A METHODOLOGY FOR ASSESSMENT OF WATER RESOURCES DEVELOPMENT: A COMPETITIVE EVALUATION MODEL FOR WATER RESOURCES DEVELOPMENT PLANNING

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ABSTRACT

The purpose of this study was to develop an effective evaluation methodology for assisting in water resources development planning. A new model was contemplated for solving two principal problems associated with the present practices of water resources development planning - the considering of individual development as isolated entity and the using of the benefit and cost ratio as the only analysis in the evaluation process.

The model was developed by using game theory concepts. The principal tactics employed in the model are the competitive measuring between benefit categories and the competitive evaluation of the development objectives. The model is basically a collection of sets of games used for obtaining comparison information of various types of development in different locations. Each set of games is headed by an evaluation criterion used for measuring the objective or goal of development. Games are arranged between two parties for whom comparison is needed. The traditional game theory terms, e.g., player, strategy, payoff coefficient, etc., are used to formulate games in the model. A new term, the utility number of a strategy which measures the absolute payoff of a strategy, was introduced as well as a new solution algorithm of taking average expected value. Solutions of games are compared, analyzed, and, then, used to draw recommendations for the decision-maker. The application of the model was validated by comparing water resources development planning of eighteen water resources basins in the United States.

The procedure used in the model enables the identifying of the following: the overall system of water resources development as well as the individual or local development, the relationship of developments in different locations, the inter-relationship between various purposes of development, and the priorities among different purposes and locations of development. The model also is able to recognize the competitive nature of water resources development and to augment some new measurements - the long-term total objective, the short-term objective, the percent of effectiveness measurement, and the percent of needs met measurement. The model as a whole provides a new approach for summarizing a large number of data into a simple and meaningful form in order to formulate systematic recommendations for the decision-maker.

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CHAPTER I

A COMPETITIVE EVALUATION MODEL FOR WATER RESOURCES DEVELOPMENT PLANNING

INTRODUCTION

Objective of this Research

Water resources development is essential to the maintenance of national strength and the achievement of satisfactory levels of living. But development is very often limited by inadequate and misapplied capital, human and institutional resources. Since World War II the relative ineffectiveness of development efforts is especially blamed on the scarcity of resources [1]. Actually, if available resources were adequately allocated and utilized, it is possible that the outcome of the development could be greater. Hence the need of a better method for resources allocation is obvious.

Theoretically, for effective allocation of resource, evaluation methodology for development planning is essential and important. Today, more adequate development planning is needed in developing countries. Evaluation procedures for development planning in more advanced countries have also reached a point where basic revision is needed. Therefore a search for a more effective evaluation method for resource development planning, in particular for water resources, should be made. The main objective of this study is to search for such a method.

An evaluation methodology, designated as the competitive evaluation model, was developed in this study by using terminologies usually employed exclusively in the theory of games. The model is mainly a collection of sets of games which are used to obtain comparison information between different water resources developments. These comparisons can be used to formulate recommendations for the decision-maker. Thus, the model as a whole may lead to a more effective evaluation procedure for water resources development planning.

Before the development of the model, a review of the present practices of water resources development planning evaluation was done. Later a study of the concepts of decision theory and game theory led to the development of the model. In the earlier stage of this research, an attempt to use the heuristic (operational) gaming approach was also carried out but abandoned due to some of the limitations of this approach. All these will be discussed in this chapter and so are the sub-objectives of the model and its simple structure.

Present Practices of Water Resources Development Planning

Most of the recent concepts of water resources development planning are based on Senate Document No. 97 (1962), entitled as "Policies, Standards, and Procedures in the Formulation, Evaluation, and Review of Plans for Use and Development of Water and Related Land Resources" [2], which shall henceforth be referred to as S.D. No. 97. This document stated that the basic objective in the formulation of plans is to provide the best use, or combination of uses, of water and related land resources to meet all forseeable short-term and long-term needs. Since plan formulation and development evaluation are the two most essential steps for effective resources allocation and development, each of them will be discussed separately in the following.

Present Concepts of Plan Formulation

The current conception of plan formulation in water resources development is usually made on individual basis. Development is planned in isolation, and its relationship with other developments is either considered lightly or ignored. Most water resources projects are the results of local or regional interest groups requesting one of the water resource agencies to solve a particular problem; and essentially this can be considered to be a compromise. In some cases, the agency can study the problem and do a limited amount of planning; these are usually rather small and limited projects. In other cases, the U. S. Congress must appropriate funds to investigate a particular problem. After the appropriation of funds, the problem is first studