projects the area has received in a five-year period. The needs of a basin are determined from the Corps' own estimates of needed water resources development.

The objective of the system, as it is currently used, is to assign priorities to the list of Corps' projects which have been authorized by Congress. The Corps suggests that federal investments in regional water resources development should eventually be made by such a system and that the regional funds should be reallocated to those agency programs for which priorities can be established.

Conclusions from the Survey

The problems of measuring project effects and considering projects as isolated entities are interrelated and are a result of changes in the philosophy of what federal expenditures should be made. The notion of the B/C ratio was developed after the Flood Act of 1936, and was formalized in "Proposed Practices for Economic Analysis of River Basin Projects" (1950). The B/C concept naturally reflected the Public Works' philosophy of that time; likewise, the method of plan formulation also reflected that policy and was geared to use the B/C ratio. When the B/C ratio and the accompanying method of plan formulation were being formalized, it was not a policy of the federal government to fund flood control and other water-related projects if their cost was greater than their worth. As time went on, more and more aspects of water resource projects were taken into account. Today the policy of the government is that every conceivable aspect or impact, from economic to social to ecological, should be taken into account. As a result, the use of the B/C ratio was extended well beyond its original scope and past the point where it produces valid measurements. With the changes in the use of the B/C ratio, the scope of plan formulation changed reflecting the changes in B/C analysis.

The current problems in formulation and analysis are not due to ill-conceived concepts. They are due to continual modification of sound methods to the point where they are not suitable for employment with today's concepts, which are called comprehensive planning. This concept provides for equal treatment of all ten possible benefits in a project. It does not address itself to the optimal use of the resource, which might be a project with a single benefit. The forced development of all benefits waters down the total benefits of the project and precluded its optimal use. By looking at regional development, sub-system optimization is possible.

Finally, in order to do resource planning, one must develop each project to its full capability. This cannot be done using B/C analysis unless the time frame is stretched to infinity or as is now done, 100 years. This is essentially dishonest because one is considering all the benefits available at the present time but spreading costs out over a long period of time.

A fresh approach to planning is needed that responds to the current and probable future philosophy of resource development.

The Proposed Methodology

As a result of the survey, it was decided that a new approach to water resource development was needed and not just a modification or extension of the present methodology. An extension and/or modification of the methods currently used would only hinder the sound and efficient development of water resources by adding more data to the already excessive data not being generated than could possibly used. A tool was needed which could be used by a planner to generate possible programs for future national and regional water resource development. It was desirable that the new method should employ the techniques of systems analysis at all levels and should not use some measure of effectiveness requiring the conversion of all tangible and intangible aspects of development to a dollar value. The tool decided upon was a computerized model consisting of two parts: a goal-oriented needs model and a consumer-oriented allocation model.

The Concept of the Needs Model

As stated above, before the allocation model can be utilized, there must be a set of needs to be met. In order to supply these needs, a demand model was formulated based on the prediction of a basin's future population. This model is flexible enough to generate any needs related to the size and/or characteristics of possible future populations.

The needs model has the highly desirable characteristic of being responsive to identifiable goals. If it is decided that the per capita personal income for all basins should approach the national average by the year 2020 (a point 50 years in the future), the needs model will array what water resource development will be required to achieve the goal. It will also indicate the assumptions of what related developments must be made in connection with water resource development.

The Concept of the Allocation Model

Basic to the allocation model is the concept of meeting future needs or demands. While meeting all future demands is impossible with a limited budget, allocating funds to minimize the discrepancy between supply and demand (minimize the deficit) given a funding level or budget is possible. Allocation must take into account cross-sectional differences in geographic and demographic areas to assure an equitable distribution of federal funds. In order to accomplish these ends, the allocation model was developed using two levels, the basin level and the national level.

The basin level model sub-optimized the development of water resources in each basin by need category for a given budget, initial state of basin development and time. The optimization of the basin's development (minimization of the deficits of development) is largely a function of its needs and requires a valid estimate of them. The model is constructed in such a way that all quantifiable needs can be taken into account whether they are tangible or intangible, if the cost to fulfill that need can be determined.

The outputs of the basin level model form the basic data which the national level model uses to optimize the national development program. The outputs of the basin level model are weighted to take into account the geographic and demographic differences in basins and to assure an equitable treatment for all basins. The outputs of the national level model are a function of funding levels and, whereas the needs model arrays what water resource development will be required for achieving a goal, the allocation model displays the allocation of funds necessary to produce that development and the amount of development that would be achieved if only a limited amount of funds are appropriated. If it is decided that the required development is not desirable or feasible, other goals and alternatives can then be looked at and evaluated until a workable solution is achieved.

CHAPTER II

THE NEEDS MODEL*

Introduction

The needs model is made up of a population model that supplies population data by attribute and an employment forecasting model that supplies economic and employment data. Both of these models feed into the needs model proper. The total population at time t is used via transducers to produce public sector requirements for water resources development. The cohorts can be used to provide additional disaggregation of these values and as a check to insure that requirements which are highly dependent on certain cohort characteristics of the population are satisfied. The industry cohort of the population model is used to provide an estimate of employment for comparison via shift analysis to the estimate developed by the employment forecasting model. Both the population and employment models start with the nation and disaggregate to the basin. The population cohort disaggregations are capable of decision criteria, while the employment disaggregation is essentially a step-down procedure, not a decision criteria.

The purpose of the needs model is to describe the system, and to develop public and private sector needs over time to achieve alternative

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*Based on a model developed for the Office of Water Resources Research by G. W. Reid, entitled "A Multistructural Demand Model for Water Requirement Forecasting" (1970).

goals, and to describe this in relation to probable futures without decision manipulation. The data inputs are of two general types, economic and population. The results are arrived at from population and industry by separate routes and are amenable to resolution; that is, the outputs become judgmental.

Unique features of the model are its emphases on outputs or goals and the comparison of what will probably happen to what could happen through public decisions, making it possible for decision makers to evaluate alternates to provide needs of people in both the public and private sectors. There are three points of comparison of possible values to probable values; they are (1) employment, occupation, and income comparisons, (2) industrial comparisons, and (3) population and service sector needs. The employment forecasting model values are compared to similar figures arrived at from the income and occupation cohorts of the population model through shift analyses; again, the output from this also is judgmental. These points of comparison provide the decision maker with a comparison essentially addressed to the questions of will an economic base provide a proper basin posture and what public sector expenditures are essential for full development?

As can be seen from the needs model format shown in Figure 2.1, the service sector is arrived at essentially through a transducer based on the ratio of service industry to basic industry over time. Public sector commitment can be further detailed or, in fact, validated by reference to industrial, occupational, and service requirements.

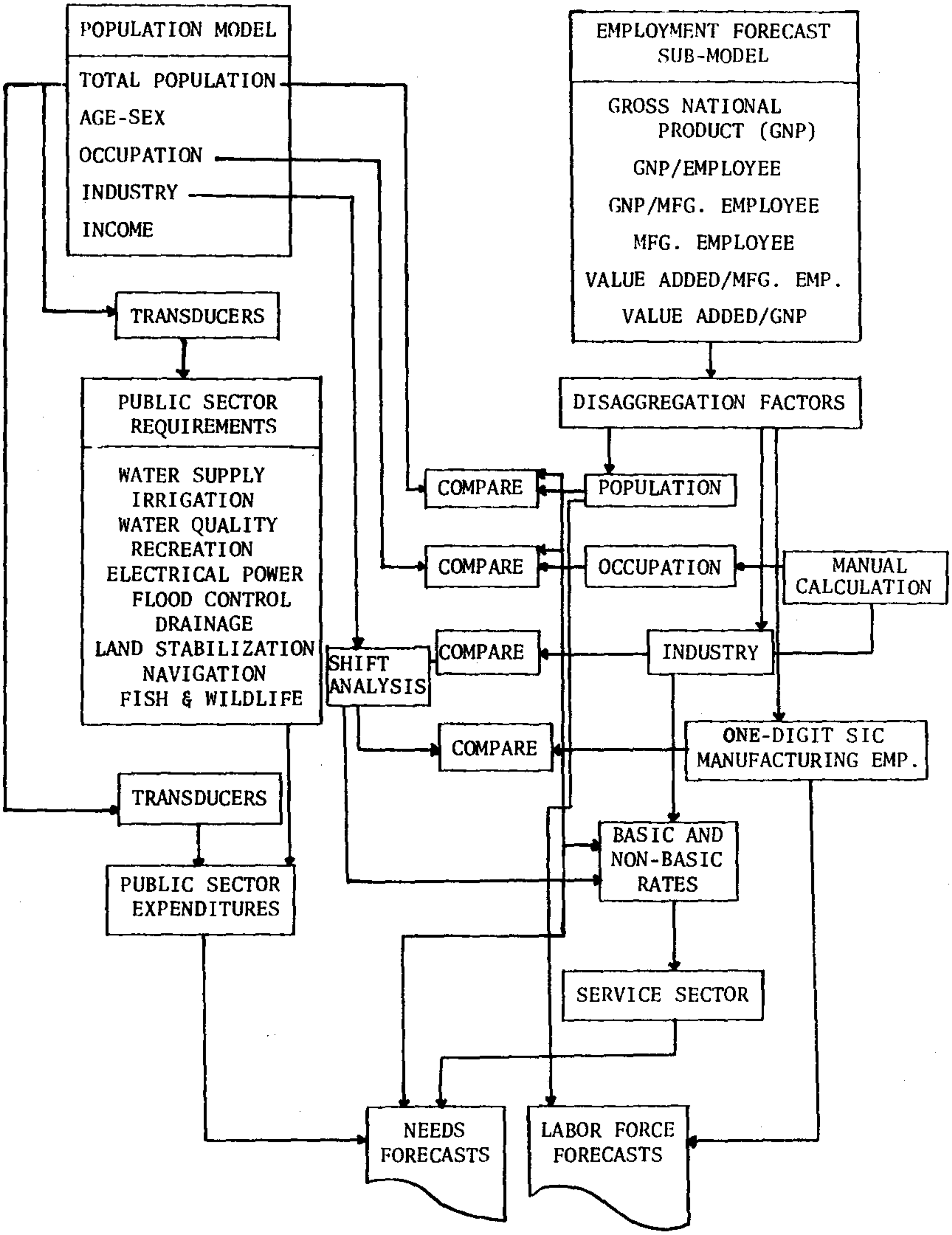

Figure 2.1. Needs Model Format

Again, judgments can be exercised.

This process says that something can be done through the decision process about one's growth, and a methodology to present the costs and benefits of alternate action that can be seen over time by the decision maker can be provided. The past is certainly not a goal criterion for the future of a basin; in fact, it is not really relevant if the basin is to become a viable institution. Predictions may be made based on the establishment of sets of goals and priorities envisioned as being desirable and reasonably obtainable. Given sets of goals, the public actions (costs) necessary for obtainment can be identified. Thus, the basin can now be seen as an intricate link in a viable system no longer constrained by history and tradition. The focus has been shifted from inputs to outputs, from static growth to dynamic interaction and action.

In this methodology, both the traditional and systems approaches are used. A look is taken at what will in all probability happen if things continue as they are verses what might happen and what it might cost if one "monkeys" with the machinery.

Components of the Needs Model

Population Model

The populations of the nation and basin are developed in this model by the cohort-survival population forecasting technique. Inherent in the population model is the difference in forecasting and predicting the population. Forecasting the population is actually growing the future population based on historic trends and continuing those trends into the future; whereas, in predicting, the population is not based on a continuation of historic trends but on goals of the area.

The nation's population is a forecast population based on cohort survival. The cohorts used are age, occupation, industry, and income. The population is a prediction. This population is developed from a disaggregation of the national population to the basin. The disaggregation is based on resource concepts and allows for identification and accomplishment of future goals, as determined by the populace of the area through its decision making body. This allows the area to grow not only as it has in the past but also as it will in the future as a result of given decisions. The resulting populations are, therefore, the "what could happen". The resources used in this concept are density, urbanization, available land, energy consumption, water consumption, and income.

The outputs of the population model for each geographical area are listed below.

(1) Population by age, sex, and race in five-year increments through 2020.

(2) Population by occupation in five-year increments through 2020.

(3) Labor force population by industry in five-year increments through 2020.

(4) Labor force population and households by income in five-year increments through 2020.

The outputs of the population model along with the outputs of the employment forecasting model serve as inputs for determining the private sector requirements. A complete description of the population model is given later in the report.

Employment Forecasting Model

The employment forecasting model is based on economic indices verses demographic indices. The output of the employment model is a direct input into the overall needs model. These outputs not only offer a comparison of the occupational and industrial cohorts of the population model; they also establish the private sector make up.

The employment forecasting model is actually a sub-model of the needs model. This was done to eliminate the need for manual transfer of data. The employment sub-model can be run separately, if desired.

The employment model forecasts the labor force by industry and by the one-digit Standard Industrial Classification Code (SIC) for manufacturers. This is done by disaggregation factors from growth of the Gross National Product (GNP) and the value added by manufacturing employees. The outputs of the employment forecasting model take the following format for each of the required geographical areas.

(1) Gross National Product (GNP)
(2) GNP/employee
(3) GNP/manufacturing employee
(4) Manufacturing employee
(5) Value added/manufacturing employee

(6) Value added/GNP

(7) Labor Force by 1-digit SIC

(8) Total labor force

(9) Total population

Shift Analysis

One basic method of analysis of regional change is the shift technique, described by Harvey S. Perloff and others (1960 & 1963).* The discussion which follows draws heavily on the sources cited.

The basic goal of this analysis is to relate the economic change in a basin to that of the nation as a whole in order to predict or estimate the direction and magnitude of future change. This is done by weighing the change in relative terms which show departures from national norms. Since much of the national economic change is growth, we will use the latter term. By defining the relation of regional growth to national growth, we can examine the characteristics of the growth pattern of the basin and evaluate its changing positions with regard to its ability to hold and attract people and industries. Further, we can study the reaction of the basin to changes in national parameters which influence both supply and demand conditions for major industries.

Within the framework and goals of shift analysis, it is necessary to analyze several elements of the economy. First, it is necessary

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*Harvey S. Perloff, Edgar S. Dunn, Jr., Eric E. Lampard, and Richard F. Muth, Regions, Resources, and Economic Growth. Baltimore: The John Hopkins Press, 1960, pp. 63-74. Harvey S. Perloff with Vera W. Dodds, How a Region Grows; Area Development in the U.S. Economy. New York, Committee for Economic Development, 1963.

to analyze the extent and character of national economic growth during the period under examination. Second, the impact of several relevant change-initiating factors that follow below and are important to growth must be considered:

(a) Technology

(b) Natural resources

(c) Population and labor force

(d) Change in taste, leading to change in consumer demand

(e) Institutional changes such as those flowing from government policy.

Third, the relative extent to which a basin has shared in national economic growth must be appraised. As a part of this element, the shift in the relative position of the basin with regard to key economic measures such as employment in a given industry must also be appraised.

Fourth, the major characteristics of the patterns of economic change of the basin are especially important. These changes may be caused by two major forces: (1) changes due to the make up of the industrial structure of a basin and (2) changes attributable to changes of location within industries. For example, a basin may grow because it has a very large share of fast growing industries or it may grow because of certain location advantages which cause firms to seek it out.

Fifth, the nature of basin must be examined with reference to its relative advantages for location (resource inputs and market requirements). An important facet of this factor is the role of agglomeration.

The starting point for the analysis of the basins is the development of the pattern of national economic growth and a study of the forces behind the growth. One series of analyses portrays some aspects of the key economic aggregates of population, income, and employment for the nation and the basin. These analyses provide a base for the measurement of differential rates of change in the economic structure of the subregions. Another series of analyses reveals absolute changes, while a second series shows the relative changes of the basins as measured against national norms. This is done by means of share analysis and shift analysis and is the means by which the basin's share of the total net shift of some growth factor is measured.

The second series of analyses is based upon the first series and will provide the basis for an analysis of growth. In addition, this series centers on the industrial structure of the basin.

The purposes of this phase of share analysis are

(1) to help define the nature of the basins by relating them quantitatively and, to some extent, qualitatively to the national totals and to each other,

(2) to help define the economic structure of the basin,

(3) to show the extent to which various aspects of growth are uniform across the nation and the extent to which shifts are from some basins to others, and

(4) to characterize the relatively stable and the less

> stable elements in the national economic structure and in the structure of the basin.

To measure this economic change in the basins, two aspects of the shift technique are used. These two aspects show variations in both the rate of change and the industrial composition of that change. The three basic economic aggregates of population, income, employment are used as base factors.

First, the net differential shift arises because certain employment sectors in the basin are expanding more rapidly than in other basins. The shift will show whether the basin has better or worse overall access to inputs or markets than do other basins engaged in the same activity. In short, a gain will have been registered if a basin has greater locational advantages for given industries.

Second, the proportionality shifts reflect the rate of change in specific employment sectors and show whether or not the basin has its share of growth industries.

A simple distinction between the two types of shifts in relation to net shift follows. The fact that employment in a given basin is greater than expected (net shift) may be due to two factors.

(1) Employment in the several sectors may have increased more than the national average because of certain advantages of location. This is the differential shift and is concerned with change within the major sectors of industry.

(2) The basin may have had a larger proportion of employees in growth industries than the nation as a whole. This is the

proportionality shift and is concerned with the relative growth of industry.

Transducers or Technical Coefficients to Water Resources Development Needs

One of the sets of information required by the planner who determines what his area will look like is the quantity and quality of services and facilities required. These needs have been called standards (transducers from demographic output to public sector requirements). These public sector requirements or needs are water resources development requirements by benefit category. They are water supply, electric power, water quality, navigation, irrigation, flood control, land stabilization, drainage, recreation, and fish and wildlife. All of the above are partially a function of scale or population. Using historic data, the relationship between the water requirement for each benefit category and the population served can be determined. This function is the size dependent transducers, shown in Figure 2.2. As several of these transducers are not only a function of scale but also of location, it is necessary to use geographically similar basins to determine the historic relationship. One example of this is the water requirement for the recreation benefit. The amount of water related to recreation needed is a function of both the population in a basin and the geographic location of the basin.

The requirements for the benefits of flood control, drainage, and land stabilization are not a direct function of scale. These requirements normally make up a constant part or percentage of the

Figure 2.2. Size Dependent Transducer

total requirement as well as the cohort (benefits) requirement.

It is possible, given the population of a basin from the population model, to determine the unit needs by benefits from the transducers and, after applying the unit need to the total basin population, to arrive at the basin water requirements (needs) by benefit category.

Population Model

Many models exist for estimating future population with varying applicability and varying success. The more traditional include arithmetic, geometric, logistic, and incremental projections. All of these are strongly dependent on the past; in fact, most are entirely dependent. There is increasing evidence that future goals represent a more viable prediction than do past records. A model is needed that responds to identified goals, that responds to some extent to past performance, that identifies an array of population measures of effectiveness, that responds over time to feedback or impacting, and that relates the parts to the whole.

The model must be capable of providing predictions and forecasting routes to alternative objectives at reasonable intervals. The objectives and levels en route must be alterable as a result of experience or suggested impacts. As the model grows, it should be subjected to inspections and modifications of the goals. Also, incremental changes in population, such as those occasioned by large additions or subtractions, must be possible. The population description must include a variety of variables, both demographic and economic. Finally, provisions must be made for modeling both small and large areas, accounting for impacting , and insuring that the parts will equal the whole.

It is believed that, if the above features are taken into account, population can be used as the independent variable in estimating future requirements. The model presented here uses the cohorts of age, occupation, employment, income, and residence as measures of effectiveness. The model could include demographic and economic metrics. If value added appears to be an important determinate, it could be included provided the historical record of values is available.

If the model is used to predict rather than forecast, predetermined goals become necessary. When forecasting, the model is simply grown based on past performance. When predicting, public policy is implicitly recognized; and national and/or basin goals are established toward which one works. It can be specified that in the year 2000 a basin should have a certain total and distribution of the cohorts. In this case, the cross section of cohorts is not constant but is directed toward a specific objective. Possible political actions necessary for goal achievements can be suggested by investigating different alternatives. The impact of a population of any size on the cohorts can be inserted into the model at any time. The effects on future cohorts can then be observed.

Via the above method, the decision making body will then have at its disposal several alternative sets of futures, together with statements identifying the inputs or costs necessary to attain the objectives of each alternative and the implications of each alternative.

In this manner, the populace of the basin can establish the future character of their basin. Because of public action, there is a difference between what will happen and what might possibly happen. Possible alternatives should be presented to the consumer for selections in terms such as "if you do this, you will look like Basin X", so that he can understand the possible choices and be able to make his selections.

The forecast population is determined using the cohort-survival population forecasting technique. The cohorts used in the population model are age, occupation, industry, and income. The relationship of the nation to the basin is described by F_1. The disaggregation function F_1 is the ratio of the basin population P_b to the national population P_n.

$$F_1 = \frac{P_b}{P_n}$$

Since the national population is forecast by the cohorts, it is necessary to develop a disaggregation function for each of the cohorts.

The population was classified by sex and age. The population by age was grouped in five year age increments (0-4, 5-9, . . . 85 & over). The standard five year age divisions were grouped again for disaggregation purposes. These new groups are listed below.

0 - 4	Pre-school
5 - 19	School
20 - 24	College or armed forces
25 - 44	Young labor force
45 - 64	Older labor force
65 - over	Retired

The occupational cohort is composed of the following groupings:

Code	Occupational
1	Professional, technical, and kindred workers
2	Managers, officials, and proprietors (except farm)
3	Clerical and kindred workers
4	Sales workers
5	Farmers and farm managers
6	Farm laborers and farm foremen
7	Skilled laborers, craftsmen, foremen, and kindred workers
8	Operators and kindred workers
9	Private household workers
10	Service workers (except private household)
11	Laborers (except farm and mine)
12	Unemployed but employable
13	Unemployed and not employable
14	Armed forces

The occupational groups are aggregated into the following classifications for future disaggregation:

Professional	(1,2)
Clerical	(3,4)
Farmers	(5,6)
Skilled	(7)
Semi-skilled	(8,9,10,11)
Unemployed but employable	(12)
Unemployed not employable	(13)
Armed Forces	(14)

The groupings for the industrial cohorts are the one digit Standard Industrial Classification (S.I.C.) Code listed below.

Agriculture
Mining
Contract Construction
Manufacturing
Transportation and Utilities
Wholesale and Retail Trade
Finance and Real Estate
Service
Government

The population by industry is actually the labor force population by industry.

The income cohort is based on personal income using a constant dollar base year, 1968. The population by income range is actually the labor force population by income range. The ranges for the income cohort are as follows:

$ 0 - 999
$ 1,000 - 1,999
$ 2,000 - 2,999
$ 3,000 - 3,999
$ 4,000 - 4,999
$ 5,000 - 5,999
$ 6,000 - 6,999
$ 7,000 - 7,999
$ 8,000 - 8,999
$ 9,000 - 9,999
$10,000 - 10,000
$11,000 - 11,999
$12,000 - 12,999
$13,000 - 13,999
$14,000 - 14,999
$15,000 - 19,999
$20,000 - 24,999
$25,000 - 49,999
$50,000 - over

The static population is projected on five year increments to the year 2020. The population by age is determined by using constant migration rates observed between 1960-1970. The population by occupation and industry are determined by applying a percentage to the total population determined by use of historical data. The population by income is based on a constant four percent GNP increase annually.

The cohorts for a basin reflect essentially a similar or static cross section over time, the relationship depicted by F_1. These values represent forecasts based entirely on past records disaggregated to the basin level. A dynamic model or prediction-producing model would alter the F_1. The cross sections would change over time in response to the national basin relationship referred to as F_{11}, where F_{11} at time t equals the ratio of the basin's population at time t, P_{bt} to the nation's population at time t, P_{nt}.

$$F_{11} = \frac{P_{bt}}{P_{nt}}$$

The dynamic population of the basin is based on the forecasted national population. The F_{11} value, relating the population of a basin at time t to that of the nation at time t, is based on resource concepts. The resource factors considered are population density, percentage of urbanization, available land, water consumption, energy consumption, and income. Each is expressed as a ratio, such as the ratio of basin population density to that of the national population density. Basin policy is an input of the changing cross section.

Population density is defined as population per square mile of land area.

Urbanization or percentage of urbanization is the percentage of the total population of a given area living in urbanized areas or urban residences.

Available land is defined as total land area minus marginal land minus land used for special special purposes. Marginal land is land such as mountains, swamps, and tidal land. Land used for special purposes is land already in use and committed. This is expressed as a per capita figure.

Water is expressed as a per capita water consumption. It takes the form of gallons/capita/day.

Energy is per capita energy consumed from bituminous and lignite coal, petroleum, natural gas, and hydroelectric power. The energy consumed from each of these sources is converted to a common energy measurement which is converted to British Thermal Units (BTU). Energy is expressed in BTU/capita/year.

Income is personal income per capita.

Historical data was collected for each disaggregation factor and each cohort component. A linear equation with the above factors X_i as the dependent variable and time t as the independent variable was developed. These equations for each time t form inputs into an equation representing F_{11}. This equation is assumed to have the following mathematical composition:

$$F_{11} = B_0 + \sum_{1}^{6} B_i X_i$$

Where B_0 and the B_i's are coefficients of a linear equation.

A multiple regression is then run on these historical inputs with the X_i's as independent variables and the F_{11}'s as dependent variables determining the B_i's. The above equation is then evaluated for X_i's determined for the various projection years.

The dynamic disaggregation factors and, therefore, the dynamic population of the basin at a given time are determined by altering the basin input in the X_i. The X_i values are looked at in terms of their approach or rate of approaching some preconceived goal. The goal might be this basin X_i approaching a national average at time t or any other reasonable goal. The goal implementation time can be obtained also. In this study the year 2020 was arbitrarily chosen as the time when the resources of the basin and the nation would be equal. It was then necessary to determine the basin's density energy at each incremental year until 2020, in order to satisfy the above hypothesis. This is done by developing an exponential equation which describes the asymptotic approach of the basin's factors in the year 2020. This is done by plotting $(\frac{Co-C}{Co})$ versus t, as shown in Figure 2.3, where Co is the ultimate value of the national factors, C is the value of the basin's factors for the desired incremental year, and t is time (the required year). The value C is utilized in the disaggregation equation to develop the dynamic basin population at the given time.

In summary, the population model is not dependent on the past but is related to it. It produces predictions of population by cohorts subject to many possible goals. A disaggregation process provides usable numbers at the basin level through allocation concepts and is safeguarded against double counting. The model is computerized and requires only historical national data and cross-sectional data. Finally, the model can be impacted in any year by changing the appropriate cohorts. Goals or inputs can be changed at any incremental year.

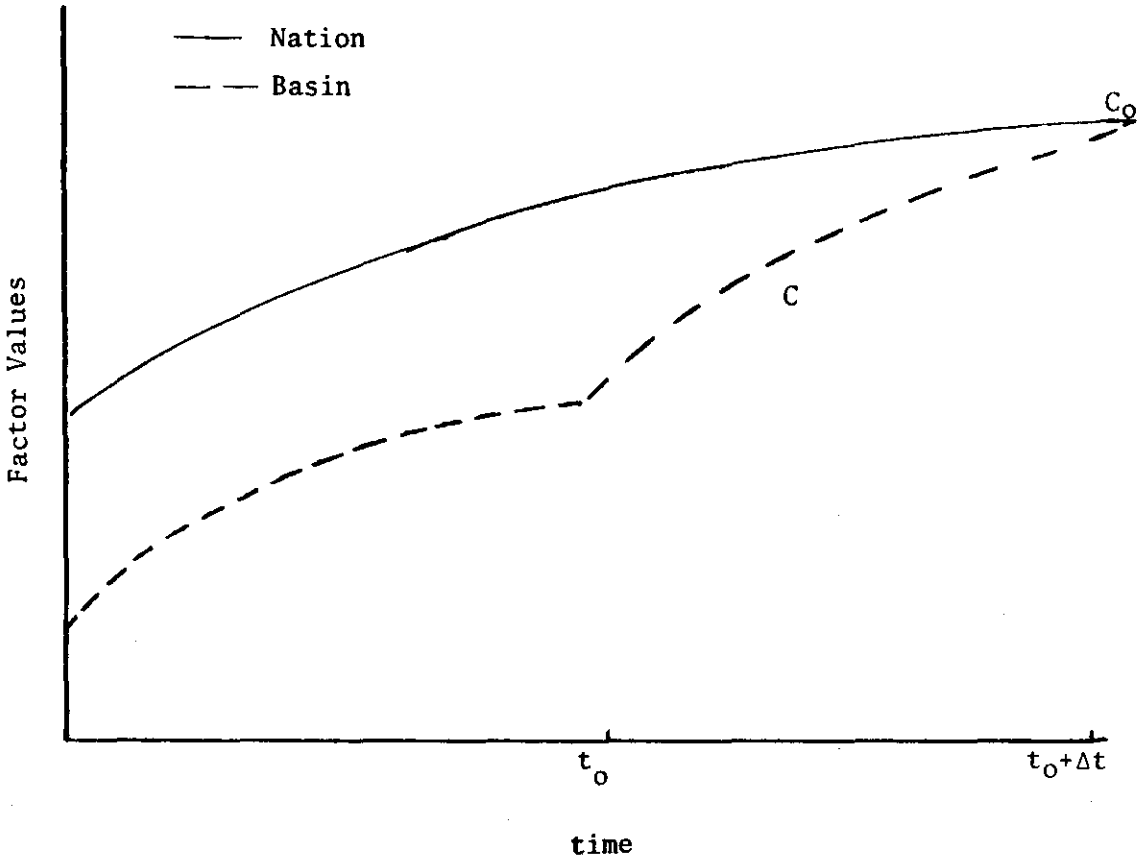


Figure 2.3. Dynamic Growth of Basin Resources

CHAPTER III

BUDGET ALLOCATION MODEL

General Description of the Model

The objective of the model was to find the most efficient way of allocating federal funds for meeting the nation's future need for water resources development. The model is composed of two levels, the national level and the basin level. At the basin level, returns from different funding levels are calculated for different benefit categories (Print 97). Returns are measured by the percentage deduction in deficits, i.e. the amount of need satisfied. The maximum return for each funding level is derived from an integer programming computation. Next, the output from the basin level model is used as input for the national model. Integer programming is again employed to obtain optimal returns for different national budgets. Thus, for each budget level the distribution of investment for each basin can be derived. This also provides a guideline for allocating funds to individual water projects according to benefit categories.

The Basin Level Model

Basic Formulation

The objective of the basin model is to minimize the sum of the water deficits in each benefit category for a given budget, B.

For each benefit category, i, there exists a set of returns, R_{ij}, derived from deficit, where the subscript j refers to the magnitude of the deficit. Corresponding to a return, R_{ij}, is a cost, C_{ij}. The model can thus be stated as follows:

Minimize

$$\sum_i \sum_j X_{ij} R_{ij} \tag{1}$$

subject to

$$\sum_i \sum_j X_{ij} C_{ij} \leq B \tag{2}$$

$$\sum_j X_{ij} = 1, \quad \text{for each } i \tag{3}$$

$$X_{ij} = \begin{cases} 1, & \text{if } R_{ij} \text{ appears in the optimal objective function} \\ 0, & \text{otherwise.} \end{cases} \tag{4}$$

The first constraint, equation 2, simply states that the sum of the costs, corresponding to the chosen return or deficit levels in each benefit category, must be equal to or less than the available budget. Constraint two, equation 3, states that one return must be chosen for each benefit category. The third constraint, equation 4, states that each activity variable, X_{ij}, associated with return R_{ij}, must be a zero-one integer, which indicates that a project would either appear as a whole or not appear at all.

The objective function, equation 1, assumes that the returns are the optimal minimum ones for each benefit category when all the benefit categories are simultaneously considered under a certain budget. In other words, one can obtain the best way, measured by minimizing deficits, to spend a certain budget among different benefit categories from this formulation. Several budgets will be introduced for each basin. The outputs will then be used as inputs for the national level model.

Model Components

Basin — Water Resources Regions

The United States Water Resources Council presently uses twenty geographic water resource regions (Table 3.1 and Figure 3.1) and one-hundred-ten subregions in planning. Seventeen of the twenty regions are in the contiguous United States. The other three are Alaska, Hawaii and Puerto Rico. These twenty regions will be employed in this study as an individual component in the basin level model. If further study is pursued, the one-hundred-ten subregions could also be used for developing a subregion or sub-basin model, but this study is limited only to the basin or region level.

With twenty water resources basins in the United States, if a national budget is being considered for the whole country, the basic level model must be operated twenty times, i.e., one for each basin, before the national budget allocation can be obtained.

Benefit Categories

In Print 97* benefits are generally defined as follows:

> Increase or gains, net of associated or induced costs, in the value of goods and services which

---

*More recent studies under the auspices of the Water Resources Council established three additional accounts, in addition to the national income account which consists of the eleven above benefits. The additional three are well-being, environment and regional development accounts. This did not alter the eleven benefits of Print 97.

REGION	
1	North Atlantic
2	South Atlantic-Gulf
3	Great Lakes
4	Ohio
5	Tennessee
6	Upper Mississippi
7	Lower Mississippi
8	Souris-Red-Rainy
9	Missouri
10	Arkansas-White-Red
11	Texas-Gulf
12	Rio Grande
13	Upper Colorado
14	Lower Colorado
15	Great Basin
16	Columbia-North-Pacific
17	California
18	Alaska
19	Hawaii
20	Puerto Rico

Table 3.1. Water Resource Regions in United States.

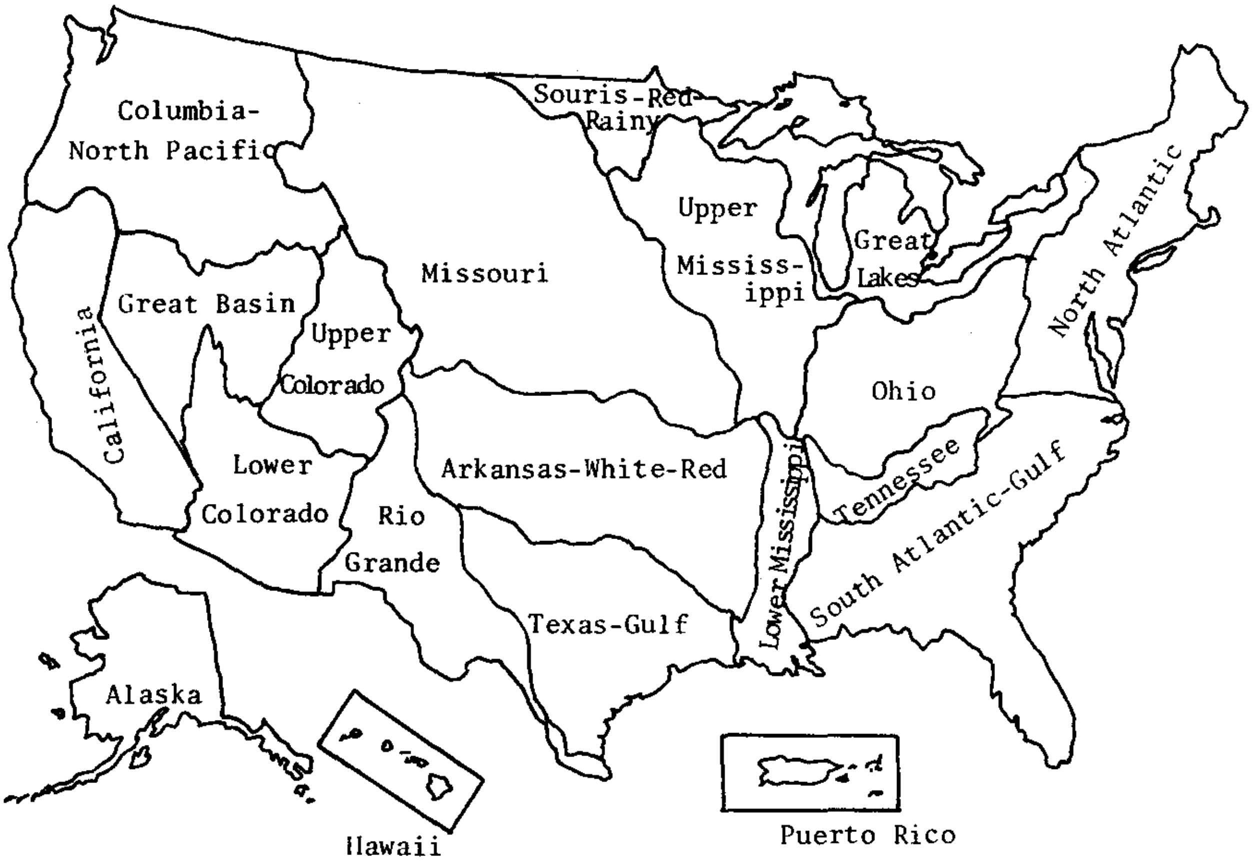


Figure 3.1. Water Resource Regions in United States

> result from conditions with the project, as compared with conditions without the project. Benefit include tangibles and intangibles and may be classed as primary or secondary.

The listed primary benefits in Print 97 will be used in the basin model as standard benefit categories. They are as follows:

(1) Domestic, municipal, and industrial water supply benefits

(2) Irrigation benefits

(3) Water quality control benefits

(4) Navigation benefits

(5) Electric power benefits

(6) Flood control and prevention benefits

(7) Land stabilization benefits

(8) Drainage benefits

(9) Recreation benefits

(10) Fish and wildlife benefits

(11) Other benefits.

Deficits

In the past, prospective water resource projects were evaluated by net benefit and/or B/C ratio following the Green Book or Print 97. In this study, development toward meeting needs will be used as measurement of benefits. This practice can thus bring all the returns from investments in different benefit categories under the same measurement units.

In order to obtain benefits, projection of future needs should be done first. Earlier, the needs model was discussed. From that model the needs for different benefit categories and years were gathered. The needs above the present supply will be designated as goals for particular years and different benefit categories. Percentage of goal achieved is then converted into a deficit unit, a number less than or equal to 1.

The conversion is illustrated by Figure 3.2. Then,

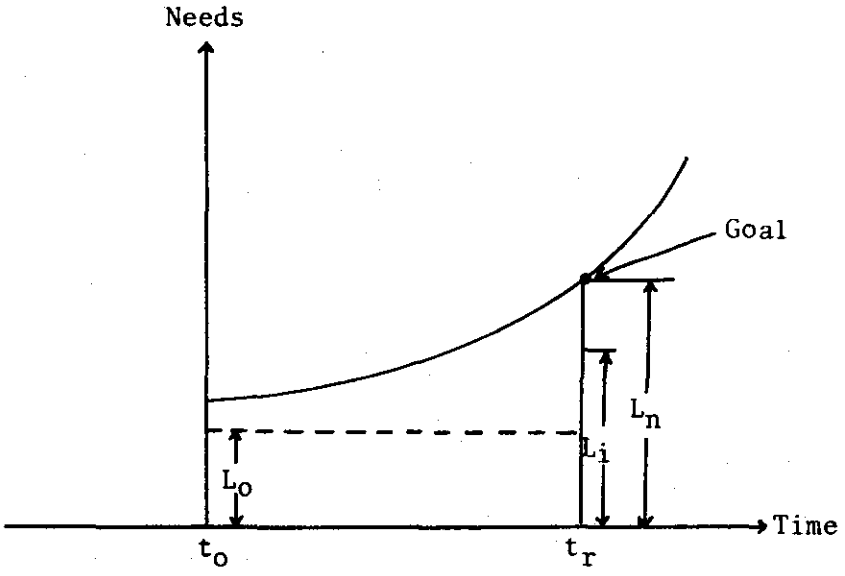
$$\text{Deficit} = 1 - \frac{L_n - L_i}{L_n - L_o} = 1 - \frac{\text{Actual additional achievement at } t_n}{\text{Additional need at } t_n}$$

A simple conversion between percent of goal achieved and deficits is shown in the following diagram.

Percent of Goal	0	25	50	75	100	125	150	. . .
Deficit Unit	1	0.75	0.50	0.25	0	-0.25	-0.5	. . .

For example, if just enough funds have been invested so that the needs are satisfied, then 100 percent of the goal is achieved, and there is zero deficit. If there are inadequate funds for obtaining the total goal, for instance, only 25 percent of the goals may be reached; this implies a 0.75 unit of deficit. But if the supply is more than needs so that more than 100 percent of the goal are achieved, then a negative deficit would occur.

The next step is to map the deficit units onto a weighted scale. The new scale is based on an exponential function as shown in Figure 3.3. The abscissa in this rectangular coordinates system represents the unit of deficit or the percent of goal; whereas, the ordinate is the returns,



t_o = present time

t_n = at time n

L_o = present level of achievement

L_n = needed level at time n

L_i = actually achieved level at time n; L_i varies with investment

Figure 3.2. Determination of Deficits

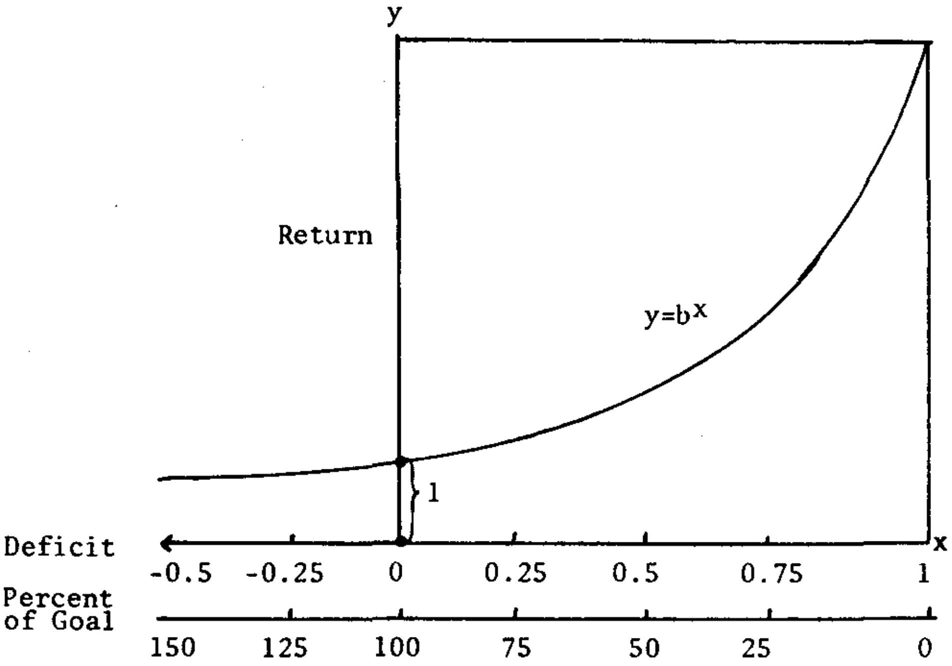


Figure 3.3. Deficit (Goal) - Return

which is in the sense of penalty. An exponential function is used to convert the deficit units into return units. The function is stated as follows:

$$f(x) = y = b^x ,$$

where b is equal to a constant. The domain of the function is

$$-\infty < x \leq 1 .$$

The range of the function is

$$0 < y \leq b .$$

The reasons for using this exponential function are:

(a) To avoid dealing with negative deficit units, since in this new scale, return = $y > 0$.

(b) Since the exponential function increases more rapidly when x value is large and decreases slowly when x is negative, this property can be used to punish the larger deficits, i.e., not achieving the goal, by giving a larger proportion of returns, penalty units and to reward small proportional returns for negative deficits, i.e., achieving more than the needs required. The net effect insures that one category is not overdeveloped at the expense of another.

For illustration purposes, observe the situation where $y = f(x) = 10^x$ (when $b = 10$) in Figure 3.4. When there is no deficit, i.e., $x = 0$, then return = $y = 1$. If there is no improvement other than the present status, i.e., deficit = $x = 1$, then return = $y = 10$. For 0.75 (=x) deficit, $y = 10^x = 10^{0.75} = 5.63$. If $x = -0.25$, i.e., 125 percent of the goal has been achieved, then $y = 10^{-.25} = 0.57$.

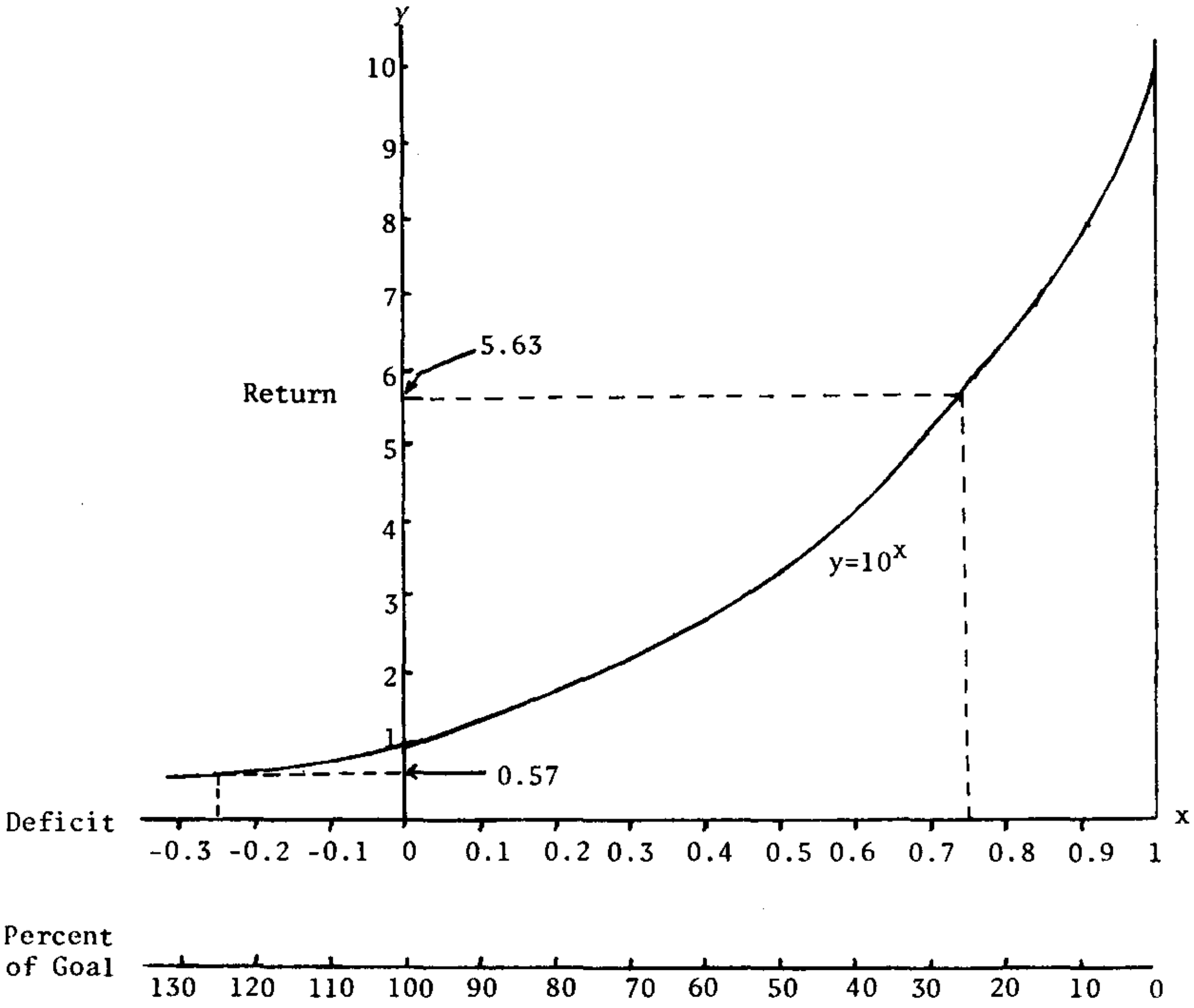


Figure 3.4. Deficit - Return $y = 10^x$

The use of the function $y = b^x$ with different constant values for b will have different effects on the return value and later on the optimal solution in the integer programming. So far, no post-sensitivity analysis has been done; therefore, the influences of this function is still unknown until further study can be conducted.

Weighting Factors

Before returns can be used in the basin model, they must be adjusted due to some influential factors. Two weighting factors will be discussed here.

Benefit Priority Weighting Factor λ_i

So far, returns from different benefit categories are considered to be at the same level of importance. In reality some region may more desparately need certain categories of development such as water supply, than any other category; therefore, a weighting factor for bringing out this priority is necessary. Since returns measuring deficits are in the penalty sense, a higher priority benefit category should be associated with a smaller weighting factor than the less urgent ones. Each basin should have its own benefit priorities and, hence, different weighting factors. The derivation of these factors cannot be done easily. Each should be derived objectively and under careful consideration with all the factors for different basins being interrelated and evaluated on the same criteria. This is necessary since returns for each budget and basin will enter the national model simultaneously. Essentially, this factor allows a decision maker familar with a basin to inject his judgment into the needs model by assigning relative importance to a basin's needs.

In this study, no effort was made to derive particular priority weighting factors for different benefits. Later, when the basin model is being verified, these factors are assumed to be equal to 1 under the special situation with which one is dealing.

The priority weighting factors are assumed to affect returns in the following way. Let λ_i be the priority weighting factor for the i^{th} benefit category; then

$$\text{Adjusted return} = \lambda_i r_{ij}$$

where r_{ij} is the original return derived from deficit level.

Expense Weighting Factor ϕ_{cij}

Distributing a basin budget to attain different benefit categories and years is the primary objective in this budget allocation model. The price paid for each goal is different. The price for achieving a higher percentage of the goal may be higher than for a lower percentage in the same benefit category. When several benefit categories are considered at the same time, achieving the same percentage of a goal in one benefit category may cost less than for another. In order to bring the spending for achieving a goal into consideration, the necessity of the expense weighting factor enters.

If two different expenditures are needed to obtain the same percentage of goals, i.e., same deficit level, in two benefit categories, the larger amount of spending should have a smaller return or penalty. The expense weighting factors are derived through this concept; a larger amount of spending would associate with a smaller expense weighting factor to give a smaller return.

Let ϕ_{cij} be the expense weighting factor, where the subscript cij indicates that ϕ is dependent on the cost C_{ij}, i for benefit category and j for deficit level; then,

$$\text{Adjusted return} = \phi_{cij} r_{ij} ,$$

where Υ_{ij} is the original return.

In this study, two expense weighting factors were used. Both factors vary linearly and inversely with respect to the cost of the original returns. For example, the factor used in the 1980 budget study was derived from the equation $\phi_{cij} = 4 - (4/400)C_{ij}$, where C_{ij} is the cost of the original return.

At this point, the determination of the expense weighting factor is almost arbitrary. Although its effect on the return and on the final solution has not been determined, at least this indicates that it is under consideration. The existence of this factor is without doubt necessary. The best way to obtain this factor will require further studies.

Measurement of Cost and Resource Development

To supply needs, there are certain prices which must be paid. Although there are many costs associated with water resource development, only the monetary cost of fulfilling need is considered in this study. The framework of the model is such that any cost can be accounted for, whether monetary or non-monetary, if it can be quantified. Of course, to remove different deficiencies for different benefit categories, different costs will be associated with these actions. Although benefits may not be a disjoint set, in this section units of measurement will be discussed according to benefit categories.

Flood Control

Flood control can be achieved either by structural or non-structural means which have a characteristic cost for a given area. For each basin and sub-basin, there is also a characteristic relationship between the means of flood control and flood damage reduction; therefore, the relationship between the cost of construction, measured in dollars, and/or evacuation and damage reduction, either in dollars or land area, can be used.

Water Supply

Water can be supplied by various means; currently, the majority is supplied by reservoirs, ground water and stream withdrawals. While there are many possible means of supply, for a given area the relationship between cost, measured in dollars, and water produced, measured in million gallons per day (MGD), is relatively constant, if the least expensive means is assumed.

Irrigation

The relationships for irrigation are developed in the same manner as for water supply.

Water Quality

Water quality control is achieved either by dilution or water treatment. Under current law, water treatment would not be a consideration in this model. For dilution, the relationships for water quality control are also developed as those for water supply are.

Electric Power

The relationships for electric power generation are similar to those for water supply with the exception that development is measured in terms of kilowatts instead of MGD.

Drainage

The relationship between drainage improvements, measured in acres, and cost, measured in dollars, is characteristic for a given area; however, this relationship is not fully developed.

Land Stabilization

The relationship for land stabilization needs to be developed.

Navigation

Navigational needs are measured in tons for harbors and in ton-miles for channels. The cost of development, measured in dollars, should also be characteristic for a given area.

Recreation

Recreation needs are currently measured in user-days. At present, no satisfactory relationships have been developed for cost and recreational development.

Fish and Wildlife

Fish and wildlife needs are measured in number of species; however, no satisfactory relationships have been developed for cost and development of this area.

As stated earlier, the model has the capability of accounting for other types of cost than direct monetary costs. These costs which will be developed in future research will be arrayed in such a manner as to let a decision maker know what additional costs are involved in developing certain water resources.

Level of Spending and Level of Deficit

Although the relationship between cost and deficit level is a continuous function, discrete levels are used in this model. A limited number of costs and deficit levels are used for each benefit category in each basin. The number used is very much dependent on the extent of the research. In this study six costs or spending levels were used. These spending levels are associated with the percentages of the goal achieved, namely, 0%, 25%, 50%, 75%, 100% and 125%. For any other study, the number of spending levels may be varied.

Budget Constraint

As stated in the basic formulation of the basin model, the first constraint is due to budget. The budget allowance for each basin is probably the most important factor in this model. In order to obtain inputs for the national level model, several budgets, which would result in several optimal returns for a basin, should be assumed. The larger the number of budgets entered, the more inputs for the national level model that could be gathered. The number of budgets is dependent on how detailed and precise a study is carried out.

In this study six budgets were used for each basin. At first, the sum of costs for arriving at the highest level (125% of the goal is used instead of 100%) was calculated. Then six budgets were approximately distributed evenly between the cost of the highest level and the zero cost which is for providing no improvements.

Summary

To get a better picture of how the basin level model is operated, a diagram is shown in Figure 3.5 to indicate each step. From Figure 3.5, it can be noted that the four main entries are return R_{ij}, cost C_{ij}, activity variable X_{ij}, and budget B.

To arrive at R_{ij}, needs are predicted from the needs model first. Needs are designated as goals which are then converted from percentages into units less than or equal to 1. Returns r_{ij} are next obtained from deficits and an exponential function $y = b^x$, where b is a constant and x is the deficit unit. Two weighting factors, the expense weighting factor ϕ_{cij} and the benefit priority weighting factor λ_i, are then multiplied to r_{ij} to get the adjusted return $R_{ij} = \lambda_i \phi_{cij} r_{ij}$.

Cost C_{ij} is derived for each benefit category from generalized relationships with respect to geographical area and type of improvement. Activity variable X_{ij} is a zero-one integer which will equal to 1 if the return associated with it appears in the optimal solution and zero otherwise. Budget B is a capital constraint.

With all these components, R_{ij}, C_{ij}, X_{ij}, and B on hand, the basin model can then be operated to derive the optimal solution for each budget in each basin.

The basin level model is only a sub-model for the national model. Solutions from the basin model will be used as inputs for the national

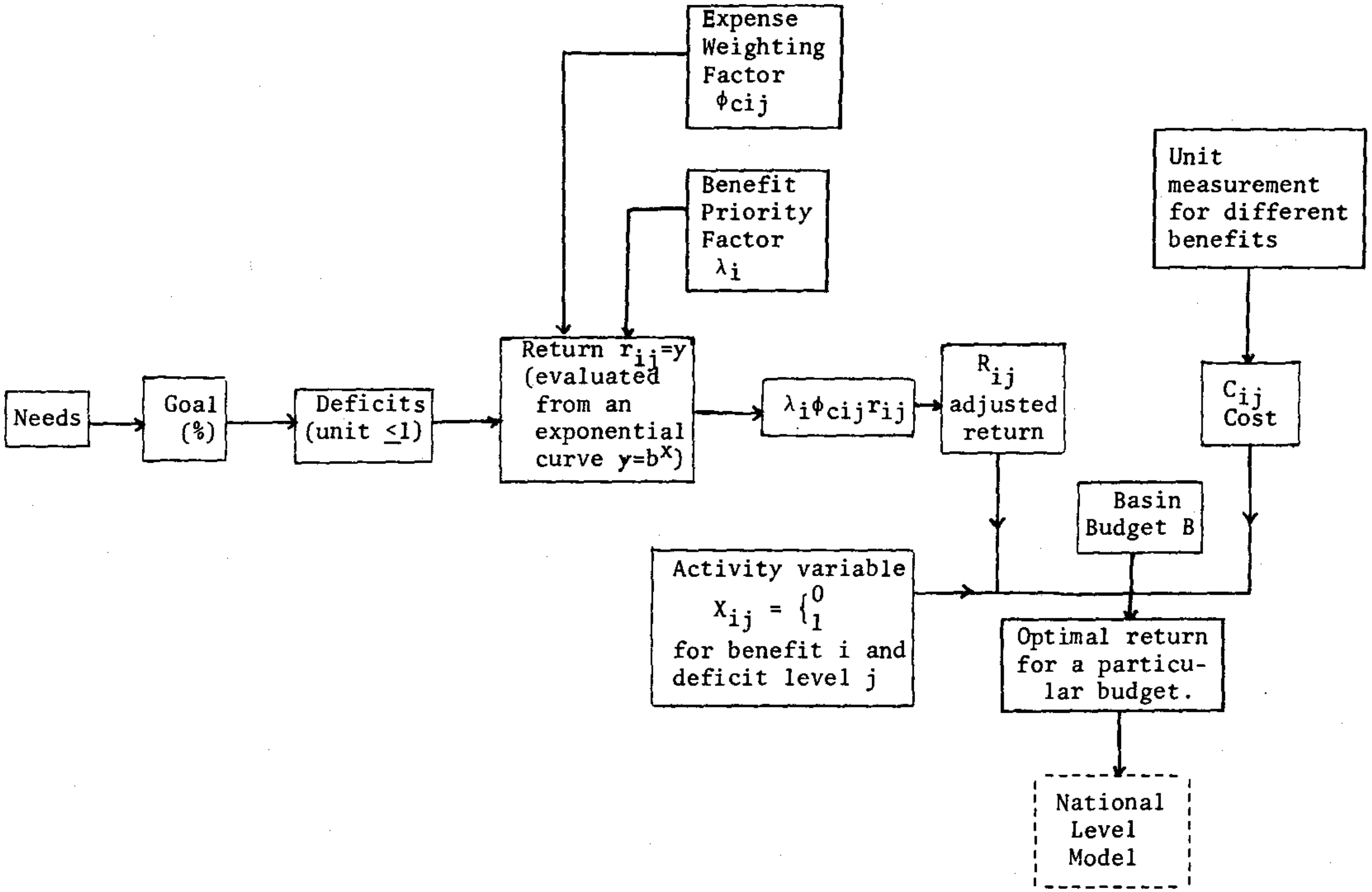


Figure 3.5. Operation of Basin Level Model

level model. The results from the basin model will be listed according to basin, year, budget, and corresponding optimal total return. These data are then used as input for the national model.

National Level Model

The national level model is essentially similar to the basin level model with the exception that the benefit categories for each basin can be replaced by the basins. There are also some minor modifications that will be pointed out.

Basic Formulation

The national level model is also based on integer programming. The basic mathematical formulation can be stated as follows:

Minimize

$$\sum_i \sum_j X_{ij} R_{ij} \qquad (1)$$

subject to

$$\sum_i \sum_j B_{ij} X_{ij} \leq P \qquad (2)$$

$$\sum_j X_{ij} \leq 1, \quad \text{for each } i \qquad (3)$$

$$X_{ij} = \begin{cases} 1, \text{ if } R_{ij} \text{ appears in the optimal} \\ 0, \text{ otherwise} \end{cases}$$

where

R_{ij} = return from basin i and budget j

B_{ij} = basin budget associated with return R_{ij}

P = national budget level

X_{ij} = activity variable for basin i and basin budget j.

As in the basin model, the first constraint, equation 2, simply states that the sum of the basin budgets, corresponding to the chosen returns for the optimal level, must be limited by the national budget, P. The second constraint, equation 3, indicates one return must be chosen for each basin; and constraint three, equation 4, shows that X_{ij}, which represents return R_{ij} for basin i and basin budget j, must be an integer less than or equal to 1, i.e., one and only one return for each basin.

Considering all the basins simultaneously for a certain national budget, the objective function, equation 1, will assume that returns from each basin are the optimal minimum.

Components of the Model

Basins

The basins used in the national level model are equivalent to the benefit categories in the basin level model. If a national budget is being considered for the entire United States, there are twenty basins under consideration according to the Water Resources Council. In this study,for the reason that data are not available from every basin at this time, only eight basins were considered for the national model.

Returns

From the basin model, optimal returns of several budgets for each basin are obtained. These returns will be used in the national model as measure of effectiveness. In this study, optimal returns associated with six basin budgets were used for the national level model.

National Budget

The basic objective for this research is to find a methodology to allocate a national budget to different basins. This national budget is the amount which the nation is willing to spend for the basins under consideration. For the sake of comparison, several national budgets were used in this study for the years 1980, 1985, 1990 and 1995.

Weighting Factor

Although it has been considered that associated with each basin budget, there should be an expense weighting factor, this factor is not used in the national model due to the fact that it has been used once before in the basin model for adjusting the return for each benefit category. A new weighting factor, the basin priority weighting factor, is introduced here for the national model.

Basin Priority Weighting Factor

According to "Public Works for Water, Pollution Control, and Power Development and Atomic Energy Commission Appropriation Bill, 1971", several priority criteria for regional distribution of funds must be considered. The regional allocation criteria developed and used by the Army Corps of Engineers in formulating water resource programs are listed below.

Regional water needs. Regions having the highest level of projected water resource needs receive the most funds.

Federal income taxes paid. Regions paying the greatest amount in federal income taxes receive the greatest amount of funds.

Population. Regions having the greatest number of people receive the greatest amount of funds.

Population and per capita income. For two regions having the same population, the one having the lower per capita income receives the greater amount of funds.

Efficiency. Regions having the projects with the highest benefit/cost ratios receive the most money. Table 3.2 shows regional allocations in percent based on each of the above criteria.

To derive the basin priority weighting factor, all five criteria mentioned here were considered to the equally important. The sum of percentages from each criterion for each basin was calculated. The basin priority factors were then obtained from the sums. The following equation can be used to calculate this factor:

$$\text{Basin Priority Weighting Factor } \theta_i \text{ for basin } i = 4 - \left(\frac{3}{A}\cdot Si\right)$$

where A is a constant greater than the largest sum of percentages for each basin; S_i is the sum of percentages for basin i.

In this study since the largest sum of percentages was one-hundred-eighteen, obtained from the North Atlantic Region, A was assumed to be equal to one-hundred-twenty. The value of θ_i varies linearly and inversely with respect to the sum of percentages.

Return r_{ij} from the basin model for basin i and budget j is then adjusted by the following method:

$$\text{Adjusted return } R_{ij} = \theta_i r_{ij}$$

Table 3.2. **Alternative Regional Allocations**** (Percent of Total)

Region	Criterion: Regional Water Needs	Criterion: Federal Income Taxes Paid	Criterion: Population	Criterion: Population & Per Capita Income	Criterion: Efficiency
New England	1	8	5	4	7
Middle Atlantic	17	26	18	17	15
Gulf & South Atlantic	11	6	11	12	5
Ohio	10	8	10	10	7
Great Lakes	8	18	10	10	2
Upper Mississippi	4	7	10	9	10
Souris-Red-Rainy	*	*	*	*	*
Missouri River	3	4	4	4	12
Arkansas-White-Red	8	3	4	4	5
Lower Mississippi	7	1	3	4	4
Rio Grande	*	1	1	1	*
Texas Gulf	3	3	5	5	9
Colorado	2	1	1	2	1
Great Basin	1	*	1	1	*
California	11	10	11	10	4
Columbia-North Pacific	6	3	3	3	13
Alaska	7	*	*	*	3
Hawaiian Islands	*	*	*	*	*
Puerto Rico & Virgin Islands	*	*	1	2	2
The Nation	100%	100%	100%	100%	100%

*0.5 percent or less

**By U. S. Army Corps of Engineers

Since there is only one priority factor for each basin, all the returns from the same basin are multiplied by the same factor. The derivation of this basin priority weighting factor was partially arbitrary and is subject to change.

Summary

Compared to the basin level model, the national level model is relatively simple. Figure 3.6 shows how the national model operates.

As is noted, the four main entries are basin budget B_{ij}, adjusted return R_{ij}, national budget P, and activity variable X_{ij}.

Basin budget B_{ij} is obtained from the basin level model with the associated return r_{ij}, which is adjusted to $R_{ij} = \theta_i r_{ij}$ by the basin priority weighting factor θ_i. P is the national spending allowance for the basins under consideration. Activity variable X_{ij} is the same as in the basin level model, except that i represents basin and j the basin budget instead of benefit category and deficit as in the basin model.

The optimal solution in the national level model is the list of minimum returns associated with a corresponding basin budget. This can be used to show how a certain national budget can be distributed among different basins more effectively with all of the basins being considered simultaneously (i.e., all of the basins are more closely interrelated).

Conclusion

Figure 3.7 shows how the whole model operates. First, the needs model projects the needs for each basin according to benefit category and year. In the basin level model needs are converted into deficits

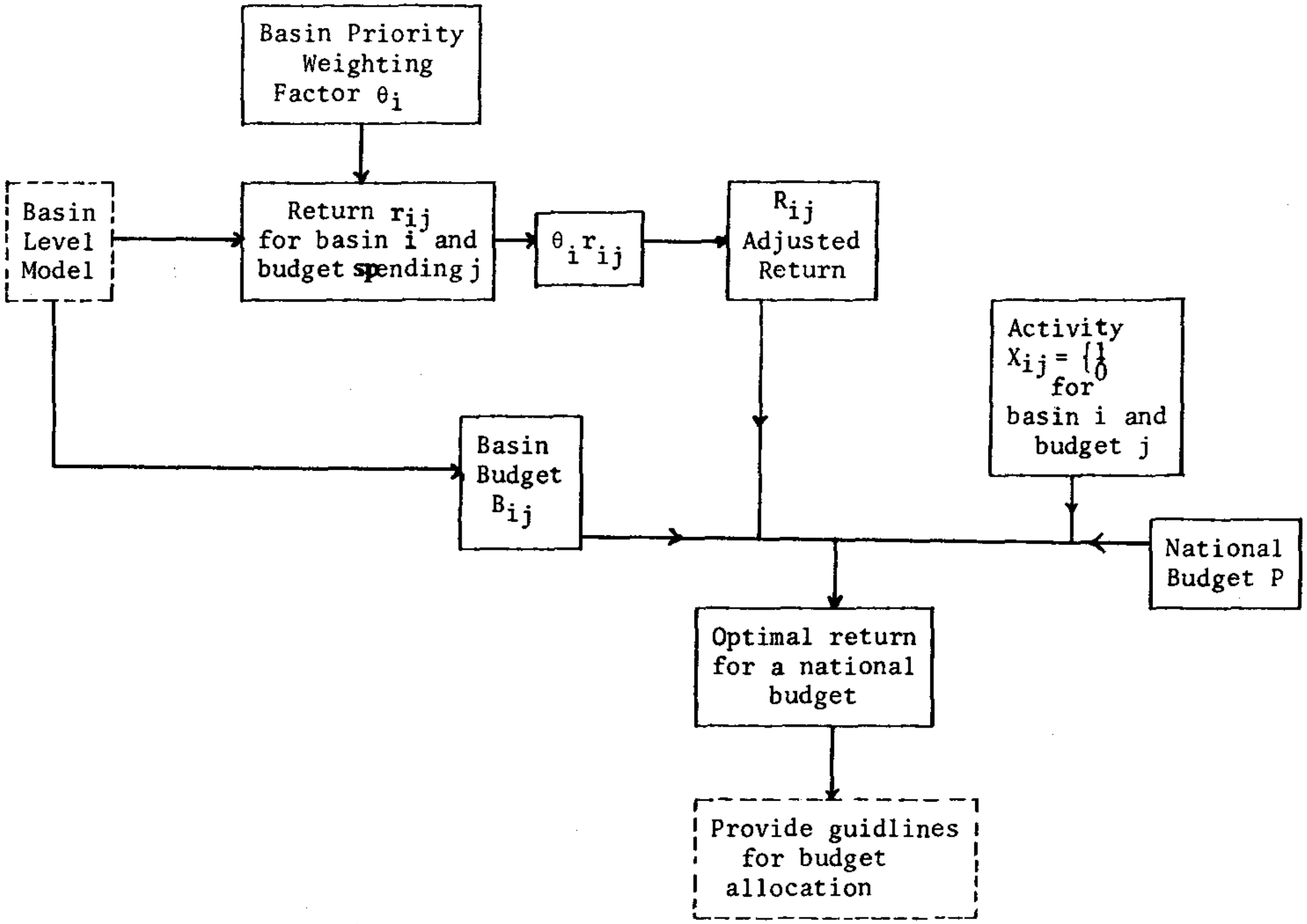


Figure 3.6. Operation of National Level Model

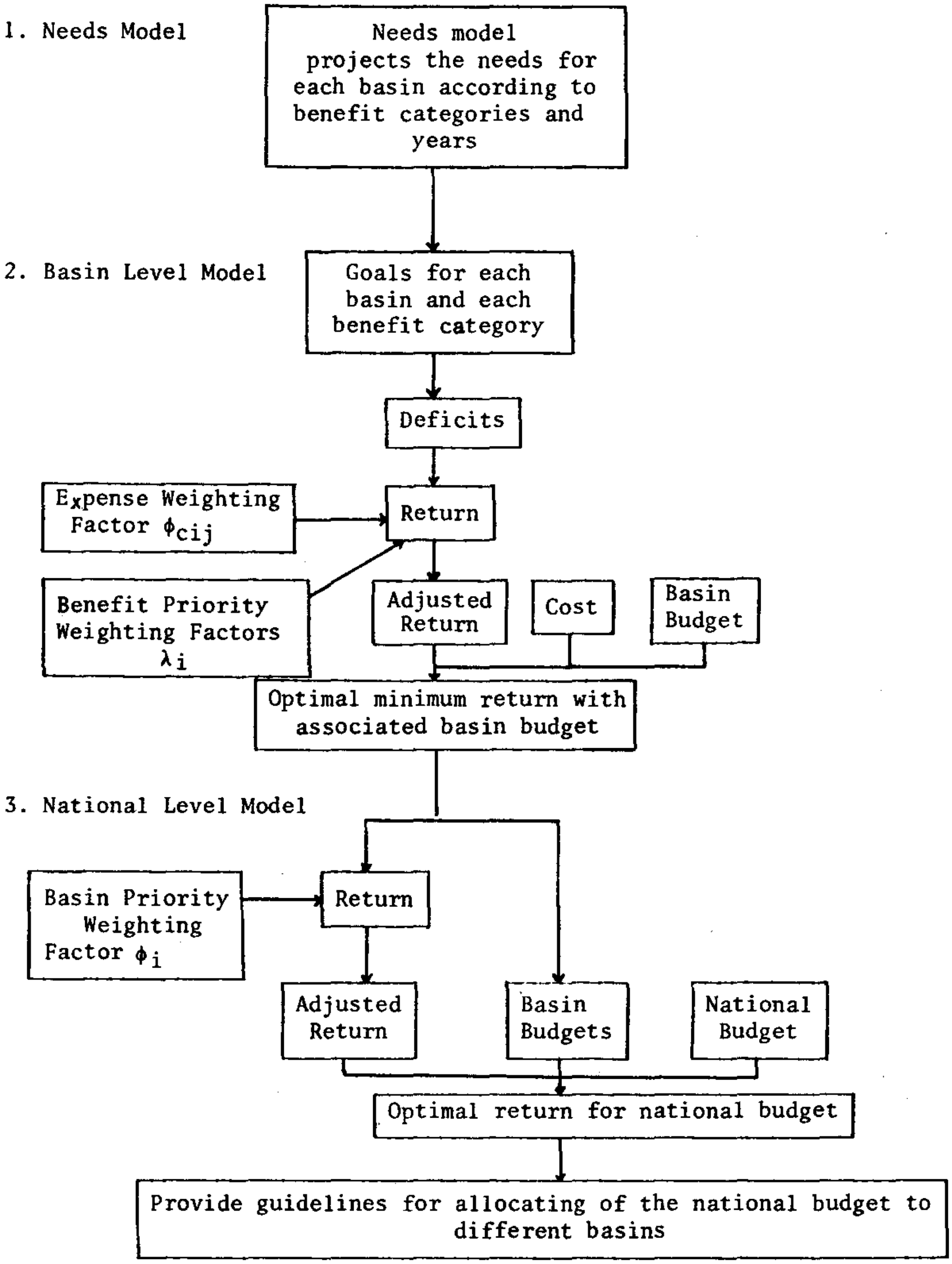


Figure 3.7. Operation of the Whole Model

and, then, into returns associated with the cost of development which appears in the output of the basin level model as an optimal minimum. The national level model is introduced next. With outputs, returns and corresponding basin budgets from the basin level model, the national level model can be used to distribute a national budget among different basins effectively.

The original purpose of this study was to find a methodology for allocation of investments in water resources projects, so that the projects under consideration are more systematically interrelated. Essentially, this model has served its original objective; yet, several assumptions used in this model still need to be subjected to further confirmation. One instance is the derivation of weighting factors. Therefore, further sensitivity analysis is still needed before this model can be realistically applied.

CHAPTER IV

VERIFICATION OF THE MODEL

The model developed earlier was tested using data from eight basins for the basin level model and using several national budgets for the national level model. In this chapter, the procedures used in testing the model will be explained.

Basin Level Model

Method of Optimization

The original formulation of the basin level model utilized integer programming to optimize returns; however, an integer programming subroutine was not available at the University of Oklahoma computer center. The model was tested using continuous variable linear programming. The constraint that the activity variable X_{ij} must be a zero-one integer was dropped. This did not pose any problems because both costs and corresponding deficits used in this study were continuous variables rather than integer variables. The revised program can thus be stated as follows:

Minimize the total return

$$\sum_i \sum_j X_{ij} R_{ij}$$

subject to

$$\sum_i \sum_j X_{ij} C_{ij} \leq B$$

$$\sum_j X_{ij} = 1 \qquad \text{for each } i$$

$$0 \leq X_{ij} \leq 1 ,$$

where X_{ij} is the activity variable, R_{ij} is the return associated with the cost C_{ij}, and B is the basin budget.

The results were obtained using the IBM Mathematical Program System/360 (MPS/360).

Inputs of the Model

Basins

The basin level model was operated for the eight water resource basins defined by the United States Water Resources Council. The selecting of these eight basins was dependent only on the availability of data. Most of the data collected for this study was from the unpublished book, Water Supply and Demand in the United States, by Wollman and Bonem. Basins defined in this report are different from those defined by the Water Resources Council. Those defined by the latter include one or more of those used by Wollman and Bonem. For the eight basins being tested in this study, the relationship between basins from the two different sources are shown in Table 4.1. Separate computer programs were then run for each of the eight basins of the Water Resources Council.

Years of study

In order to get comparisons, studies for the years of 1980, 1985, 1990 and 1995 were carried out for each basin.

Table 4.1. The Basins of the Water Resources Council and the Basins of Wollman-Bonem.

	The Basins of the Water Resources Council	The Basins of Wollman-Bonem
(1)	Arkansas-White-Red	Lower Arkansas-Red-White Upper Arkansas-Red
(2)	Great Lakes	Eastern Great Lakes Western Great Lakes
(3)	Lower Mississippi	Lower Mississippi
(4)	North Atlantic	New England Delaware-Hudson Chesapeake Bay
(5)	Ohio	Ohio Cumberland
(6)	South Atlantic-Gulf	Southeast
(7)	Tennessee	Tennessee
(8)	Upper Mississippi	Upper Mississippi

Needs and Goals

In the Wollman-Bonem report, distribution of the existing storage as of 1964, the maximum physical development of storage, and the additional storage needed to approach maximum physical development capacity of reservoirs was available for every basin in the United States (see Table 4.2). (Maximum physical capacity is fixed at the point where increase in gross flow [marginal flow] is equal to the increase in evaporation [marginal evaporation] per unit increase in the reservoir capacity.)

Since the needs model was basically the same as that developed, documented, computerized and validated in an earlier study (G. W. Reid, A Multistructural Demand Model for Water Requirement Forecasting, 1970), and since the data necessary for the input of the needs model was not readily available, it was not considered either necessary or justifiable to validate the needs model at this time. The additionally needed storages developed in the Wollman-Bonem report were assumed to be the needs for the year 2000. These storages were distributed linearly among the years from 1965 to 2000. Table 4.3 shows the storages needed for all of the basins considered in this study from the year 1975 to 2000 in five-year increments. The zero storage needed for the Upper Arkansas-Red Basin is due to the fact that the existing storage in this area is very close to the maximum physical capacity. Hence, storages needed in the Lower Arkansas-Red-White Basin were assumed to be what were needed for the entire Arkansas-White-Red Basin.

The total storages needed for each basin and for each year were then distributed according to function -- benefit categories.

Table 4.2. Existing, Maximum Physical and Additional Needed Storage by Basin for U.S.A. (*From Wollman-Bonem Report).

Basin	Storage (Million Acre-feet)*		
	Existing Storage	Maximum Physical Development Storage	Additional Storage Needed for Reaching Maximum Physical Development
New England	11	180	169
Delaware-Hudson	3	82	79
Chesapeake Bay	2	174	172
Ohio	16	495	479
Eastern Great Lakes	2	84	82
Western Great Lakes	1	70	69
Upper Mississippi	10	81	71
Lower Missouri	6	63	57
Southeast	54	412	358
Cumberland	14	38	24
Tennessee	16	192	176
Lower Mississippi	5	83	78
Lower Arkansas-Red-White	41	157	116
Upper Missouri	102	68	-34
Upper Arkansas-Red	17	19	2
West Gulf	42	88	46
Rio Grande-Pecos	8	6.4	-1.6
Colorado	75	28.7	-46.3
Great Basin	5	11.3	6.3
South Pacific	2	4.5	2.5
Central Pacific	26	122	96
Pacific Northwest	48	464	416
U. S. A.	506	2923	2417

Table 4.3. Total Additional Storage in Million Acre-feet Needed by Year and by Basin beyond Existing (1964) Storage

Basins		Storage (Million Acre-feet)						
Water Resources Council Basins	Wollman-Bonem Basins	Existing (1964)	1975	1980	1985	1990	1995	2000
(1) Arkansas-White-Red	Lower A-R-W	41	31	49	66	81	99	146
	Upper A-R	17	0	0	0	0	0	0
(2) Great Lakes	E. G. Lakes	2	23	35	47	58	70	82
	W. G. Lakes	1	19	29	39	49	59	69
(3) Lower Mississippi	Lower Mississippi	5	22	33	44	55	66	78
(4) North Atlantic	New England	11	49	73	96	121	144	169
	Delaware-Hudson	3	23	35	45	57	68	79
	Chesapeake Bay	2	48	73	98	124	148	172
(5) Ohio	Ohio	16	134	204	272	340	409	479
	Cumberland	14	7	10	14	17	21	24
(6) South Atlantic-Gulf	Southeast	54	102	153	205	255	305	358
(7) Tennessee	Tennessee	16	50	75	100	125	151	176
(8) Upper Mississippi	Upper Mississippi	10	20	30	40	50	60	70

Information about the existing and planned distribution of reservoir storage was also available in the Wollman-Bonem report. It was mentioned in the report that the distribution of reservoir capacity according to function indicates that the dominant purposes served by storage now being planned by federal agencies are not likely to be much different in the future than what they are at the present time.

It was then assumed that the pattern for distributing planned storages by function in the Wollman-Bonem report was similar to the distributing pattern storages needed in this study. Therefore, the storage ratio between each function and the total capacity for the planned reservoirs from the Wollman-Bonem report was calculated and used to distribute the total needed storages into different benefit categories. Four benefit categories (flood, irrigation, power, and other) were designated in the Wollman-Bonem report. The "other" category included such purposes as recreation, municipal water supply, low flow argumentation for water dilution, and, in a few instances, navigation. An unknown share of the "other" category stands for multiple-purpose capacity. The calculated storage ratio between the planned and the total storage is shown in Table 4.4. By using the storage figures from Table 4.3 and the ratio from Table 4.4, storage needed for different functions and years can be calculated as shown in Tables 4.5 to 4.8.

Next, the additional storages needed by function and by year for each basin were designated as the goals for the four functions or benefit categories and for the four different years. These goals were then used as standards for calculating deficits.

Table 4.4. Calculated Storage Ratio Between the Planned and Total Storage by Function.

	Function Basin	Flood	Power	Irrigation	Other
(1)	Lower Arkansas-Red-White	0.372	0.360	0.011	0.257
(2)	Eastern Great Lakes	0.452	0.418	0	0.129
	Western Great Lakes	0.116	0.743	0	0.141
(3)	Lower Mississippi	0.231	0	0	0.769
(4)	New England	0.047	0.333	0.004	0.616
	Delaware-Hudson	0.238	0.158	0	0.604
	Chesapeake Bay	0.185	0.408	0	0.407
(5)	Ohio	0.655	0.146	0	0.199
	Cumberland	0.291	0.305	0	0.404
(6)	Southeast	0.128	0.618	0.016	0.238
(7)	Tennessee	0.290	0.300	0	0.410
(8)	Upper Mississippi	0.654	0.205	0	0.141

Deficit Levels

It was mentioned earlier in Chapter III that deficits were derived from the percentage of the goal achieved. Since storage needed by function and year in each basin was designated as the goal for a particular function and year, the calculation of deficit units, through the percentage of the goal, was then based on the percentage of needed storage built.

Although it would be more realistic to obtain different levels of deficit, (i.e., different percentages of the goal achieved) by the amount of money invested, for convenience several deficit levels were assumed in this study. The six deficit units used in this study were 1, 0.75, 0.5, 0.25, 0 and -0.25, corresponding to the percentages of the goals, 0%, 25%, 50%, 75%, 100% and 125%, respectively.

Table 4.5. Additional Storage Needed for Each Basin by Function for 1980 in Million Acre-feet.

Basin	Function	Flood	Power	Irrigation	Other	Total
(1)	Lower Arkansas Red-White	18.228	17.640	0.539	12.446	49
(2)	E. Great Lakes	15.820	14.630	0	4.515	35
	W. Great Lakes	3.364	21.547	0	4.089	29
(3)	Lower Mississippi	7.623	0	0	25.377	33
(4)	New England	3.431	24.309	0.292	44.895	73
	Delaware-Hudson	8.330	5.530	0	21.140	35
	Chesapeake Bay	13.140	29.784	0	29.711	73
(5)	Ohio	133.620	29.784	0	40.596	204
	Cumberland	2.910	3.050	0	4.040	10
(6)	Southeast	19.584	94.554	2.448	36.414	153
(7)	Tennessee	21.750	22.500	0	30.750	75
(8)	Upper Mississippi	19.620	6.150	0	4.230	30

Table 4.6. Additional Storage Needed for Each Basin by Function for 1985 in Million Acre-feet.

Function Basin		Flood	Power	Irrigation	Other	Total
(1)	Lower A-R-W	24.552	23.760	0.726	16.764	66
(2)	E. Great Lakes	21.244	19.646	0	6.063	47
	W. Great Lakes	4.524	28.977	0	5.499	39
(3)	Lower Mississippi	10.164	0	0	33.836	44
(4)	New England	4.512	31.968	0.384	59.040	96
	Delaware-Hudson	10.710	7.110	0	27.180	45
	Chesapeake Bay	17.640	39.984	0	39.886	98
(5)	Ohio	178.160	39.712	0	54.128	272
	Cumberland	4.074	4.270	0	5.656	14
(6)	Southeast	26.240	126 690	3.280	48.790	205
(7)	Tennessee	29.000	30.000	0	41.000	100
(8)	Upper Mississippi	26.160	8.200	0	5.640	40

Table 4.7. Additional Storage Needed for Each Basin by Function for 1990 in Million Acre-feet.

Function Basin		Flood	Power	Irrigation	Other	Total
(1)	Lower A-R-W	30.132	29.160	0.891	20.574	81
(2)	E. Great Lakes	26.216	24.244	0	7.482	58
	W. Great Lakes	5.684	36.407	0	6.909	49
(3)	Lower Mississippi	12.705	0	0	42.295	55
(4)	New England	5.687	40.293	0.484	74.415	121
	Delaware-Hudson	13.566	9.005	0	34.428	57
	Chesapeake Bay	22.320	50.520	0	50.468	124
(5)	Ohio	222.700	49.640	0	67.660	340
	Cumberland	4.947	5.185	0	6.868	17
(6)	Southeast	32.640	157.590	4.080	60.690	255
(7)	Tennessee	36.250	37.500	0	51.250	125
(8)	Upper Mississippi	32.700	10.250	0	7.050	50

Table 4.8. Additional Storage Needed for Each Basin by Function for 1995 in Million Acre-feet.

Function Basin		Flood	Power	Irrigation	Other	Total
(1)	Lower A-R-W	36.828	35.640	1.089	25.146	99
(2)	E. Great Lakes	31.640	29.260	0	9.030	70
	W. Great Lakes	6.844	43.837	0	8.319	59
(3)	Lower Mississippi	15.246	0	0	50.754	66
(4)	New England	6.708	47.952	0.576	88.560	144
	Delaware-Hudson	16.184	10.744	0	41.072	68
	Chesapeake Bay	26.640	60.384	0	60.236	148
(5)	Ohio	267.895	59.714	0	81.391	409
	Cumberland	6.111	6.405	0	8.484	21
(6)	Southeast	39.040	188.490	4.880	72.590	305
(7)	Tennessee	43.790	45.300	0	61.910	151
(8)	Upper Mississippi	39.240	12.300	0	8.460	60

Returns

Deficit levels were then converted into returns by using the exponential curve, $y = 10^x$, where y designates return and x, deficit. The reasons for using this curve were explained in the last chapter, and an example of this particular curve was also illustrated in Figure 3.4. Hence, the explanation for the mapping will not be repeated. The six deficit units used in this study (1, 0.75, 0.5, 0.25, 0 and -0.25) are equivalent to the return units of 0.57, 1, 1.78, 3.17, 5.63 and 10, respectively. The following table shows the relationship between the percent of the goal achieved, deficit units, and the unadjusted raw return which was derived by using the exponential curve, $y = 10^x$.

Percent of Goal Achieved	125	100	75	50	25	0
Unit of Deficit	-0.25	0	0.25	0.5	0.75	1
Unadjusted Return	0.57	1	1.78	3.17	5.63	10

Costs

Associated with every deficit level, there is a cost. In the "Wollman-Bonem" report, different cost-storage relationships were listed. For the purpose of this study, the relationship between the cumulative storage and the annual cumulative cost was employed to obtain the cost-storage curves. The annual cumulative cost was derived from the capital cost by using the factor of 0.0425. The factor is equivalent to a life of fifty years, an interest rate of 4 percent, and ¼ percent of the capital costs for operation and maintenance. The cost-storage curves for the basins considered in this study are shown in Figures 4.1 to 4.12. These curves were used to calculate the costs needed for removing different storage deficiencies.

Next, storage costs from the same function and the same deficit level in every basin were added together for each of the basins of the Water Resources Council. For example, storage costs for achieving 100 percent of the goal and for the flood control benefit from the basins of the Eastern and Western Great Lakes were added together to obtain the total storage cost for their corresponding Water Resources Council basin, Great Lakes, for the same function and the same percentage of the goal.

Total storages needed for the different functions and the different deficit levels in every Water Resources Council basin were also obtained in a similar fashion.

Weighting Factors

Benefit Priority Weighting Factor λ_i

No particular benefit priority weighting factor was developed for this study. This factor was assumed to be equal to 1 in this study due to the fact that when the total storages were being distributed according to functions, the needs for each benefit category were evaluated as being equally important.

Expense Weighting Factor ϕ_{cij}

Two such factors were used in this study. The one used for the 1980 study was derived from the following formula:

$$\text{Expense weighting factor } \phi_{cij} = 4 - (4/400\ C_{ij})$$

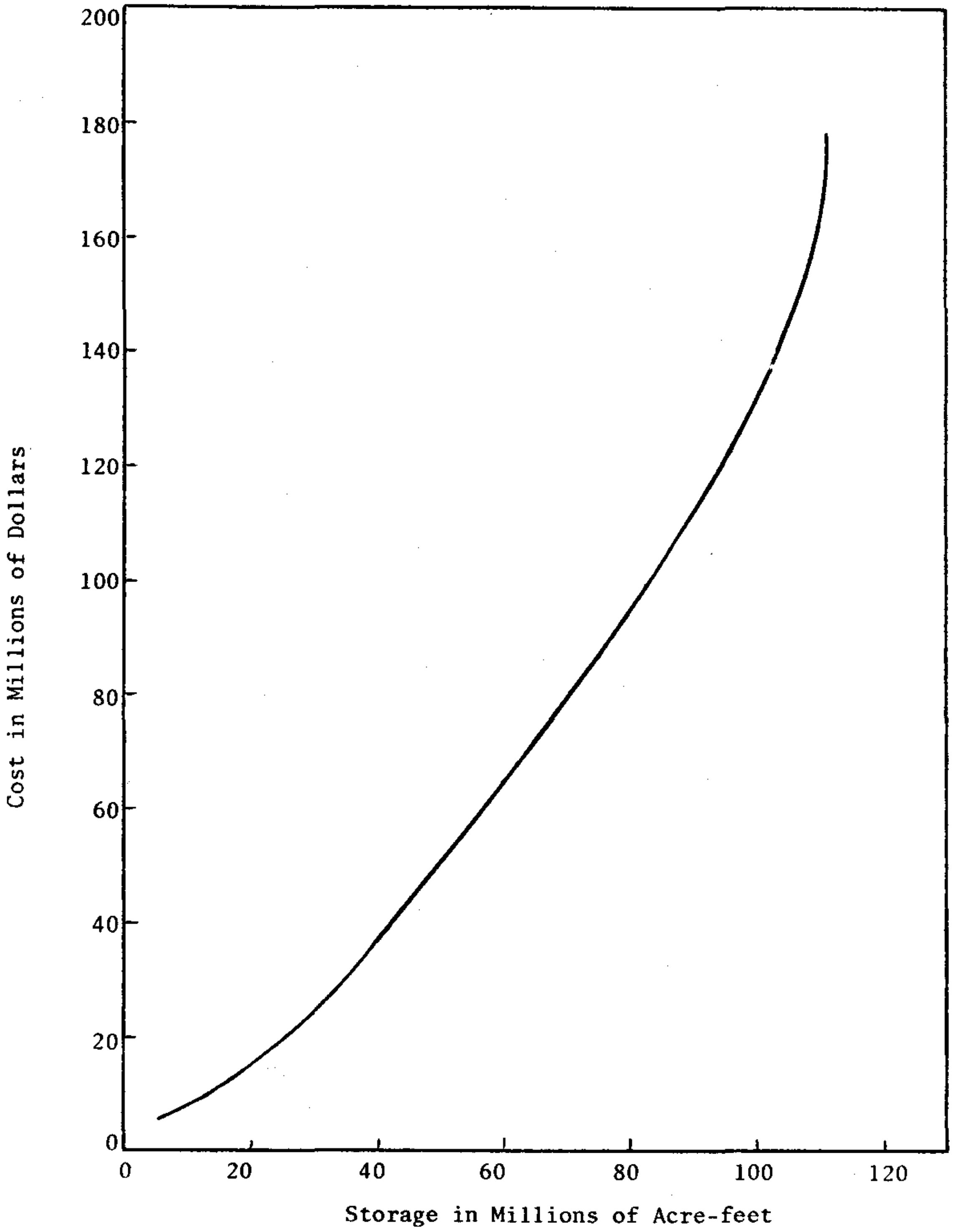


Figure 4.1. Cost-storage Relationship for the Lower Arkansas-Red-White Region.

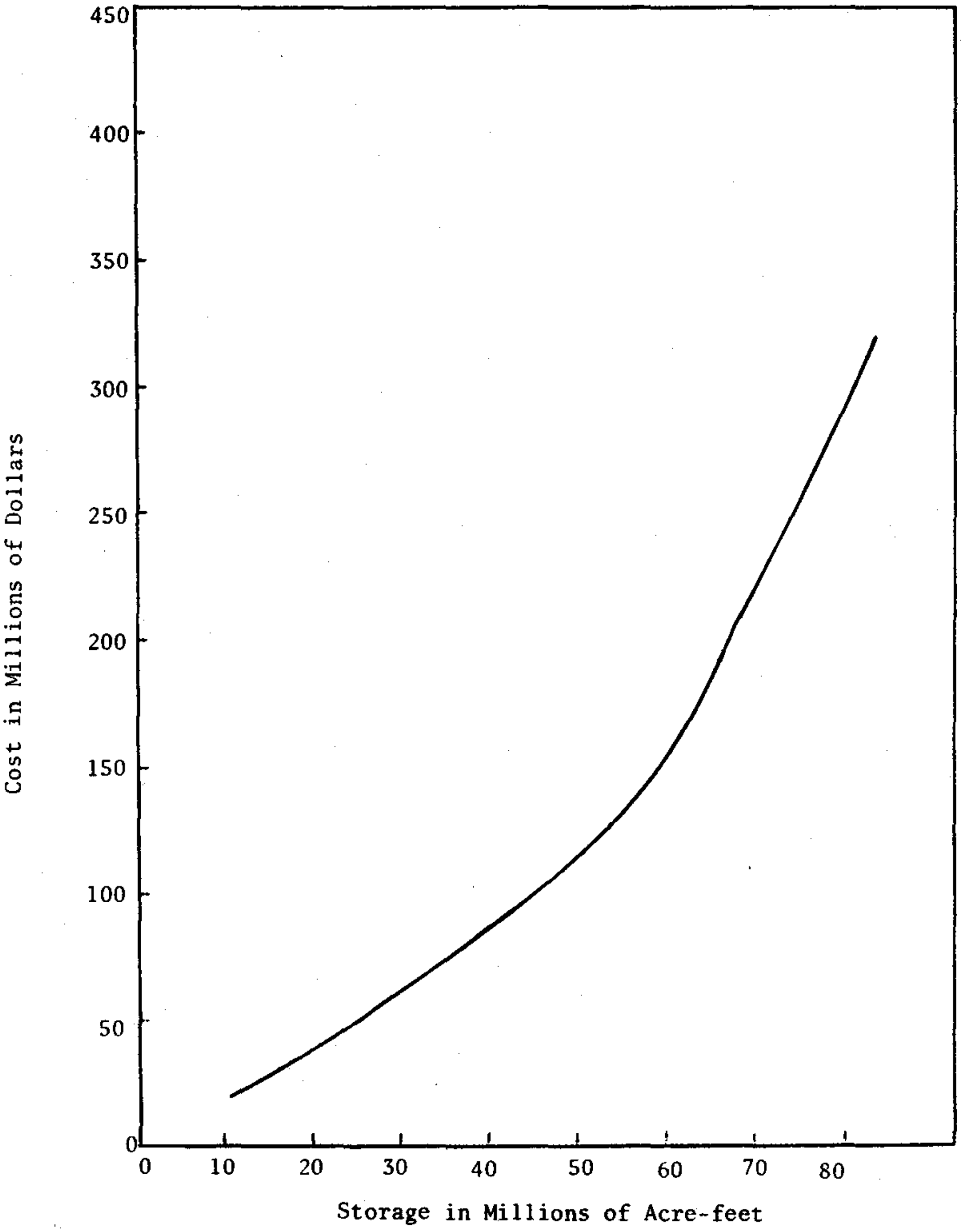


Figure 4.2. Cost-storage Relationship for the Eastern Great Lakes Region.

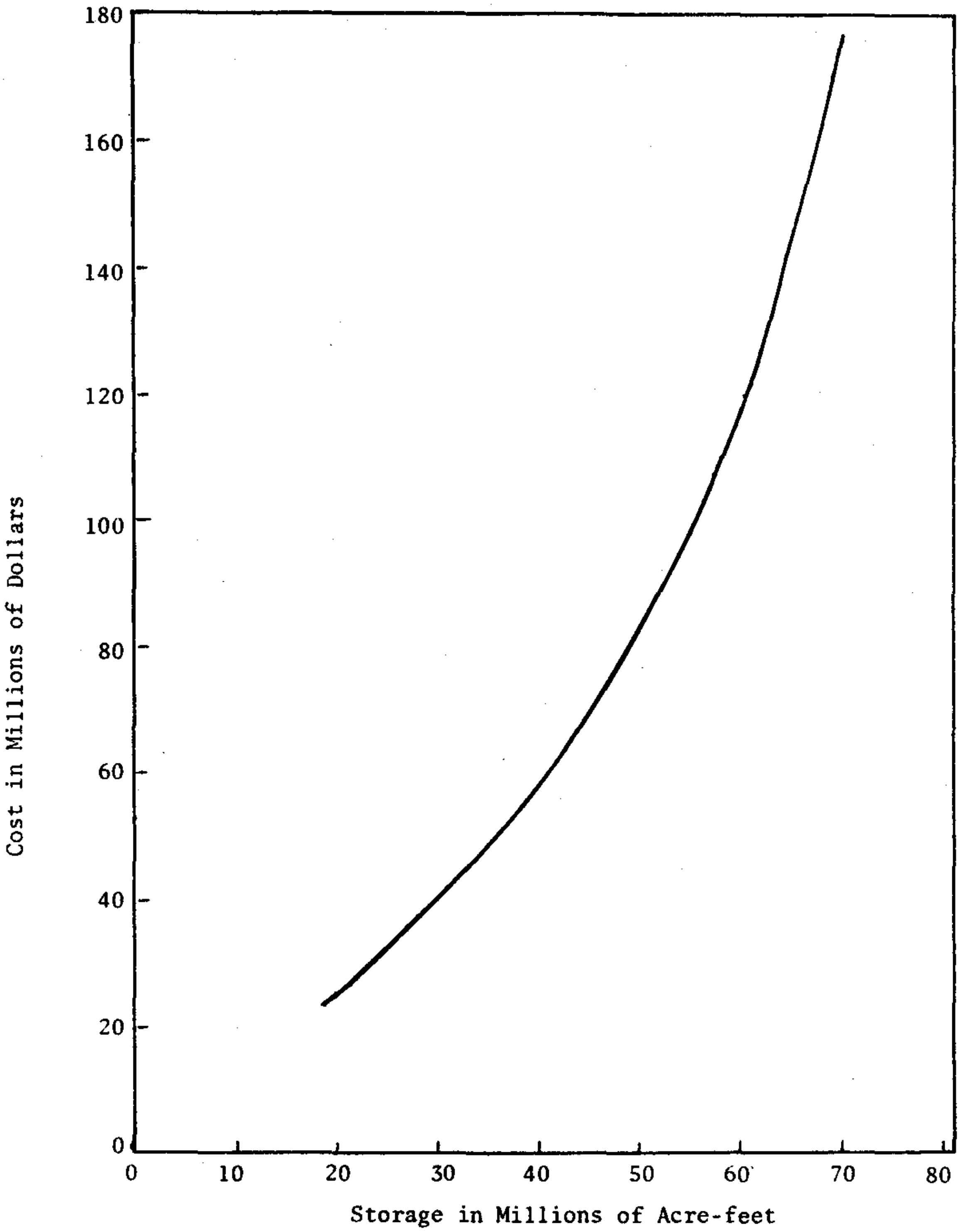


Figure 4.3. Cost-storage Relationship for the Western Great Lakes Region.

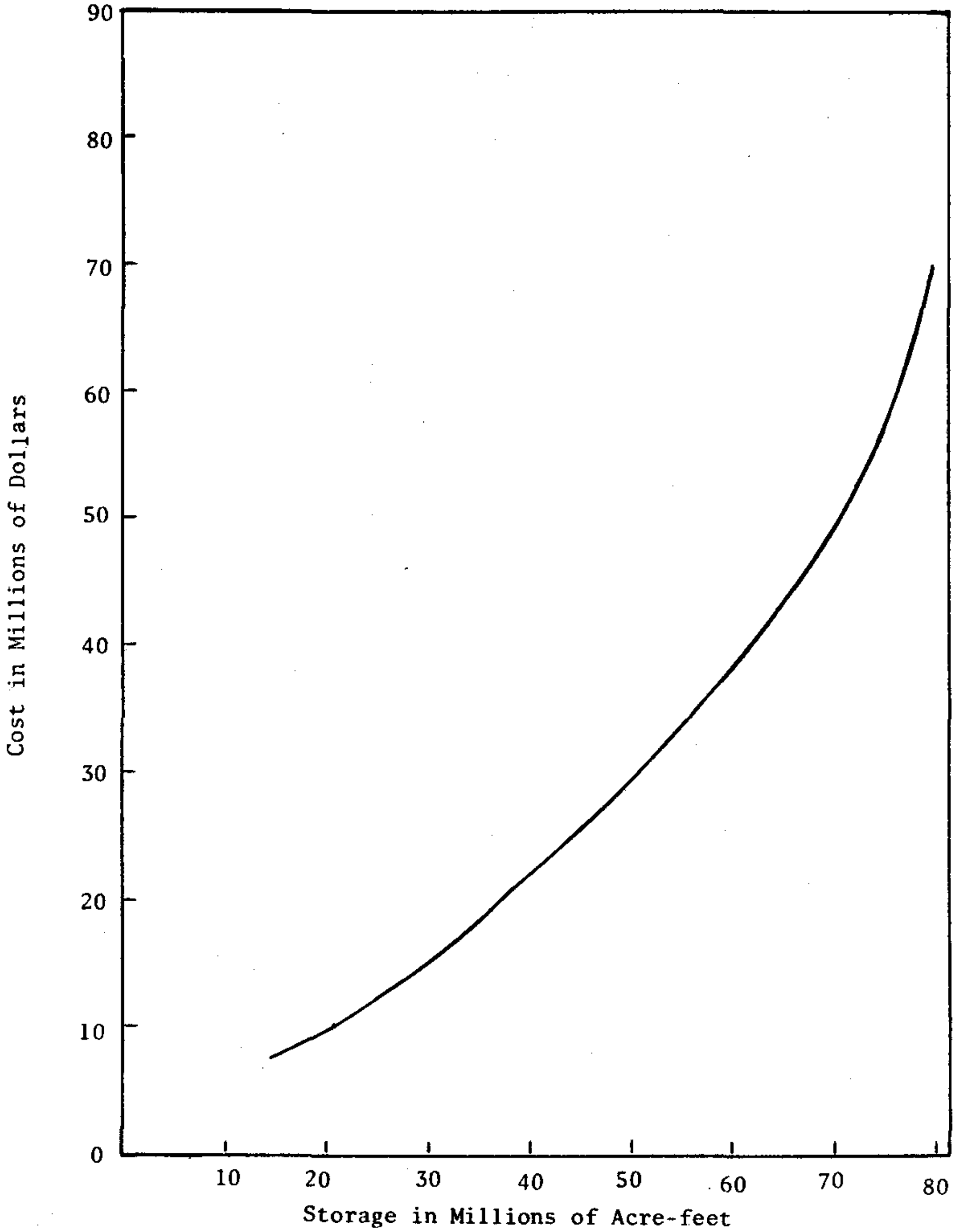


Figure 4.4. Cost-storage Relationship for the Lower Mississippi Region.

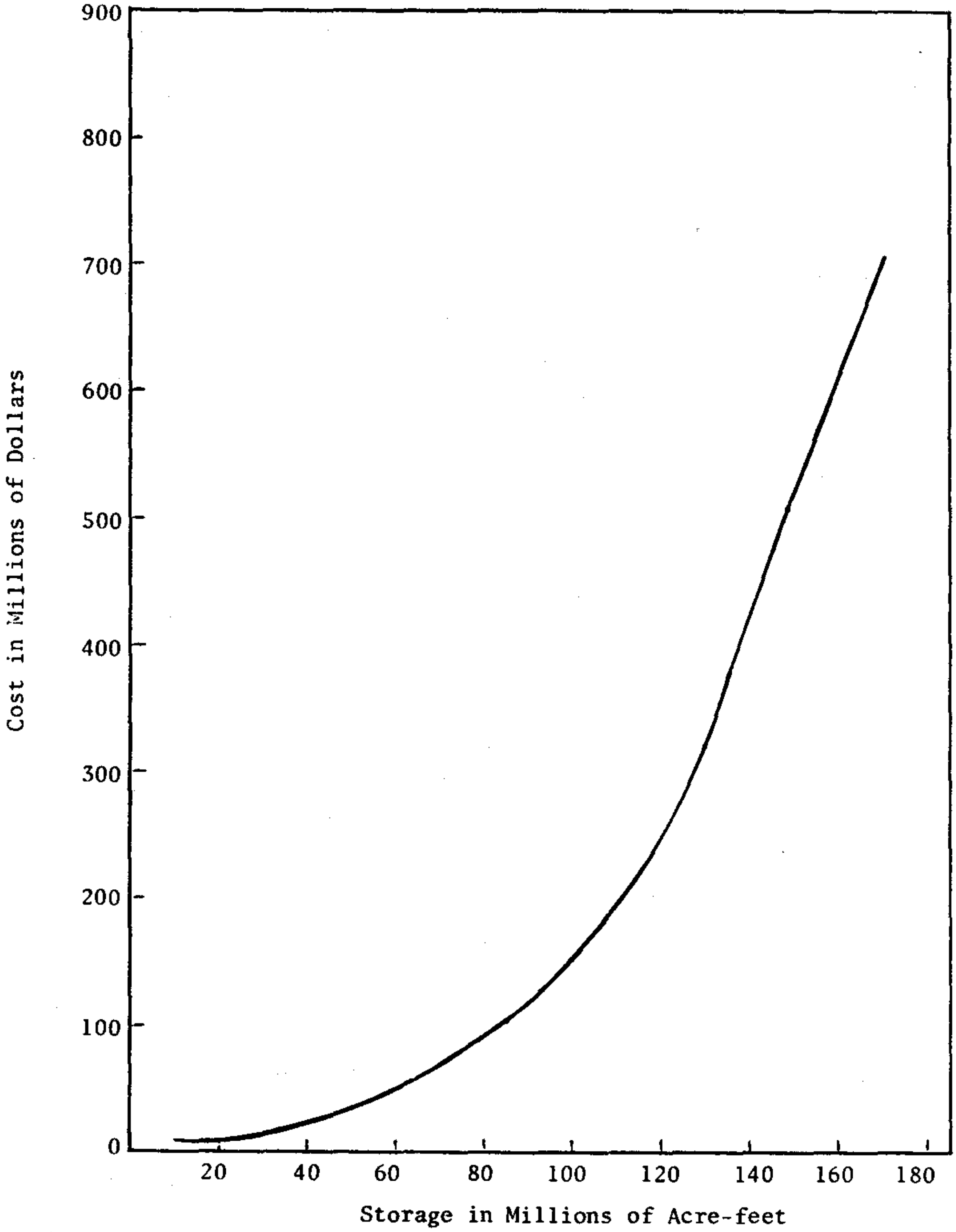


Figure 4.5. Cost-storage Relationship for the New England Region.

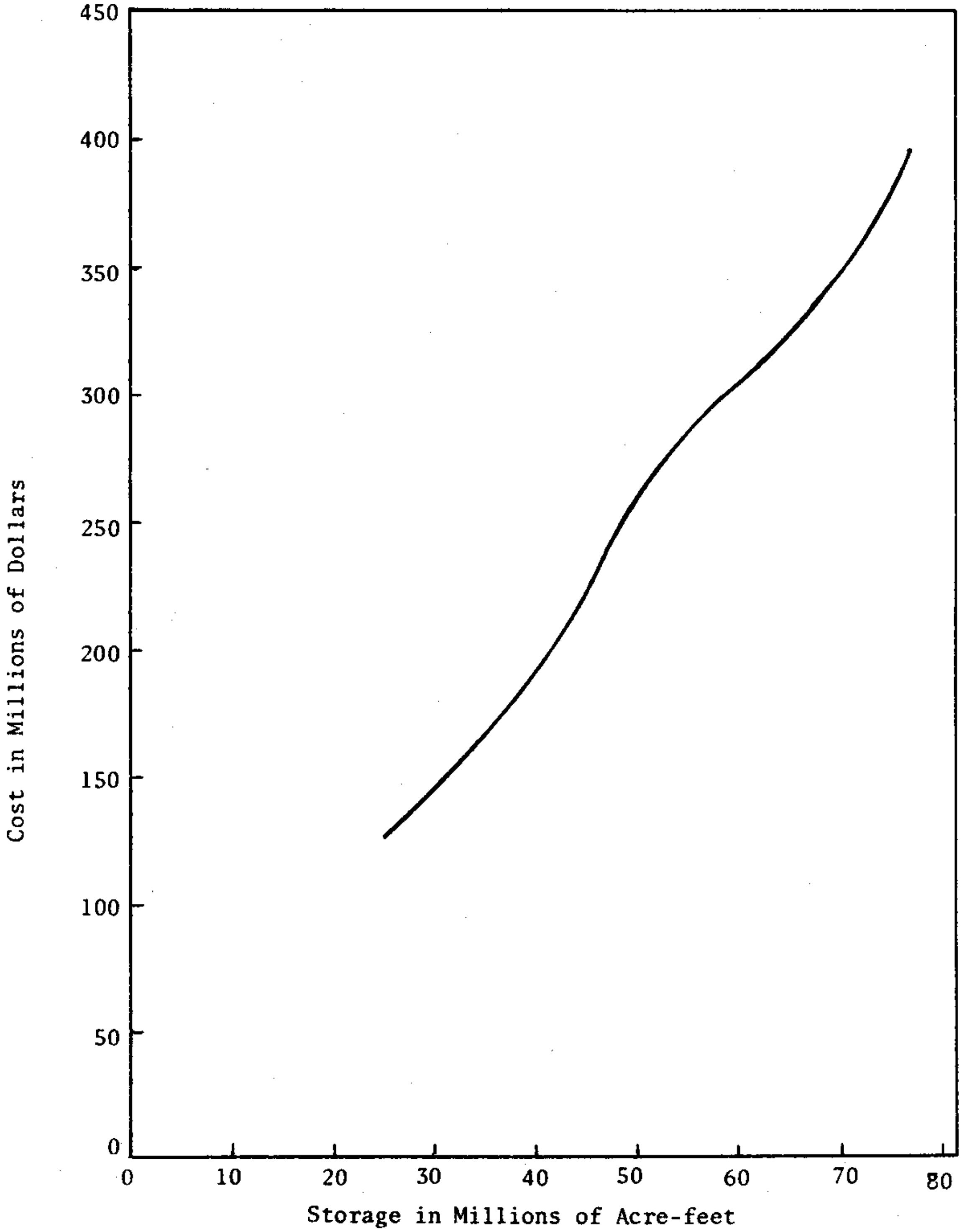


Figure 4.6. Cost-storage Relationship for the Delaware-Hudson Region.

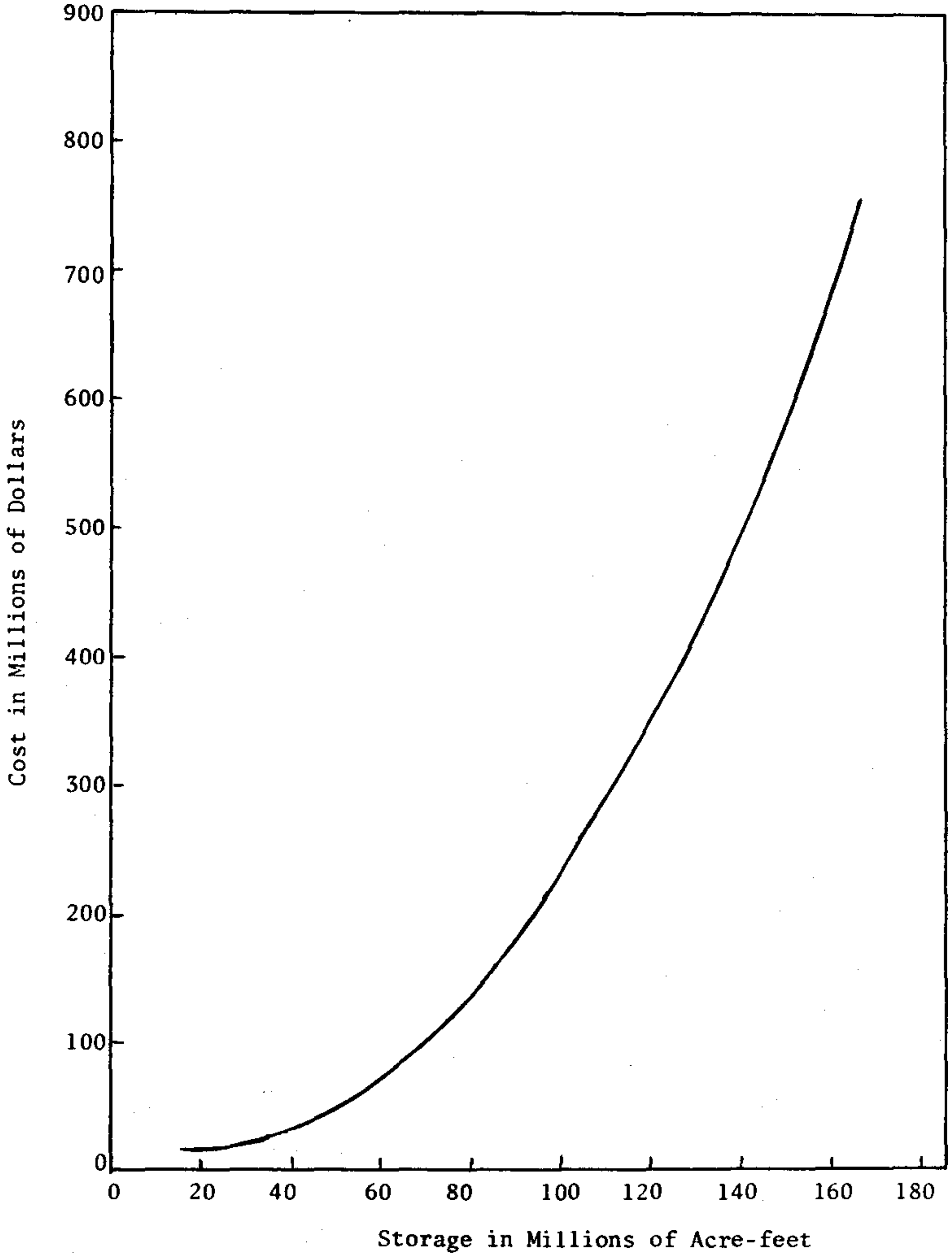


Figure 4.7. Cost-storage Relationship for the Chesapeake Bay Region.

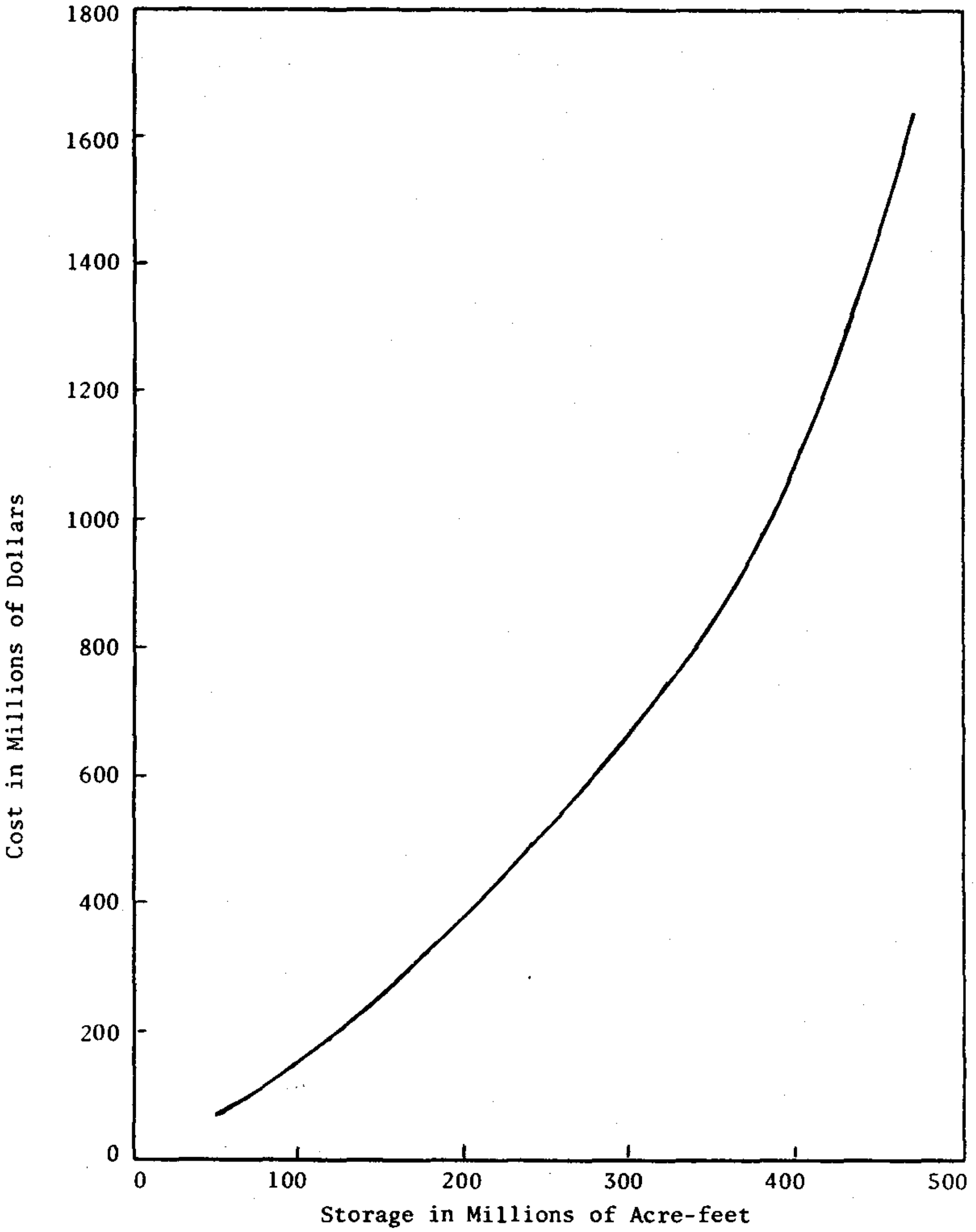


Figure 4.8. Cost-storage Relationship for the Ohio Region.

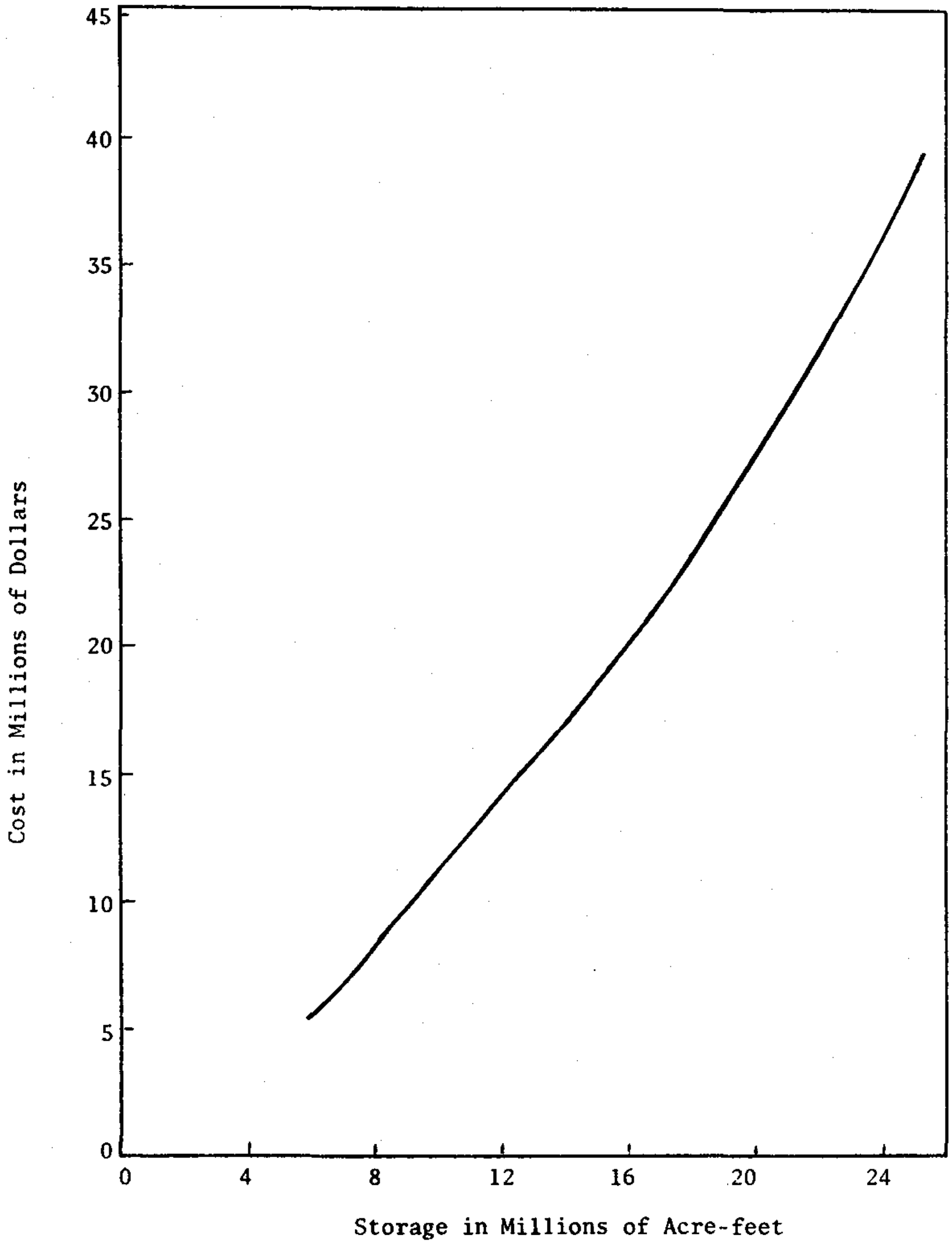


Figure 4.9. Cost-storage Relationship for the Cumberland Region.

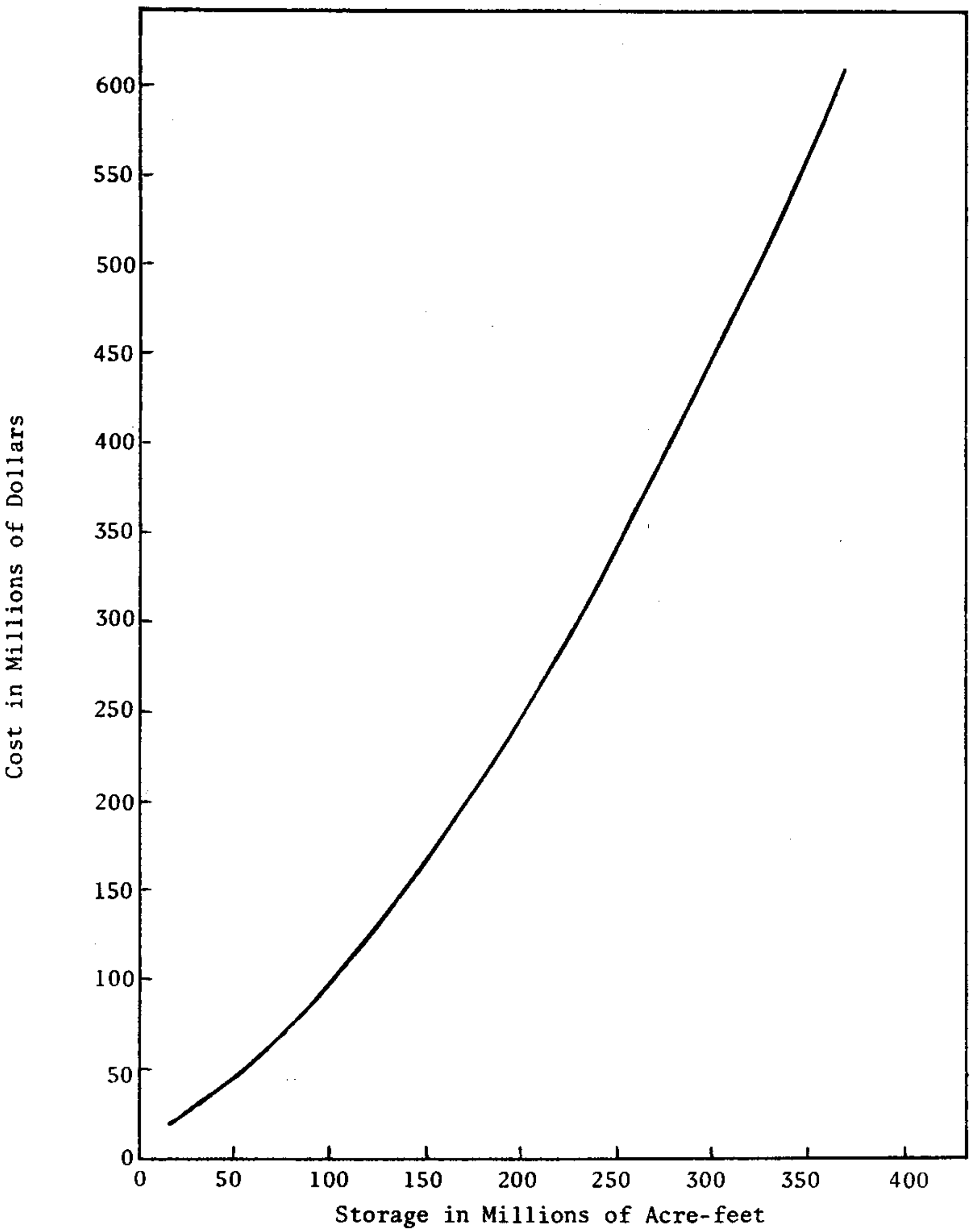


Figure 4.10. Cost-storage Relationship for the Southeast Region.

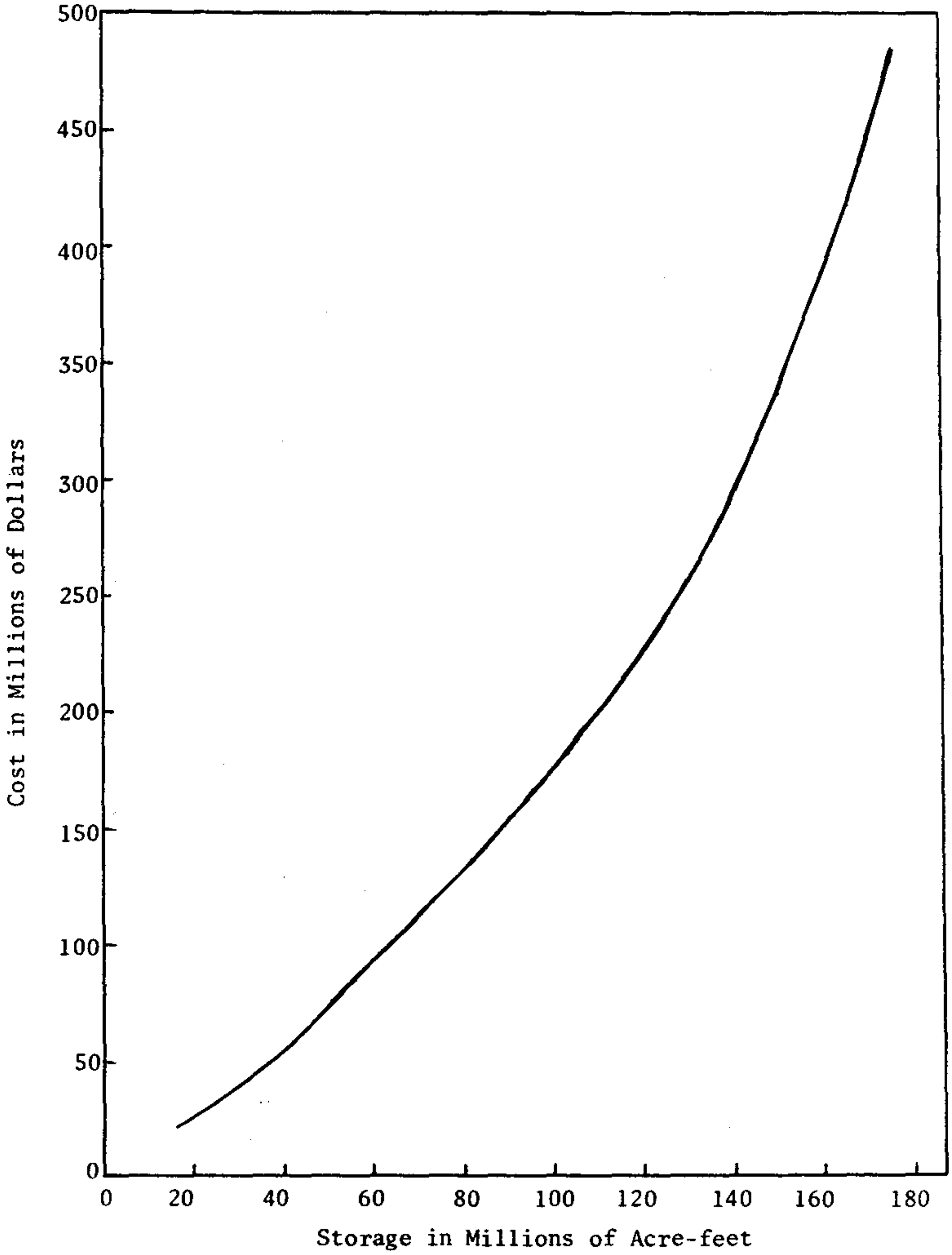


Figure 4.11. Cost-storage Relationship for the Tennessee Region.

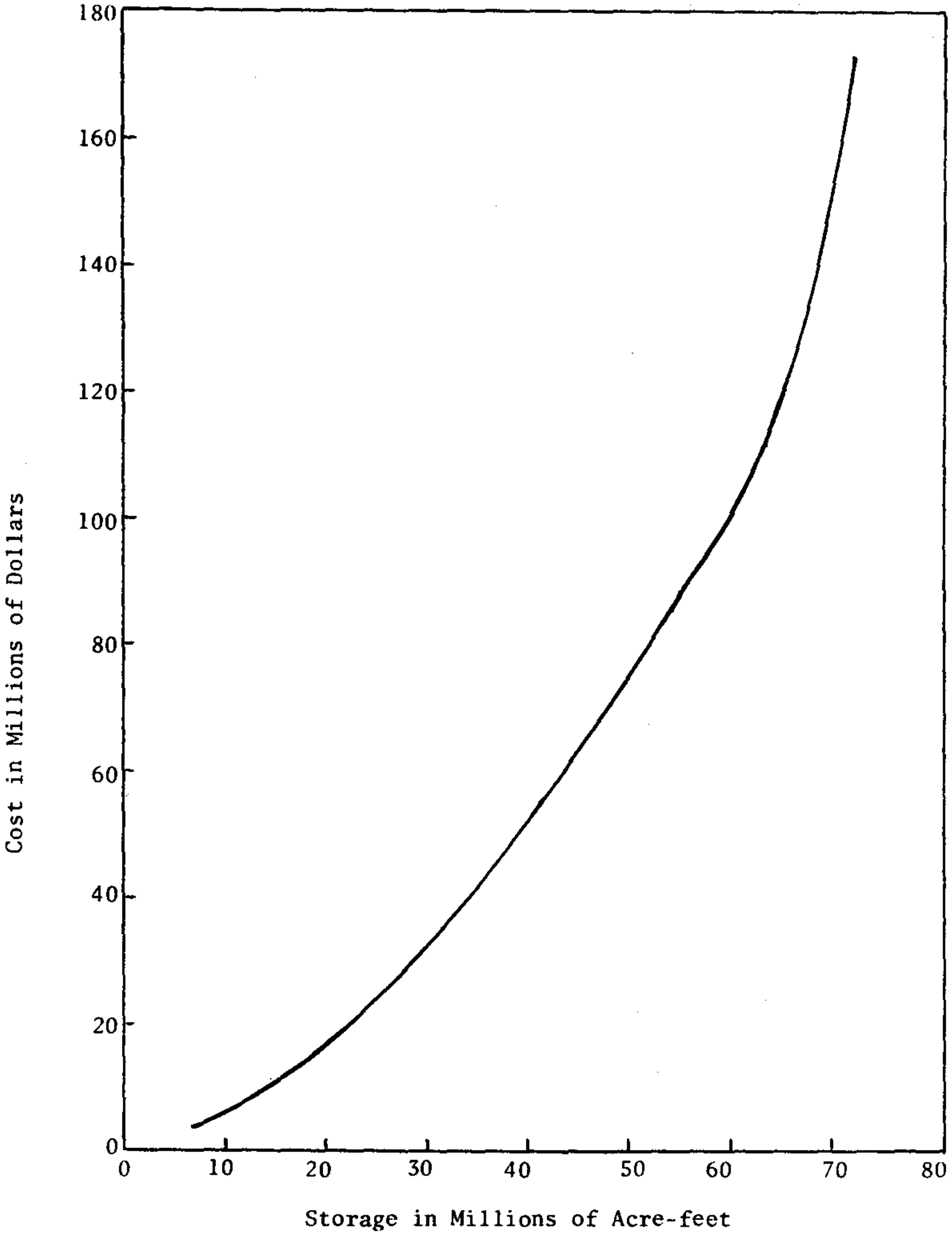


Figure 4.12. Cost-storage Relationship for the Upper Mississippi Region.

where C_{ij} is the cost. The other factor, used in the 1985, 1990, and 1995 study, was derived as follows:

$$\text{Expense weighting factor } \phi_{cij} = 4 - (4/800\ C_{ij}) \ .$$

These two weighting factors were then multiplied by their corresponding original returns which were derived from deficits to obtain the adjusted returns.

Activity Variable X_{ij}

Since continuous linear programming was employed for this study the constraint that X_{ij} (where i stands for the benefit category and j for the deficit level) must be a zero-one integer was dropped. This means that in the solution set, X_{ij} would assume any value between 0 and 1 depending on how optimum was reached. In other words, to satisfy the constraint $\sum_j X_{ij} = 1$ for each benefit i, there could be more than one X_{ij} with the same i appearing in the optimal solution. Every X_{ij} represents a particular deficit level j. The appearance of more than one X_{ij} with the same i and different j in the optimal set indicates that more than one deficit level with associated costs should be considered. So far, only two X_{ij}'s with same i had appeared in any basin model study. In order to obtain the unique optimal solution for every benefit category, a weighted average was calculated based on these two different X_{ij}'s. For example, in the 1980 Upper Mississippi Basin model study (basin budget 22 million dollars), two X_{ij}'s appeared for the flood control benefit. They were X_{12} and X_{13} with a value equal to

0.58987 and 0.41013, respectively. The X_{12} represented 100 percent of the goal achieved with a cost of 15.82 million dollars, storage of 19,620 acre-feet, and a return of 3.84; whereas, X_{13} represented a 75 percent of goal with cost 11.87 million dollars, storage of 14,715 acre-feet, and a return of 6.91. The optimal values for the percent of the goal achieved, the cost, the storage, and the return were derived by summing of the two values represented by X_{12} and X_{13} and multiplied by the values of X_{12} and X_{13}.

Therefore,

Total optimal percentage of the goal achieved = $100\% \times X_{12} + 75\% \times X_{13}$

$= 100\% \times 0.58987 + 75\% \times 0.41013 = 89.75\%$.

Total cost = $[(15.82 \times X_{12}) + (11.87 \times 0.41013)]$ million dollars

= 14.2 million dollars.

Total storage = $(19620 \times X_{12} + 14715 \times X_{13})$A-f = 17608 acre-feet.

Total return = $3.84 \times X_{12} + 6.91 \times X_{13} = 5.1$.

The appearance of two X_{ij}'s does not affect the national model because only the total return for a basin budget is used in the national model. For the basin level study, the percentage of the goal achieved, the storage needed, and the cost can easily be obtained by the above method.

Basin Budget

As was mentioned earlier in Chapter III, six basin budgets, ranging from what was needed to achieve the highest percentage of the goal to a budget of zero, were used in this study. These six budgets were distributed approximately evenly from the highest to the lowest.

Summary

The following summarizes all of the needed input data for the basin level model:

(a) Basin - Eight Water Resources Council Basins.

(b) Year - 1980, 1985, 1990 and 1995.

(c) Benefit Category - Four categories:

$i = 1$ - representing the flood control benefit
$i = 2$ - representing the power benefit
$i = 3$ - representing the irrigation benefit
$i = 4$ - representing other benefits

All four were not considered for each basin.

(d) Deficit Levels - Six deficit levels:

$j = 1$ - representing deficit unit -0.25, 125% of the goal achieved
$j = 2$ - representing deficit unit 0, 100% of the goal achieved
$j = 3$ - representing deficit unit 0.25, 75% of the goal achieved
$j = 4$ - representing deficit unit 0.5, 50% of the goal achieved
$j = 5$ - representing deficit unit 0.75, 25% of the goal achieved
$j = 6$ - representing deficit unit 1, 0% of the goal achieved.

(e) Weighting Factors -

Basin benefit priority weighting factor $\lambda_i = 1$

Two expense weighting factors ϕ_{cij}

1 - used only for the 1980 study
2 - used for the 1985, 1990 and 1995 studies.

(f) Cost - Storage-cost curves from the Wollman-Bonem report were used to derive storage costs for the basins of the Water Resources Council.

(g) Activity Variable X_{ij} - i representing benefit and j, deficit level. There were twenty-four such variables for every basin.

(h) Adjusted Return - Original return $r_{ij} = y = 10^x$, where x is the deficit unit.

$$\text{Adjusted return } R_{ij} = \lambda_{ij}\phi_{cij}r_{ij}$$

(i) Basin Budget - Six basin budgets for each basin. A sample of the input is shown in Table 4.9.

Data by year and basin were then used in the linear programming defined earlier to obtain the optimal solution (a list of total returns associated with the corresponding basin budgets for the eight basins). A sample of the output is shown in Table 4.10.

With these results in hand, the national level model was used for the eight basins.

National Level Model

Output data from the basin level model were then used for the national level model. How the national model was tested will be discussed in this section.

Method for Calculation

The same linear programming that was used for the basin model was also used for the national model, also dropping the constraint that the activity variable X_{ij} must be a zero-one integer.

Inputs of the Model

Basins

The eight basins used for the basin level model were used in the national level model.

Table 4.9. Sample of Input for Basin Level Model Using the South Atlantic-Gulf Basin as an Example (1995).

Function	Activity Variable	Percent of Goal	Deficit Unit	Storage in 1000 acre-feet	Return	Adjusted Return	Cost
Flood	X_{11}	125	0.57	48800	0.57	2.16	42.47
	X_{12}	100	1.00	39040	1.00	3.83	34.28
	X_{13}	75	1.78	29280	1.78	6.89	25.71
	X_{14}	50	3.17	19520	3.17	12.43	17.14
	X_{15}	25	5.63	9760	5.63	22.04	7.46
	X_{16}	0	10.00	0	10.00	40.00	0
Power	X_{21}	125	0.57	235613	0.57	1.40	310.00
	X_{22}	100	1.00	188490	1.00	2.84	233.00
	X_{23}	75	1.78	141368	1.78	5.70	159.00
	X_{24}	50	3.17	94245	3.17	11.05	103.00
	X_{25}	25	5.63	47123	5.63	21.36	41.38
	X_{26}	0	10.00	0	10.00	40.00	0
Irrigation	X_{31}	125	0.57	6100	0.57	2.27	4.68
	X_{32}	100	1.00	4800	1.00	3.99	3.75
	X_{33}	75	1.78	3660	1.78	7.09	2.81
	X_{34}	50	3.17	2440	3.17	12.65	1.88
	X_{35}	25	5.63	1220	5.63	22.45	0.94
	X_{36}	0	10.00	0	10.00	40.00	0
Other	X_{41}	125	0.57	90738	0.57	2.01	95.00
	X_{42}	100	1.00	72590	1.00	3.64	72.00
	X_{43}	75	1.78	54443	1.78	6.68	50.00
	X_{44}	50	3.17	36295	3.17	12.17	31.87
	X_{45}	25	5.63	18148	5.63	22.07	15.94
	X_{46}	0	10.00	0	10.00	40	0

Table 4.10. Sample of Output from Basin Level Model using the South Atlantic-Gulf Basin as an Example (1995).

Basin Budget in Million Dollars	Function	Chosen Activity Variable and its Value	Per-Cent of Goal	Cost Million Dollars	Return	Total Return for the Budget in Million Dollars
50	Flood	$X_{13}=1$	75	25.71	6.89	68.95
	Power	$X_{26}=1$	0	0	40.00	
	Irrigation	$X_{31}=1$	125	4.68	2.27	
	Other	$X_{44}=0.23038$ $X_{45}=0.76965$	31	19.61	19.79	
100	Flood	$X_{13}=1$	75	25.71	6.89	44.33
	Power	$X_{25}=0.91203$ $X_{26}=0.08793$	23	37.74	22.84	
	Irrigation	$X_{31}=1$	125	4.68	2.27	
	Other	$X_{44}=1$	50	31.87	12.17	
150	Flood	$X_{11}=1$	125	42.47	2.16	30.55
	Power	$X_{24}=0.18614$ $X_{25}=0.81386$	30	52.85	19.44	
	Irrigation	$X_{31}=1$	125	4.68	2.27	
	Other	$X_{43}=1$	75	50.00	6.88	
200	Flood	$X_{11}=1$	125	42.47	2.16	22.19
	Power	$X_{24}=0.99757$ $X_{25}=0.00243$	50	102.85	11.08	
	Irrigation	$X_{31}=1$	125	4.68	2.27	
	Other	$X_{43}=1$	75	50.00	6.68	
300	Flood	$X_{11}=1$	125	42.47	2.16	12.22
	Power	$X_{23}=1$	50	159.00	5.70	
	Irrigation	$X_{31}=1$	125	4.68	2.27	
	Other	$X_{41}=0.95$ $X_{42}=0.05$	124	93.85	2.09	

Table 4.10. Sample of Output from Basin Level Model using the South Atlantic-Gulf Basin as an Example (1995) (Cont'd.)

Basin Budget in Million Dollars	Function	Chosen Activity Variable and its Value	Per-Cent of Goal	Cost Million Dollars	Return	Total Return for the Budget in Million Dollars
400	Flood	$X_{11}=1$	125	42.47	2.11	8.82
	Power	$X_{21}=0.32273$ $X_{22}=0.67727$	108	257.85	2.44	
	Irrigation	$X_{31}= 1$	125	4.68	2.77	
	Other	$X_{41}=1$	125	45.00	2.01	

Year

The national model was operated for the same four years as the basin model (1980, 1985, 1990 and 1995).

Basin Budget Level

The six budgets for each basin used in the basin model were entered.

Activity Variable X_{ij}

Since there were eight basins and six basin budgets, there were forty-eight activity variables in the national model.

The basins corresponding to the subscript i for X_{ij} are shown below:

i = 1 - Arkansas-White-Red Basin
i = 2 - Great Lakes Basin
i = 3 - Lower Mississippi Basin
i = 4 - North Atlantic Basin
i = 5 - Ohio Basin
i = 6 - South Atlantic-Gulf Basin
i = 7 - Tennessee Basin
i = 8 - Upper Mississippi Basin.

Basin budgets corresponding to the subscript j were varied from basin to basin. They are shown in the input table (see sample input Table 4.11).

X_{ij} could take any value between 0 and 1 in the optimal program output. If a X_{ij} value was anything other than 0 and 1, its value was then used to find the final weighted optimal solution by the same method discussed in the basin model.

Table 4.11. Sample Input Table for the National Level Model (1980) (Cont'd.)

Basin	Activity Variable	Return	Adjusted Return	Basin Budget in Million Dollars
North Atlantic	X_{41}	6.78	7.12	415.28
	X_{42}	8.56	8.99	340.00
	X_{43}	14.57	15.30	250.00
	X_{44}	27.06	29.17	170.00
	X_{45}	56.78	59.62	80.00
	X_{46}	160.00	168.00	0
Ohio	X_{51}	4.09	11.76	480.68
	X_{52}	5.80	16.68	390.00
	X_{53}	10.58	30.42	290.00
	X_{54}	21.26	61.12	190.00
	X_{55}	49.56	142.49	90.00
	X_{56}	120.00	345.00	0
South Atlantic-Gulf	X_{61}	7.98	22.94	199.25
	X_{62}	10.64	30.59	160.00
	X_{63}	15.77	45.34	120.00
	X_{64}	20.74	76.88	80.00
	X_{65}	52.32	150.42	40.00
	X_{66}	160.00	460.00	0

Table 4.11 Continued

Table 4.11. Sample Input Table for the National Level Model (1980) (Cont'd.)

Basin	Activity Variable	Return	Adjusted Return	Basin Budget in Million Dollars
Tennessee	X_{71}	6.09	17.51	130.93
	X_{72}	8.09	23.26	110.00
	X_{73}	12.45	35.79	90.00
	X_{74}	22.06	63.42	60.00
	X_{75}	59.51	171.09	25.00
	X_{76}	120.00	345.00	0
Upper Mississippi	X_{81}	6.63	19.89	35.57
	X_{82}	7.58	22.74	29.00
	X_{83}	9.61	28.83	22.00
	X_{84}	21.26	63.78	15.00
	X_{85}	30.44	91.32	8.00
	X_{86}	120.00	360.00	0

Weighting Factor

Only one weighting factor, the basin priority weighting factor, was used. This factor was derived by using the criteria developed by the Army Corps of Engineers. The derivation was discussed in Chapter III. The exact formula used in this study is shown as follows:

$$\text{Basin Priority Weighting Factor } \theta_i = 4 - (3/120\ S_i) ,$$

where S_i is the sum of the percentages of the five criteria developed by the Army Corps of Engineers for basin i. The derived factors for the eight basins and their S_i's are shown on Table 4.12.

Returns

Six returns r_{ij}, corresponding to the six basin budgets for every basin by year from the basin model, were used. They were then multiplied by the basin priority weighting factor θ_i to become the adjusted returns R_{ij} before entering the national model.

$$\text{Adjusted Return } R_{ij} = \theta_i r_{ij}$$

National Budgets

Six national budgets were used for each year. These six budgets, ranging from what was needed to meet the highest percentage of the goal to a budget of zero, were distributed approximately even from the largest to the smallest.

Summary

After collecting all of the needed data (return R_{ij}, basin budget B_{ij}, activity variable X_{ij}, and national budget P) the national model was then run for the years of 1980, 1985, 1990, and 1995. A

Table 4.12. Basin Priority Weighting Factors

i	Basin	S_i Sum of the Percent of the Five Criteria	Θ_i Basin Priority Weighting Factor
1	Arkansas-White-Red	24	3.400
2	Great Lakes	48	2.800
3	Lower Mississippi	19	3.525
4	North Atlantic	118	1.050
5	Ohio	45	2.875
6	South Atlantic-Gulf	45	2.875
7	Tennessee	-	2.875*
8	Upper Mississippi	40	3.000

*Since data was not available for the Tennessee Basin, this factor was assumed to be the same as the Ohio Basin and the South Atlantic-Gulf Basin.

sample of the national model input is shown in Table 4.11. Outputs of the national level model for the different years are shown in Table 4.13 to Table 4.16.

Conclusions

Observing the results from the basin level model, it was noted that, in general, for any basin budget the optimal solution always selected the returns which had larger unit costs first. Returns are in penalty sense; more investment implies less return. In other words, those benefit categories which cost less to achieve higher percentages of goals were selected first by the optimal solution. As the basin budget increased, returns from the benefit categories which were comparatively more expensive to accomplish were then selected. Investments were always used to satisfy the less expensive needs first.

An example of the results from the 1995 South Atlantic-Gulf Basin is shown in Figure 4.13. In this figure, the relationship between function and cost for different basin budgets is illustrated. The four functions indicated by i represent flood control, power, irrigation, and other benefits. For the six basin budgets, straight lines joining the costs of each function for different basin budgets are shown. From the curves, it can be seen that function 3, the irrigation benefit, which has the lowest costs for higher percentages of the goals was satisfied first for every basin budget. Funds were allocated to the power benefit last because it was the most expensive item.

Figure 4.14 is similar to Figure 4.13 with the exception that the cost is replaced by return. If lines joining returns for each function are repeated for several budgets, the line represents the largest return

Table 4.13. Output from the National Model for the Year 1980.

National Budget in Million Dollars	Basin	Chosen Activity Variable and its Value	Return	Basin Budget in Million Dollars	Total Return
200	Arkansas-White-Red	$X_{13}=1$	88.71	30.00	1015.22
	Great Lakes	$X_{24}=0.12$ $X_{25}=0.88$	149.34	28.00	
	Lower Mississippi	$X_{32}=1$	21.50	20.00	
	North Atlantic	$X_{46}=1$	168.00	0	
	Ohio	$X_{56}=1$	345.00	0	
	South Atlantic-Gulf	$X_{65}=1$	150.42	40.00	
	Tennessee	$X_{74}=1$	63.42	60.00	
	Upper Mississippi	$X_{83}=1$	28.83	22.00	
400	Arkansas-White-Red	$X_{11}=1$	29.95	55.25	581.56
	Great Lakes	$X_{24}=1$	82.12	50.00	
	Lower Mississippi	$X_{31}=1$	15.58	23.77	
	North Atlantic	$X_{45}=0.23725$ $X_{46}=0.76275$	142.29	18.98	
	Ohio	$X_{55}=1$	142.49	90.00	
	South Atlantic-Gulf	$X_{64}=1$	76.88	80.00	
	Tennessee	$X_{74}=1$	63.42	60.00	
	Upper Mississippi	$X_{83}=1$	28.83	22.00	
600	Arkansas-White-Red	$X_{11}=1$	29.95	55.25	370.72
	Great Lakes	$X_{22}=1$	25.90	105.00	
	Lower Mississippi	$X_{31}=1$	15.58	23.77	
	North Atlantic	$X_{45}=1$	59.62	80.00	
	Ohio	$X_{54}=0.4698$ $X_{55}=0.5302$	104.26	136.98	
	South Atlantic-Gulf	$X_{64}=1$	76.88	80.00	
	Tennessee	$X_{73}=1$	35.79	90.00	
	Upper Mississippi	$X_{82}=1$	22.74	29.00	

Table 4.13 Continued

800	Lower Mississippi	$X_{31}=1$	17.52	30	358.48
	North Atlantic	$X_{46}=1$	84.91	50	
	Ohio	$X_{55}=1$	86.74	200	
	South Atlantic-Gulf	$X_{64}=1$	56.84	120	
	Tennessee	$X_{71}=1$	25.04	150	
	Upper Mississippi	$X_{81}=1$	23.31	40	

Table 4.14 Continued

Table 4.13. Output from the National Model for the Year 1980 (Cont'd.)

National Budget in Million Dollars	Basin	Chosen Activity Variable and its Value	Return	Basin Budget in Million Dollars	Total Return
800	Arkansas-White-Red	$X_{11}=1$	29.95	55.25	252.11
	Great Lakes	$X_{21}=1$	17.08	130.68	
	Lower Mississippi	$X_{31}=1$	15.58	23.77	
	North Atlantic	$X_{44}=0.16357$ $X_{45}=0.83633$	54.64	94.73	
	Ohio	$X_{54}=1$	61.12	190.00	
	South Atlantic-Gulf	$X_{62}=1$	30.59	160.00	
	Tennessee	$X_{72}=1$	23.26	110.00	
	Upper Mississippi	$X_{81}=1$	19.89	35.57	
1000	Arkansas-White-Red	$X_{11}=1$	29.95	55.25	189.45
	Great Lakes	$X_{21}=1$	17.08	130.68	
	Lower Mississippi	$X_{31}=1$	15.58	23.77	
	North Atlantic	$X_{44}=1$	29.17	170.00	
	Ohio	$X_{53}=1$	30.42	290.00	
	South Atlantic-Gulf	$X_{61}=0.09682$ $X_{62}=0.90318$	29.85	163.80	
	Tennessee	$X_{71}=1$	17.51	130.93	
	Upper Mississippi	$X_{81}=1$	19.89	35.57	
1200	Arkansas-White-Red	$X_{11}=1$	29.95	55.25	157.05
	Great Lakes	$X_{21}=1$	17.08	130.68	
	Lower Mississippi	$X_{31}=1$	15.58	23.77	
	North Atlantic	$X_{43}=1$	15.30	250.00	
	Ohio	$X_{52}=0.8455$ $X_{53}=0.1545$	18.80	374.55	
	South Atlantic-Gulf	$X_{61}=1$	22.94	199.25	
	Tennessee	$X_{71}=1$	17.51	130.93	
	Upper Mississippi	$X_{81}=1$	19.89	35.57	

Table 4.14. Output from the National Model for the Year 1985 (Cont'd.)

National Budget in Million Dollars	Basin	Chosen Activity Variable and its Value	Return	Basin Budget in Million Dollars	Total Return
1100	Arkansas-White-Red	$X_{11}=1$	34.85	70	247.66
	Great Lakes	$X_{21}=1$	24.72	150	
	Lower Mississippi	$X_{31}=1$	17.52	30	
	North Atlantic	$X_{44}=1$	33.08	200	
	Ohio	$X_{54}=1$	49.57	300	
	South Atlantic-Gulf	$X_{63}=1$	41.57	160	
	Tennessee	$X_{71}=1$	25.04	150	
	Upper Mississippi	$X_{81}=1$	23.31	40	
1400	Arkansas-White-Red	$X_{11}=1$	34.85	70	200.55
	Great Lakes	$X_{21}=1$	24.72	150	
	Lower Mississippi	$X_{31}=1$	17.52	30	
	North Atlantic	$X_{43}=1$	19.72	300	
	Ohio	$X_{52}=0.2$ $X_{53}=0.8$	28.80	420	
	South Atlantic-Gulf	$X_{61}=1$	26.57	240	
	Tennessee	$X_{71}=1$	25.04	150	
	Upper Mississippi	$X_{81}=1$	23.31	40	
1700	Arkansas-White-Red	$X_{11}=1$	34.85	70	180.42
	Great Lakes	$X_{21}=1$	24.72	150	
	Lower Mississippi	$X_{31}=1$	17.52	30	
	North Atlantic	$X_{41}=0.2$ $X_{42}=0.8$	12.11	420	
	Ohio	$X_{51}=1$	16.31	600	
	South Atlantic-Gulf	$X_{61}=1$	26.57	240	
	Tennessee	$X_{71}=1$	25.04	150	
	Upper Mississippi	$X_{81}=1$	23.31	40	

Table 4.15. Output from the National Model for the Year 1990.

National Budget in Million Dollars	Basin	Chosen Activity Variable and its Value	Return	Basin Budget in Million Dollars	Total Return
400	Arkansas-White-Red	$X_{15}=1$	124.00	40	1026.30
	Great Lakes	$X_{26}=1$	167.13	30	
	Lower Mississippi	$X_{35}=1$	47.87	20	
	North Atlantic	$X_{46}=1$	71.17	100	
	Ohio	$X_{56}=1$	178.14	100	
	South Atlantic-Gulf	$X_{66}=1$	183.08	50	
	Tennessee	$X_{76}=1$	180.06	40	
	Upper Mississippi	$X_{85}=1$	74.85	20	
800	Arkansas-White-Red	$X_{11}=1$	34.44	85	486.98
	Great Lakes	$X_{23}=1$	50.71	120	
	Lower Mississippi	$X_{31}=1$	16.32	40	
	North Atlantic	$X_{46}=1$	71.17	100	
	Ohio	$X_{55}=0.35$ $X_{56}=0.65$	154.66	135	
	South Atlantic-Gulf	$X_{64}=1$	73.44	150	
	Tennessee	$X_{74}=1$	60.69	120	
	Upper Mississippi	$X_{82}=1$	25.50	50	
1200	Arkansas-White-Red	$X_{11}=1$	34.44	85	300.66
	Great Lakes	$X_{22}=1$	33.21	160	
	Lower Mississippi	$X_{31}=1$	16.32	40	
	North Atlantic	$X_{45}=0.5$ $X_{46}=0.5$	63.17	125	
	Ohio	$X_{54}=1$	52.87	350	
	South Atlantic-Gulf	$X_{63}=1$	52.58	200	
	Tennessee	$X_{72}=1$	26.08	180	
	Upper Mississippi	$X_{81}=1$	21.99	60	

Table 4.15 Continued

Table 4.15. Output from the National Model for the Year 1990 (Cont'd.)

National Budget in Million Dollars	Basin	Chosen Activity Variable and its Value	Return	Basin Budget in Million Dollars	Total Return
1600	Arkansas-White-Red	$X_{11}=1$	34.44	85	217.79
	Great Lakes	$X_{21}=1$	22.6	200	
	Lower Mississippi	$X_{31}=1$	10.32	40	
	North Atlantic	$X_{44}=1$	27.56	300	
	Ohio	$X_{53}=0.43333$ $X_{54}=0.56667$	43.15	415	
	South Atlantic-Gulf	$X_{61}=1$	31.37	300	
	Tennessee	$X_{71}=1$	20.36	200	
	Upper Mississippi	$X_{81}=1$	21.99	60	
2000	Arkansas-White-Red	$X_{11}=1$	34.44	85	180.83
	Great Lakes	$X_{21}=1$	22.60	200	
	Lower Mississippi	$X_{31}=1$	16.32	40	
	North Atlantic	$X_{42}=0.1$ $X_{43}=0.9$	14.80	465	
	Ohio	$X_{52}=1$	18.95	650	
	South Atlantic-Gulf	$X_{61}=1$	31.37	300	
	Tennessee	$X_{71}=1$	20.36	200	
	Upper Mississippi	$X_{81}=1$	21.99	60	
2385	Arkansas-White-Red	$X_{11}=1$	34.44	85	168.95
	Great Lakes	$X_{21}=1$	22.60	200	
	Lower Mississippi	$X_{31}=1$	16.32	40	
	North Atlantic	$X_{41}=1$	7.95	700	
	Ohio	$X_{51}=1$	13.92	800	
	South Atlantic-Gulf	$X_{61}=1$	31.37	300	
	Tennessee	$X_{71}=1$	20.36	200	
	Upper Mississippi	$X_{81}=1$	21.99	60	

Table 4.16. Output from the National Model for the Year 1995.

National Budget in Million Dollars	Basin	Chosen Activity Variable and its Value	Return	Basin Budget in Million Dollars	Total Return
500	Arkansas-White-Red	$X_{13}=0.75$ $X_{14}=0.25$	109.29	55	984.68
	Great Lakes	$X_{26}=1$	109.37	50	
	Lower Mississippi	$X_{34}=1$	50.69	25	
	North Atlantic	$X_{46}=1$	60.80	150	
	Ohio	$X_{56}=1$	193.49	100	
	South Atlantic-Gulf	$X_{66}=1$	198.23	50	
	Tennessee	$X_{76}=1$	176.50	50	
	Upper Mississippi	$X_{85}=1$	82.25	20	
1000	Arkansas-White-Red	$X_{11}=1$	38.73	100	440.54
	Great Lakes	$X_{25}=1$	51.27	100	
	Lower Mississippi	$X_{31}=1$	15.76	50	
	North Atlantic	$X_{46}=1$	60.86	150	
	Ohio	$X_{55}=1$	120.32	200	
	South Atlantic-Gulf	$X_{63}=0.3$ $X_{64}=0.7$	80.62	165	
	Tennessee	$X_{73}=1$	47.87	170	
	Upper Mississippi	$X_{82}=1$	25.11	65	
1500	Arkansas-White-Red	$X_{11}=1$	38.73	100	283.57
	Great Lakes	$X_{24}=1$	30.49	150	
	Lower Mississippi	$X_{31}=1$	15.76	50	
	North Atlantic	$X_{45}=0.13333$ $X_{46}=0.86667$	57.13	170	
	Ohio	$X_{54}=1$	60.32	400	
	South Atlantic-Gulf	$X_{62}-1$	35.13	300	
	Tennessee	$X_{71}=1$	24.44	250	
	Upper Mississippi	$X_{81}=1$	21.57	80	

Table 4.16 Continued

Table 4.16. Output from the National Model for the Year 1995 (Cont'd.)

National Budget in Million Dollars	Basin	Chosen Activity Variable and its Value	Return	Basin Budget in Million Dollars	Total Return
2000	Arkansas-White-Red	$X_{11}=1$	38.73	100	211.20
	Great Lakes	$X_{23}=1$	24.42	200	
	Lower Mississippi	$X_{31}=1$	15.76	50	
	North Atlantic	$X_{44}=0.13333$ $X_{45}=0.86667$	31.08	320	
	Ohio	$X_{53}=1$	29.84	600	
	South Atlantic-Gulf	$X_{61}=1$	25.36	400	
	Tennessee	$X_{71}=1$	24.44	250	
	Upper Mississippi	$X_{81}=1$	21.57	80	
2500	Arkansas-White-Red	$X_{11}=1$	38.73	100	175.92
	Great Lakes	$X_{21}=1$	17.22	300	
	Lower Mississippi	$X_{31}=1$	15.76	50	
	North Atlantic	$X_{43}=0.46667$ $X_{44}=0.53333$	15.99	520	
	Ohio	$X_{52}=1$	16.85	800	
	South Atlantic-Gulf	$X_{61}=1$	25.36	400	
	Tennessee	$X_{71}=1$	24.44	250	
	Upper Mississippi	$X_{81}=1$	21.57	80	
3000	Arkansas-White-Red	$X_{11}=1$	38.73	100	163.12
	Great Lakes	$X_{21}=1$	17.22	300	
	Lower Mississippi	$X_{31}=1$	15.76	50	
	North Atlantic	$X_{41}=0.46667$ $X_{42}=0.53333$	8.11	800	
	Ohio	$X_{51}=1$	11.93	1000	
	South Atlantic-Gulf	$X_{61}=1$	25.36	400	
	Tennessee	$X_{71}=1$	24.44	250	
	Upper Mississippi	$X_{81}=1$	21.57	80	

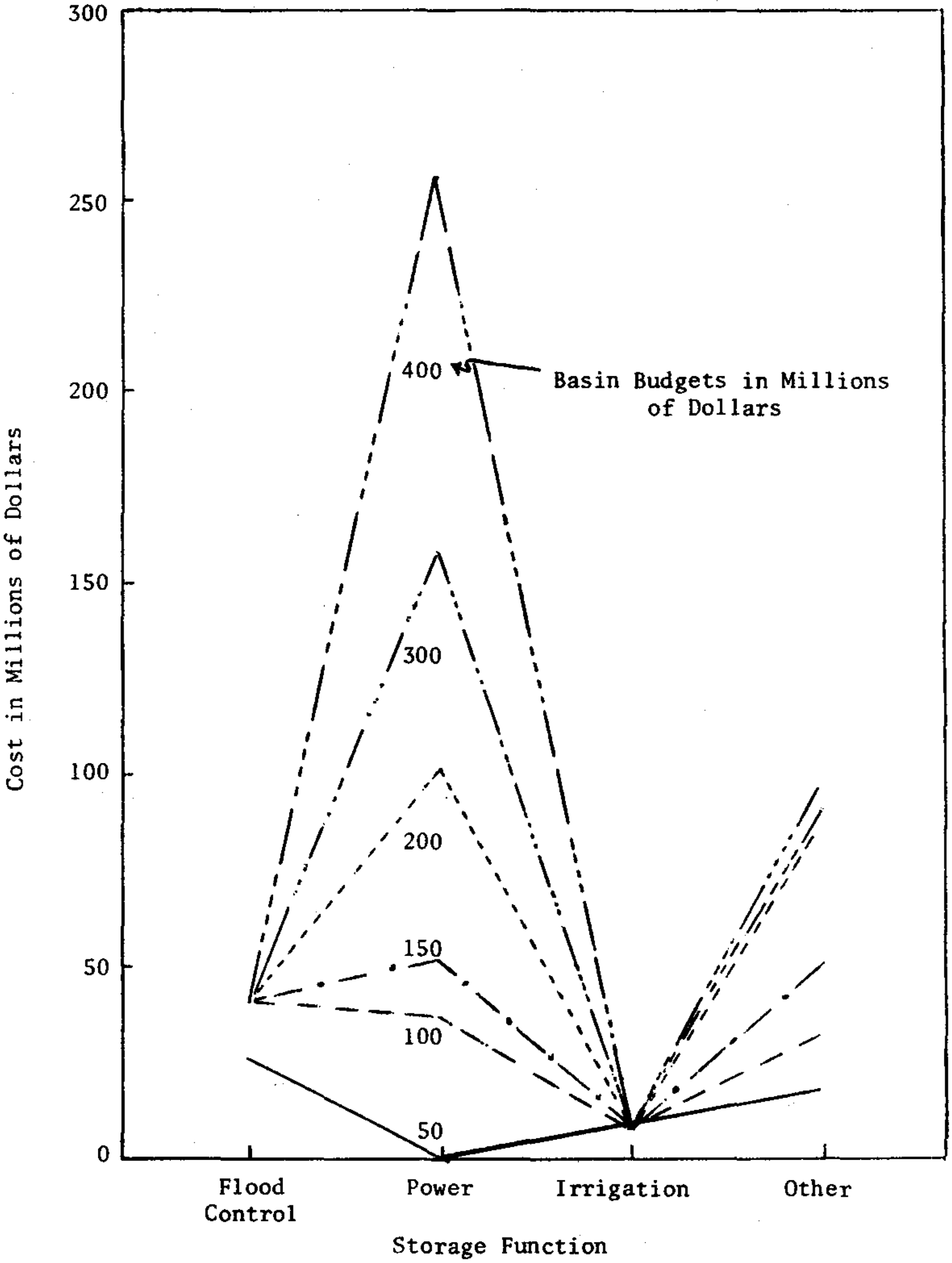


Figure 4.13. Cost-function Relationship for the 1995 South Atlantic-Gulf Basin Budgets.

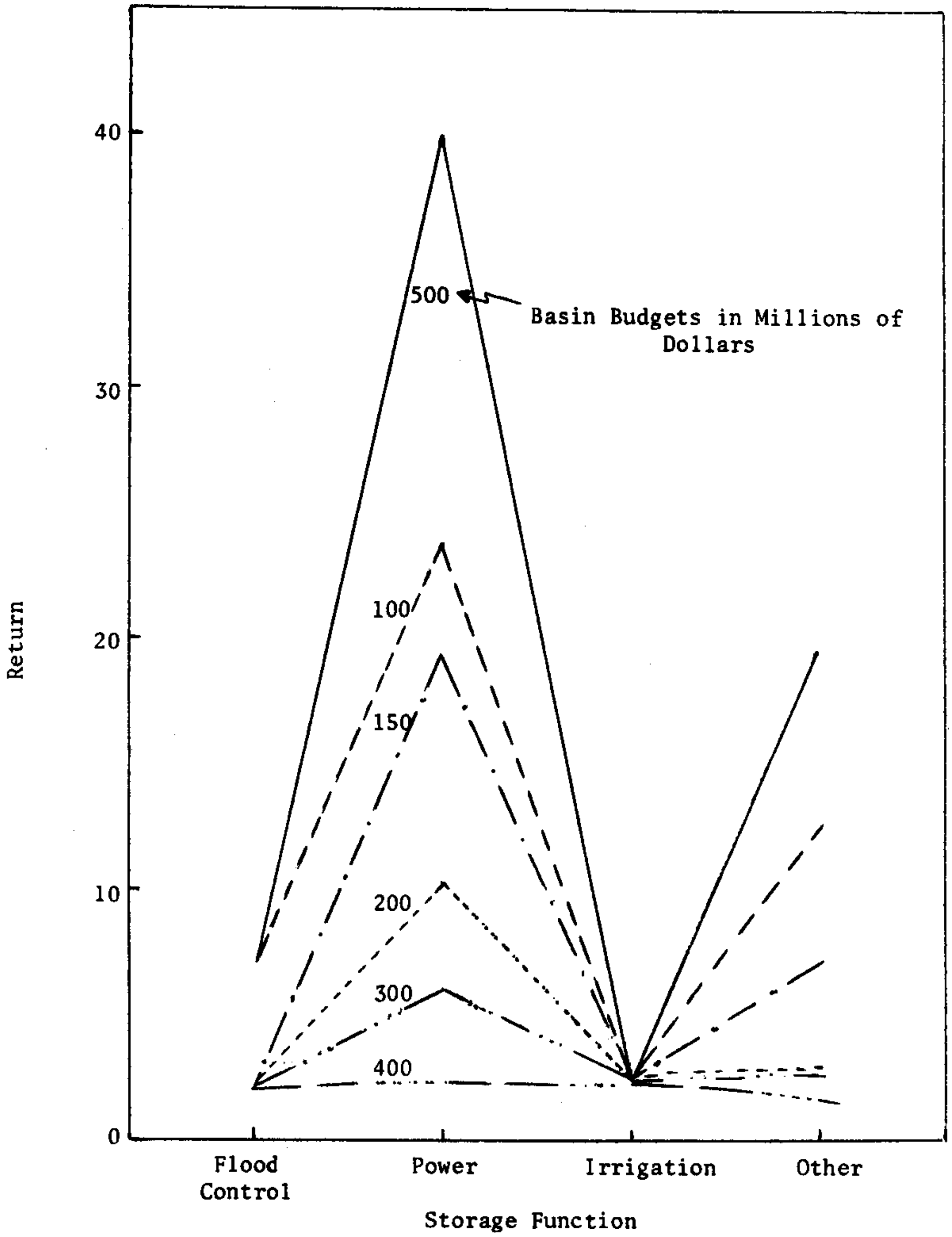


Figure 4.14. Return-function Relationship for the 1995 South Atlantic-Gulf Basin Budgets.

is shown. Notice the low returns from the irrigation benefits in each budget curve and the large returns for the power benefits with smaller budgets.

The tendency for investments to be allocated to less expensive benefits first and finally to the more expensive ones then becomes obvious.

For the national level model, the distributions of a national budget for different basins and years are shown in Figure 4.15 to Figure 4.18. One common characteristic shown by all of these figures is that for any national budget, funds were always allocated first to basins which needed smaller investments to reach their goals. As the size of national budget increased, money was distributed to basins which needed greater amounts of money to reach their goals. As the national budget increases, each basin receives more funds.

Figures 4.19 to 4.22 show return-basin curves. The size of the national budget is inversely proportionate to the returns for each basin.

Figure 4.23 shows the same national budget, 800 million dillars, for 1980, 1985, and 1990. The way this budget was distributed varied with time. This indicates that it is not possible to allocate the same budget to different basins and have the same outcome because years vary. It is necessary to find the different allocations for the different years. Figure 4.24 shows that for the same national budget, eight-hundred million dollars, returns from each basin also vary with time. The returns from 1980 are less than those from the other years because the needs for the year 1980 were smaller.

Essentially, this budget allocation model satisfies the original objectives. Yet, in the process of calculation, the method used for collecting data was often quite tedious; hence, a more effective way of collecting input data is still needed. If further study is pursued, more calculations should be carried out by computer.

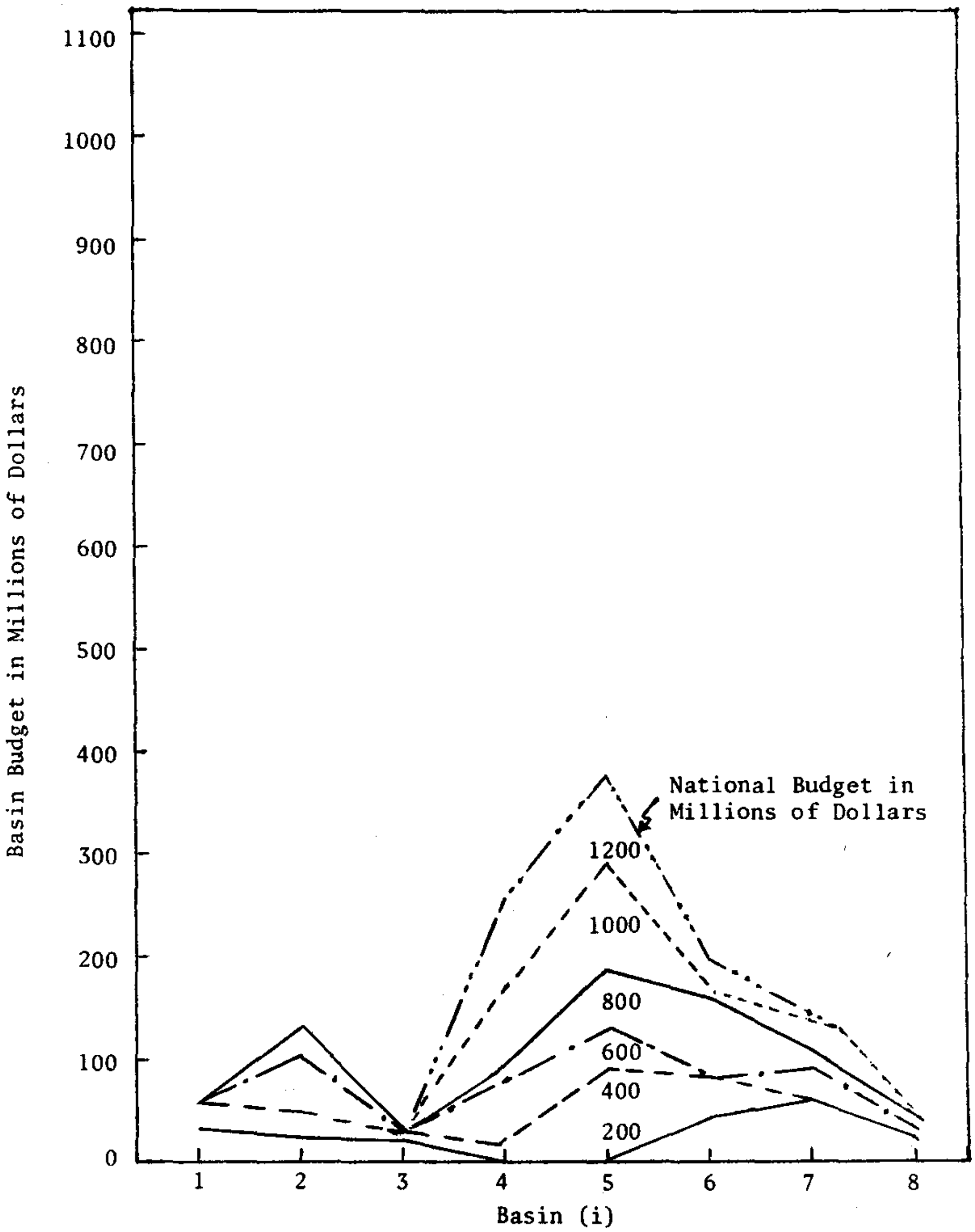


Figure 4.15. Basin Budget-Basin-National Budget Relationship from the National Model for 1980.

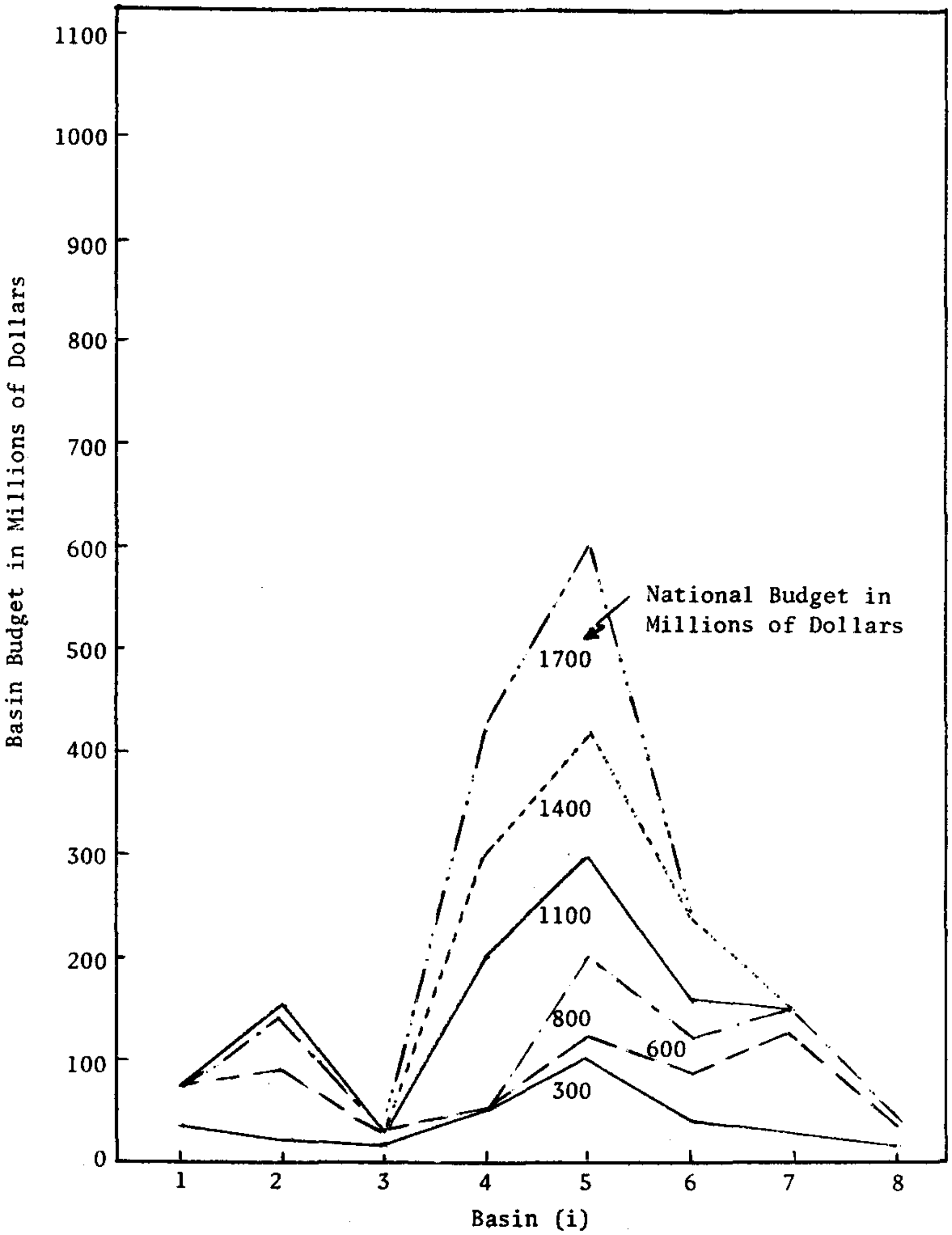


Figure 4.16. Basin Budget-Basin-National Budget Relationship from the National Model for 1985.

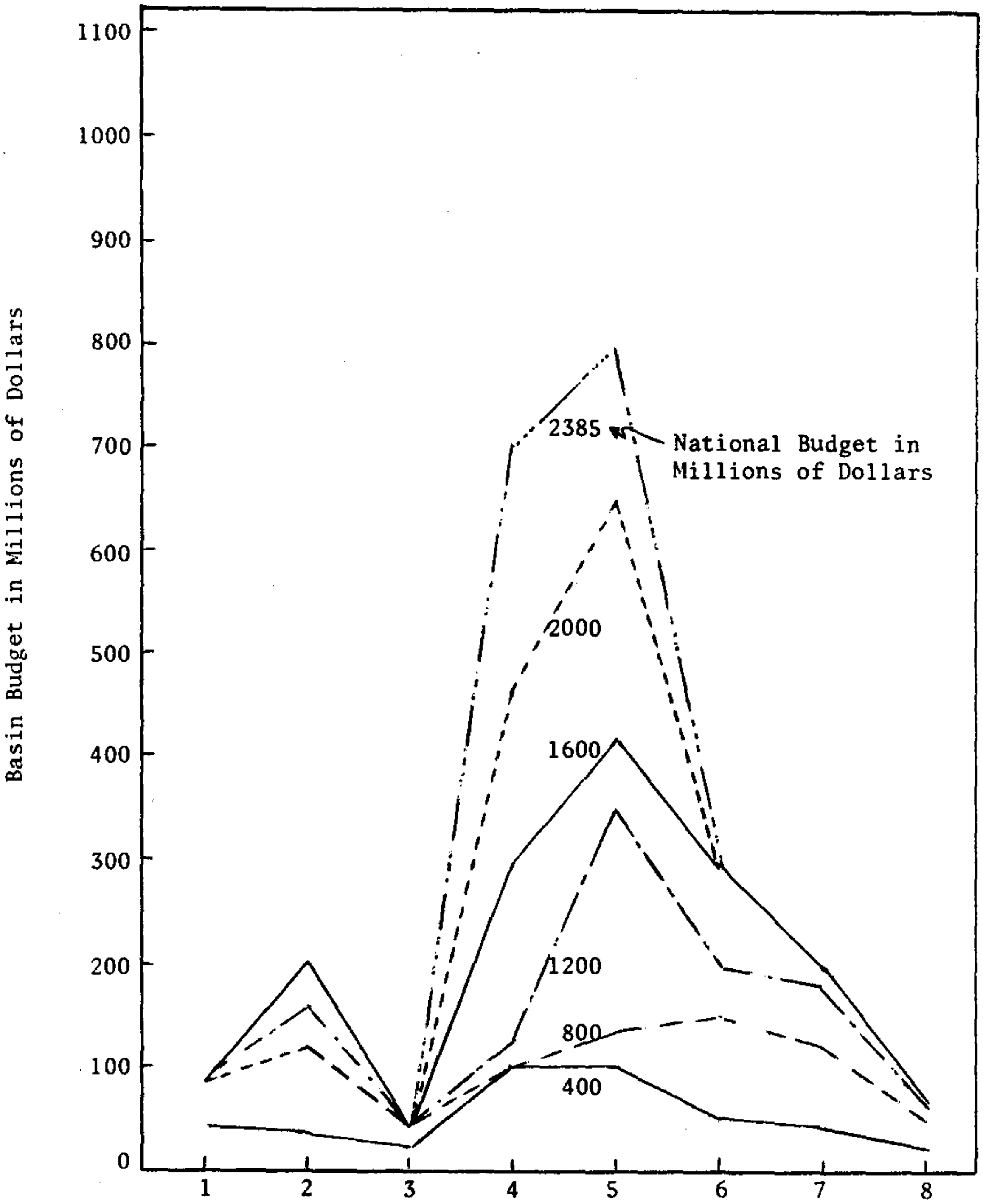


Figure 4.17. Basin Budget-Basin-National Budget Relationship from the National Model for 1990.

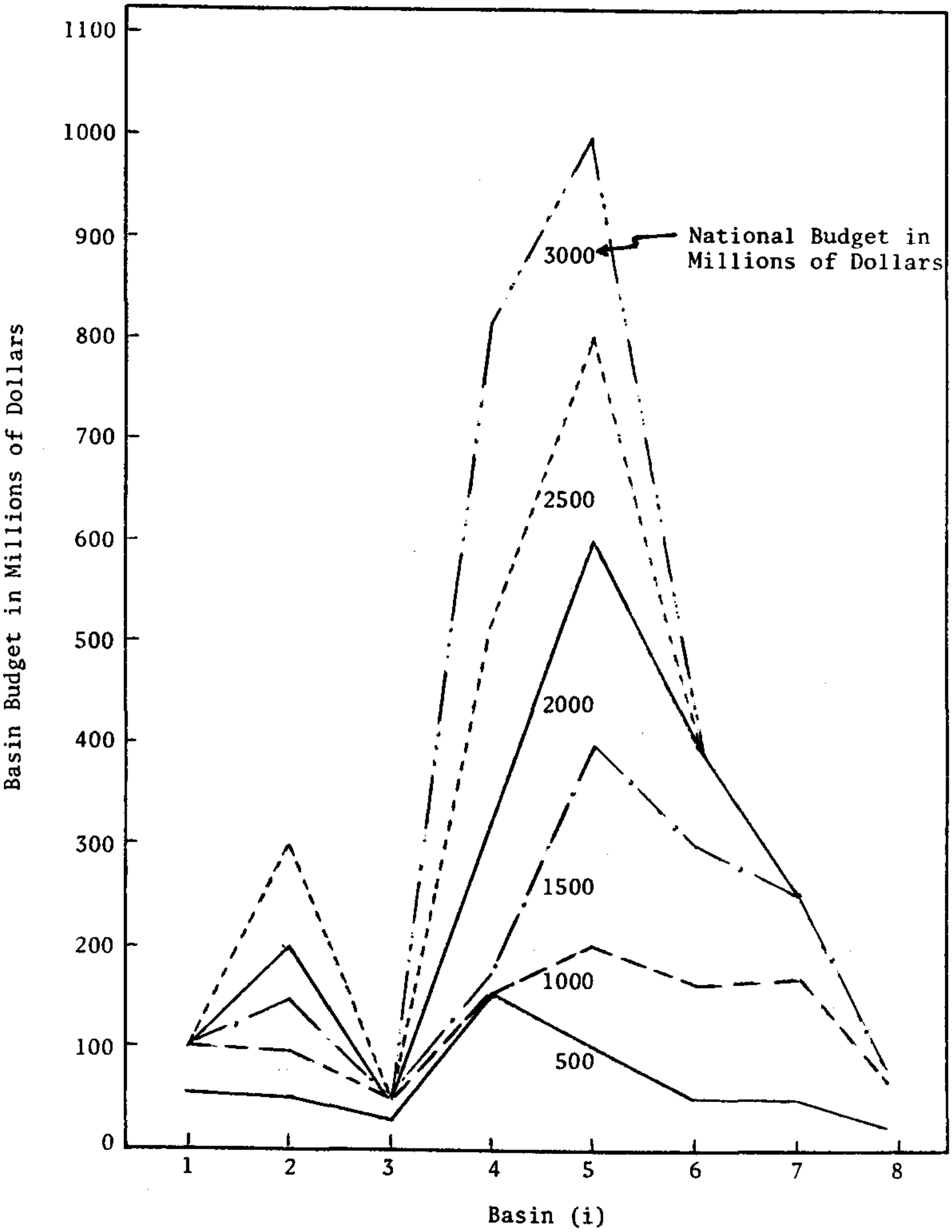


Figure 4.18. Basin Budget-Basin-National Budget Relationship from the National Model for 1995.

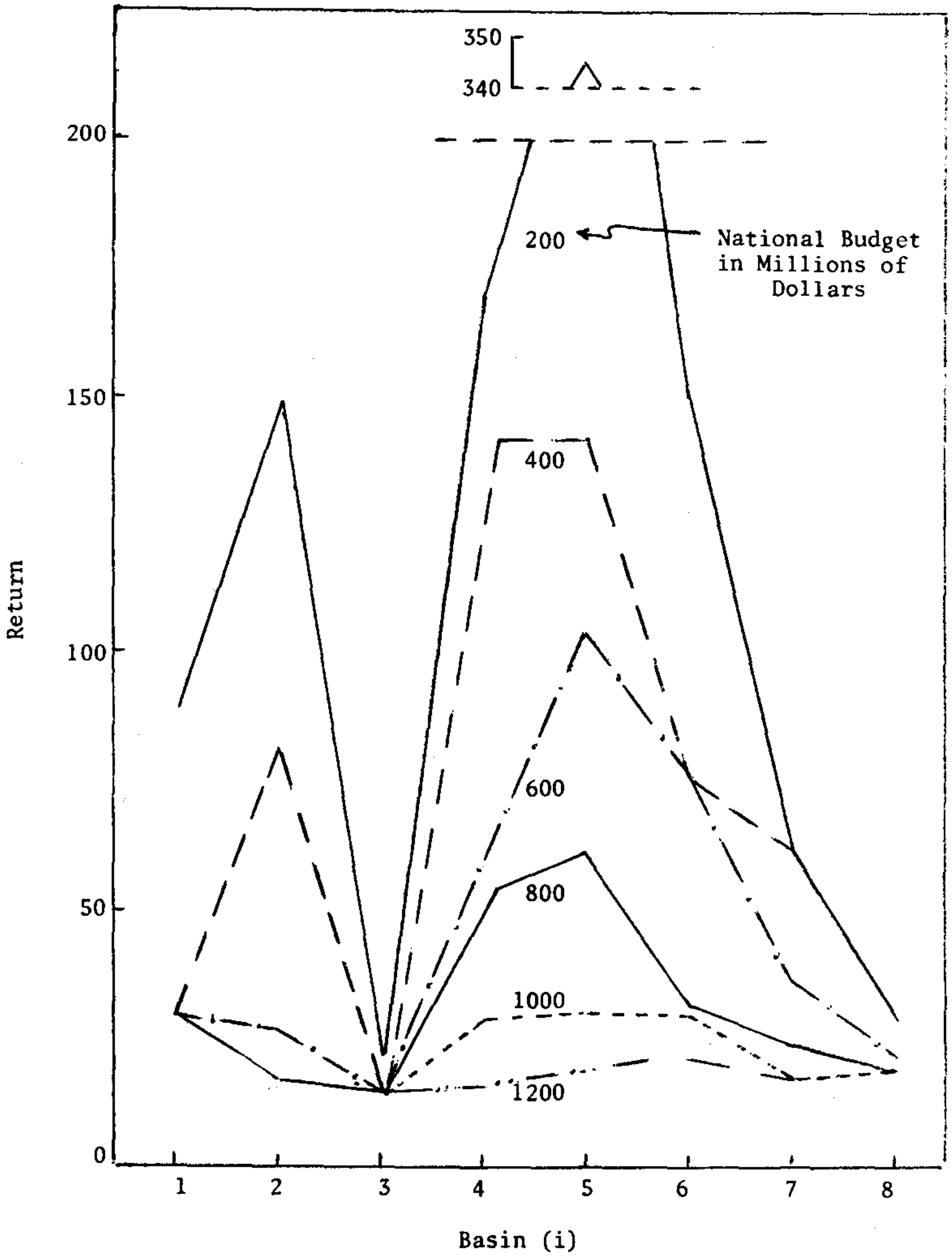


Figure 4.19. Return-Basin-National Budget Relationship from National Model for 1980.

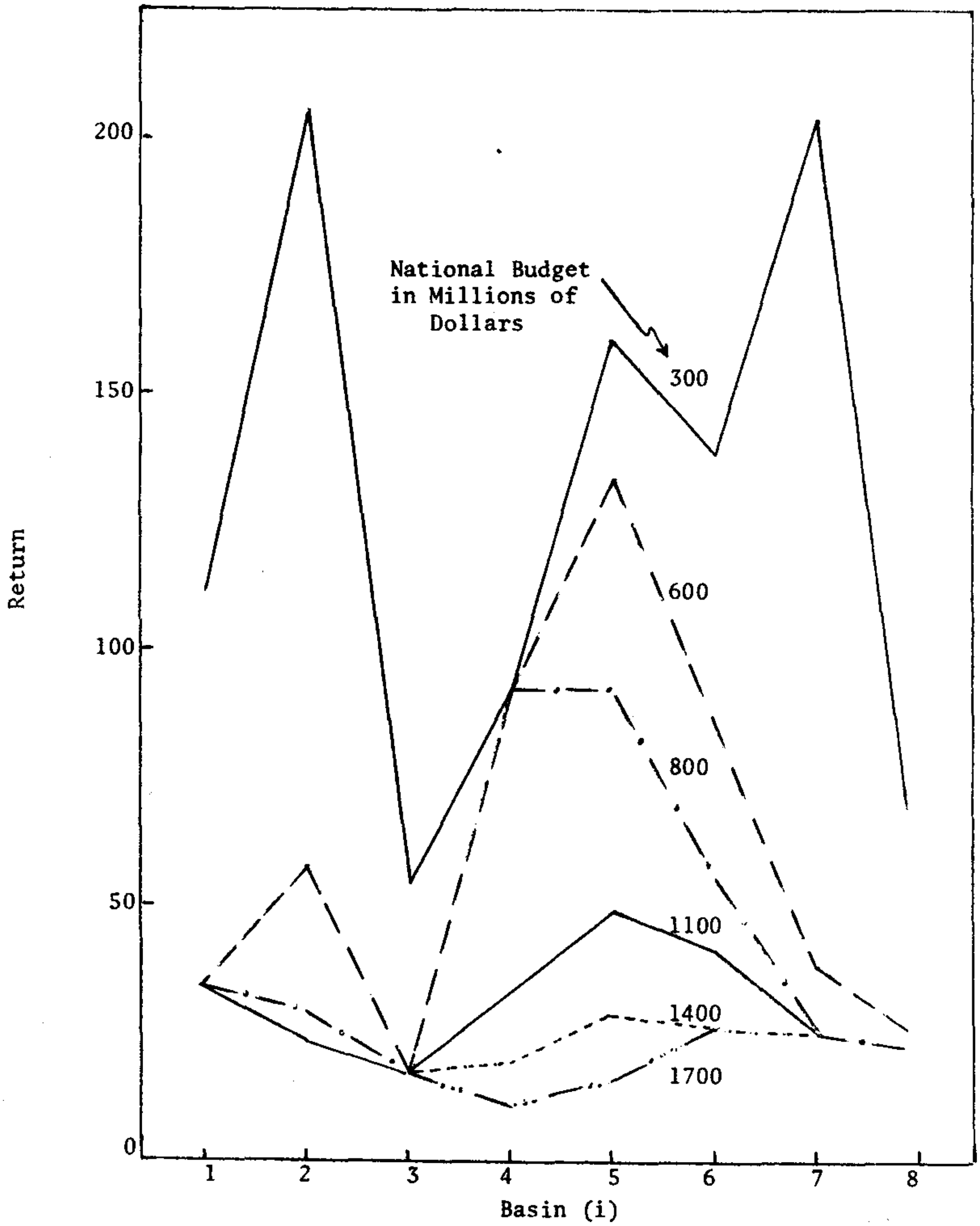


Figure 4.20. Return-Basin-National Budget Relationship from National Model for 1985.

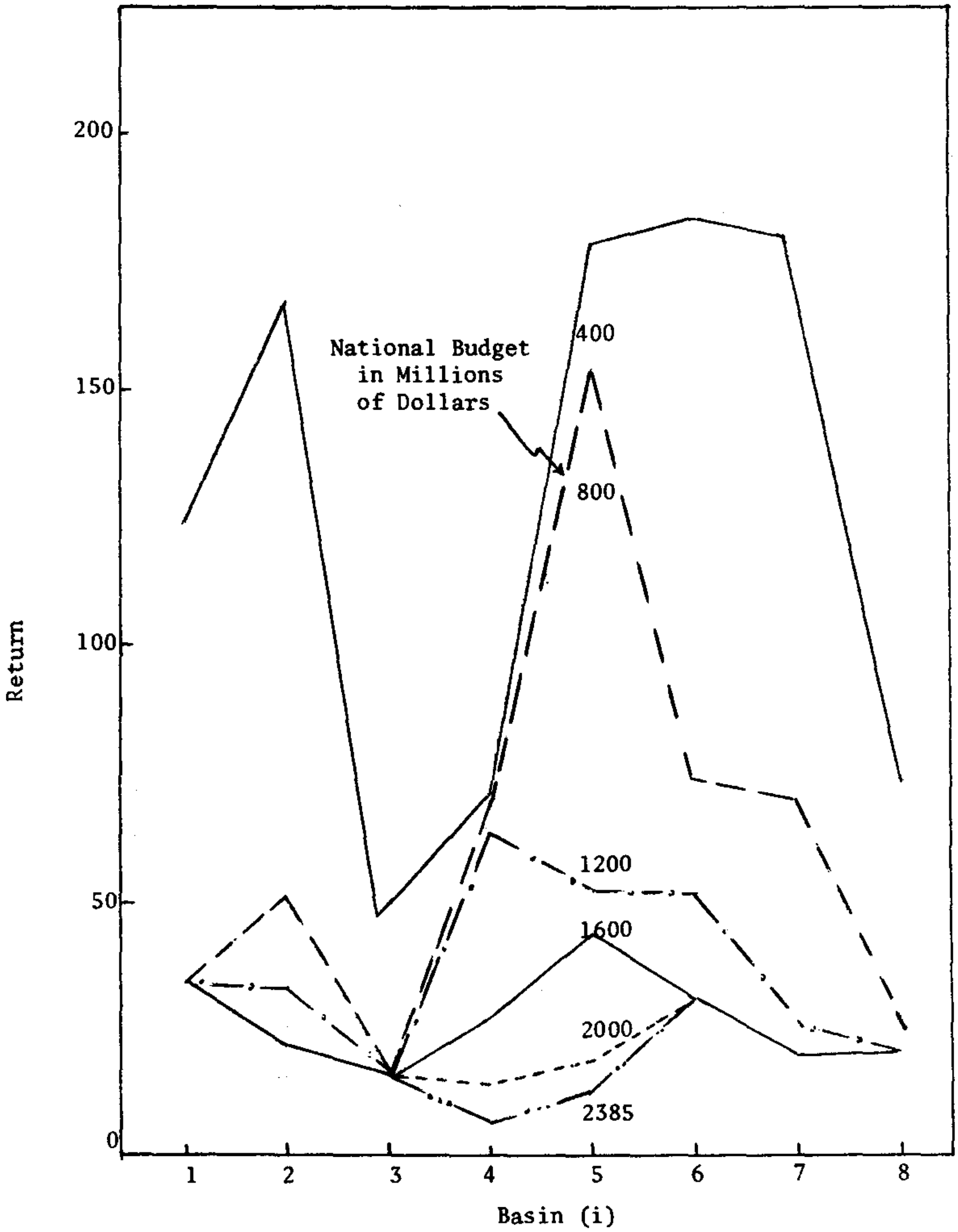


Figure 4.21. Return-Basin-National Budget Relationship from National Model for 1990.

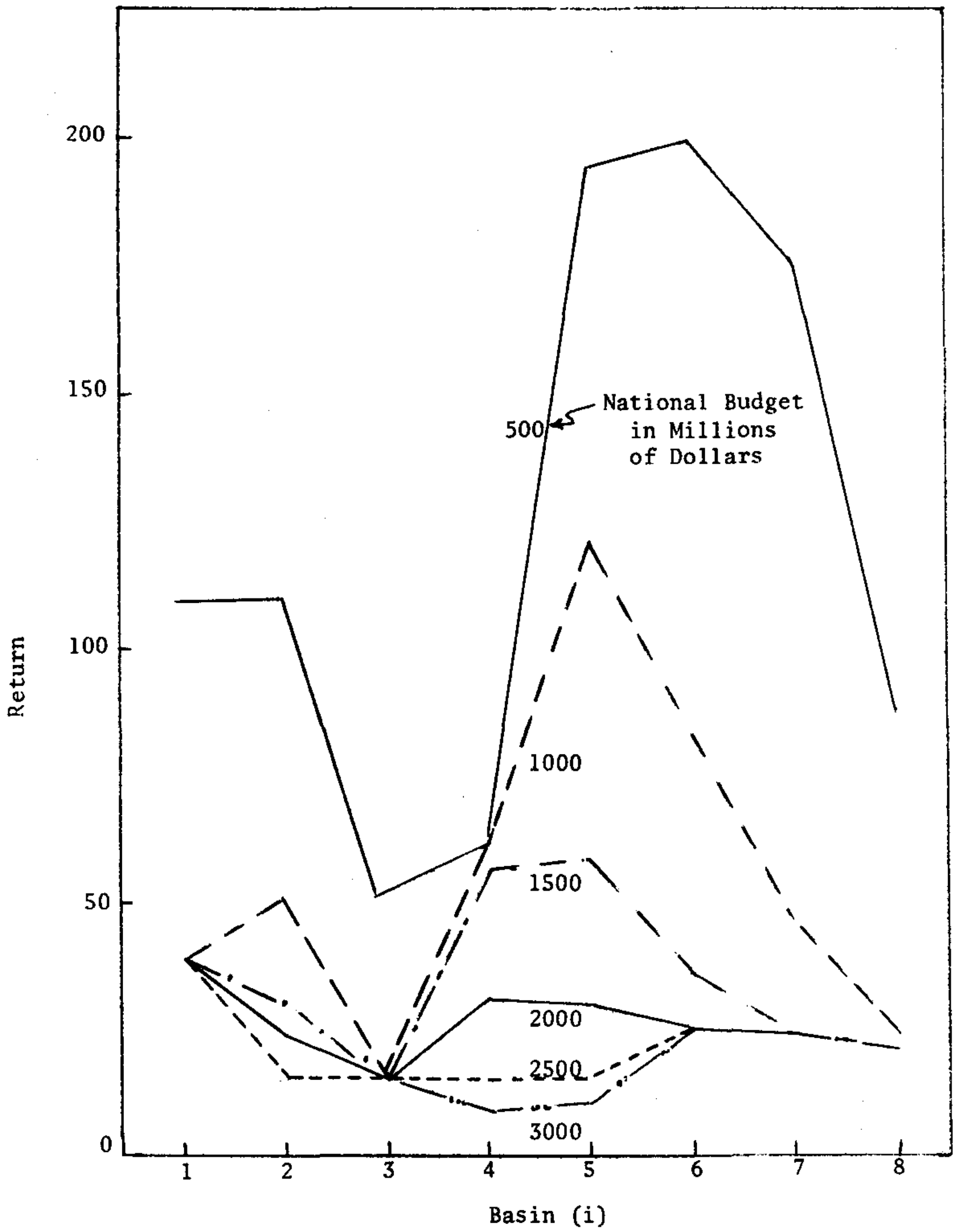


Figure 4.22. Return-Basin-National Budget Relationship from National Model for 1995.

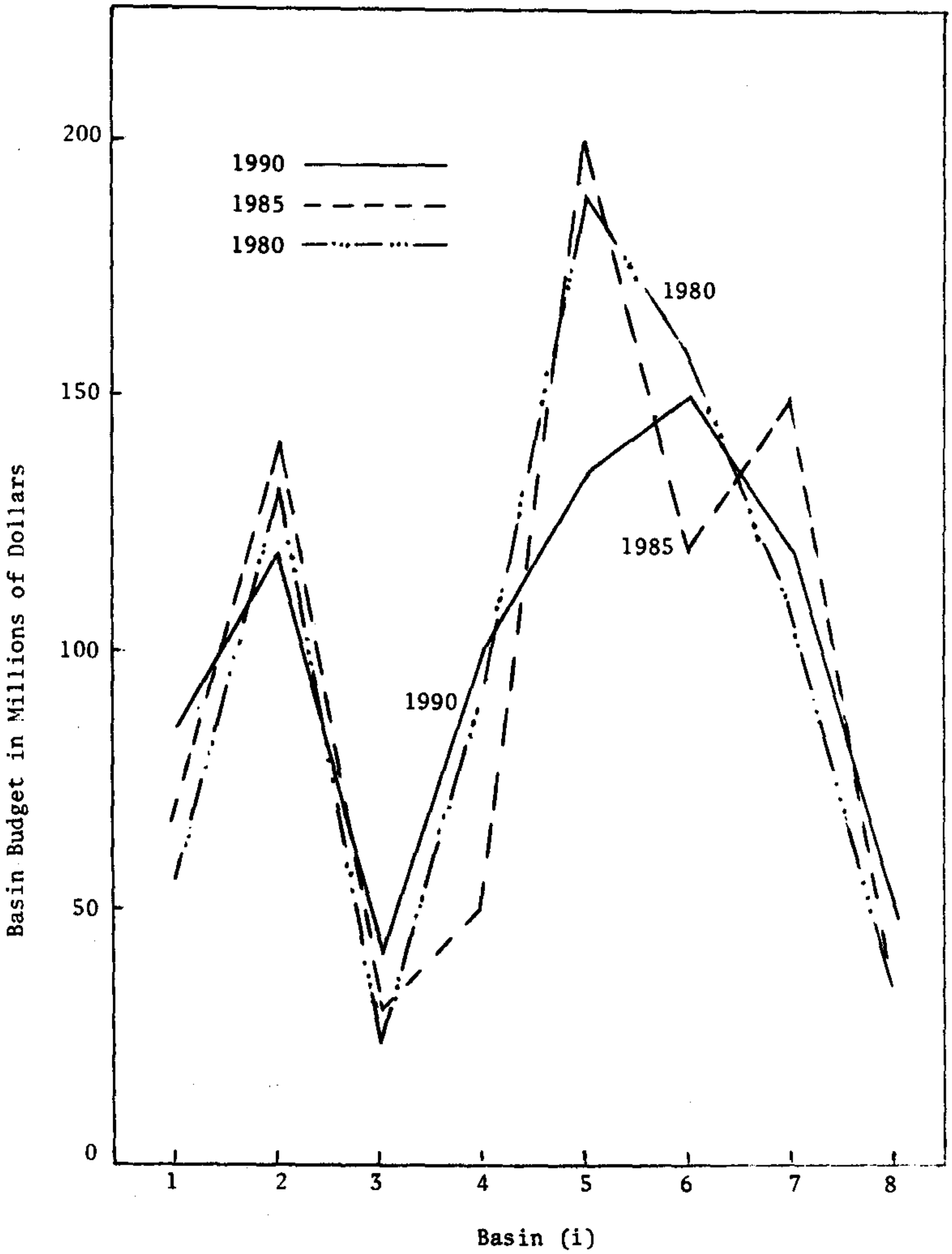


Figure 4.23. Basin Budget-Basin-Year Relationship for a National Budget of 800 Million Dollars.

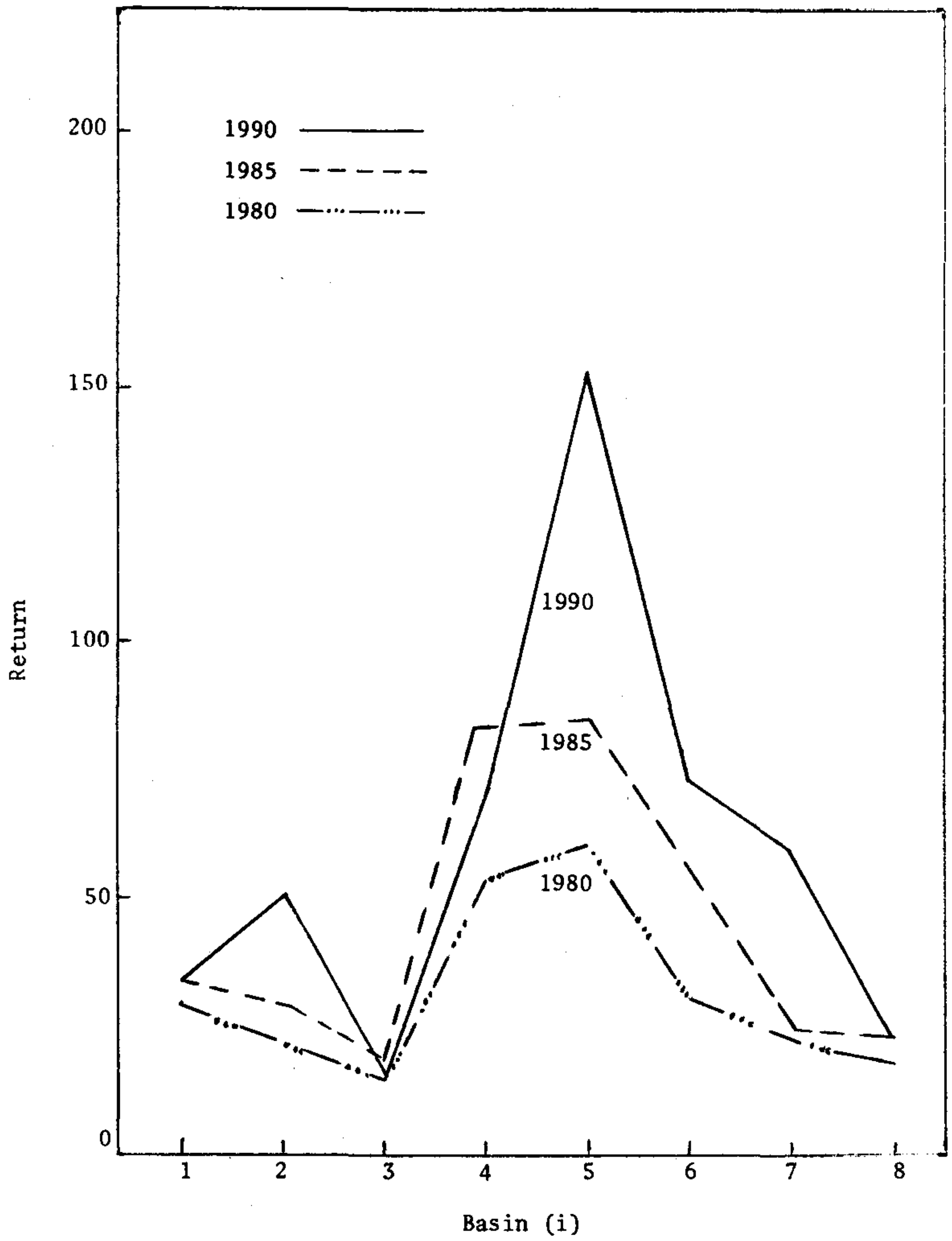


Figure 4.24. Return-Basin-Year Relationship for a National Budget of 800 Million Dollars.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

A new approach to the task of allocating federal funds to the development of the nation's water resources has been presented which circumvents the problems of measuring all benefits of water resources development in monetary terms and of trying to optimize water resource development by choosing among individual projects which were formulated as isolated entities. The approach also avoids the type of comprehensive planning which forces every project to embrace all possible types of benefits, precluding the sub-optimization of individual projects.

The approach presented here has the advantage of being based on the fulfillment of needs. The measure of effectiveness used is the percentage of a need met, a straightforward measure common to all needs. This allows the consideration of both tangible and intangible needs on an equal basis. An additional advantage of having a model which is based on needs is that needs are a reflection of one's goals; therefore, the entire water resource allocation model is responsive to identifiable goals.

The water resource allocation model attempts to fulfill all enumerated needs using only the available budget. Since not all needs can be fulfilled in a short time time span with limited funds, the model optimizes development on both the basin and the national level. Unlike the comprehensive planning approach, the optimization of the basin allows individual projects to become fully developed for the purposes for which they are best suited.

The water resource allocation model looks at the development of a basin's water resources on a long term basis in the light of total resource development. Since future developmental needs are considered at the same time as present needs are, the spoilage of sites by short-term planning is avoided. This, of course, assumes that the results of the model are fully utilized as a guideline.

Although the basic formulation of the allocation model, integer programming or linear programming, has been applied to other areas, its application for water resource problems is still a newcomer. The fact that its basic formulation is quite simple and that calculations can be acquired from the standard computer code will make this model useful and convenient to handle.

Although the water resource allocation model is a step in the right direction, it does make several assumptions which may be open to question. First, the needs model assumes that the nation will experience continued growth; this is certainly not an unreasonable assumption. Second, the assumption is made that water resource development is good. While this is a common assumption, sometimes water resource development can harm an area. Another assumption made is water resource development has no effect on future needs. This is not true. To a greater or lesser extent, water resource development produces a feedback, which stimulates regional growth. At the present time the stimulation of growth due to water resource development is not taken into account.

The original purpose of this study was to find a methodology for allocating investments in water resources projects that eliminated the problems found in the other systems for allocation. Essentially, the water resource allocation model has fulfilled that objective; yet, a great deal more work is still needed before this model can be considered as a workable model with practical uses. The needs model is based on "The Multistructural Demand Model for Water Requirement Forecasting" by G. W. Reid (1970), which has been fully validated. The basin level model and the national level model have been partially validated. Although parts of the model have been validated, further validation procedures must still be performed on the total water resource allocation model. In addition, further sensitivity analysis of the effects of the weighting factors is needed. The effect of the equation used in converting deficits to returns on the final allocation of funds also needs to be analyzed.

Further improvements in the model should include the development of other needs categories. The only needs considered in the validation of the basin and national level models were monetary needs because of the lack of readily available data for other needs. The model is fully capable of handling any needs related to population and geographic areas, but these relationships must still be developed. This would involve the use of additional transducers. More work should be done on the prediction of what the transducers of the future will look like. The change in transducers will be a result of the change in the life style of the nation's population.

Another area for additional investigation should be the development of technological forecasting procedures which the current model is capable of handling. Such areas as nuclear power generation are sure to see technological breakthroughs in the near future which will have significant impacts on water requirements. Although the current methods of technological forecasting are not very well developed at the present time, their inclusion could improve predictions greatly.

As the water resource allocation model exists now, the problem of assigning priorities to goals is left to the user of the model. By experimenting with different goals, trying them, and seeing the results obtained from the model, the user is assigning priorities to the goals. A more structured method, in which the ideas of several planners can interact, may be of value in producing a more representative set of goal priorities. One method of accomplishing this is from feedback from heuristic games. The development of a heuristic water resource game that sould be used in conjunction with this model is desirable.

Although the water resource allocation model was formulated with water resources in mind, its structure is general enough to permit handling any allocation problem where only limited funds are available. With a few modifications, it could be used to allocate funds in the fields of housing, transportation, public health, or a combination of such fields.

CHAPTER VI

SUMMARY

The purpose of this study was to analyze and evaluate the present methods used in the allocation of funds for water resource projects and to develop a more suitable method for allocating funds. In order to analyze and evaluate the methods actually used, an in depth survey involving the offices of the Corps of Engineers, the Bureau of Reclamation, and the Soil Conservation Service was conducted. The survey showed that two major problem areas exist in the present methods used to plan and evaluate water resource projects. The first problem area centers around the methods currently being used to measure benefits. Most of the current systems require benefits to be expressed in dollars, while the scope of benefits measured actually extends to include many intangibles which defy expression in monetary terms. The second area of difficulty involves viewing projects in isolation. The development of water resources is currently accomplished by allocating funds to individual projects that have been conceived, formulated and authorized as isolated entities. A definite need existed for a new method of allocation, based on future regional needs, that would involve an integral system for predicting needs and generating alternatives for meeting those needs.

In order to predict regional needs, the multistructural demand model, developed earlier by G. W. Reid (1970), was modified. Prediction of future water resource needs of the nation by resource region was possible with the resulting model, the needs model. It is composed of a population model that supplies population data by attribute and an employment forecasting model that supplies economic and employment data. The population model uses the cohort-survival technique of prediction, while the employment forecasting model uses a step-down procedure. The results of these models are reconciled by means of shift analysis, yielding the predicted population and its cohorts. The data produced is fed into the needs model proper, which enumerates water resource needs by means of transducers. The needs model has the capability of predicting water resource needs as a function of possible national and regional goals. It also has the capability of reflecting technological changes altering water resource usage.

After basin needs are determined, the basin level model is used to generate a set of allocations of funds for the development of each basin. The objective of the basin level model is the fulfillment of the predicted needs, but since only a limited amount of money is available for the development of water resources, not all of a basin's needs can be fulfilled. Therefore, the model minimizes the sum of the differences between needs and development (deficits) for a given budget, initial state of resource development and time. In minimizing the deficits, a benefit priority weighting factor is used which takes into account the possibility of a greater importance of some benefits in a given basin.

The development of all needs is assured by mapping the deficits onto a scale which assigns diminishing returns for additional development as the need approaches the point of being satisfied.

The national level model is then utilized to allocate the federal water resource budget to the basins. This is done by minimizing the sum of the basin deficits. In order to assure an equatable treatment for all basins, a basin priority weighting factor was used. This factor is necessitated by the unequal population and income distribution throughout the nation. The model output is a set of national and basin allocations for various levels of federal funding for a series of years. The planner can then choose between the possible alternatives developed via the model. Properly used, the water resource allocation model would lead to efficient development of water resources.

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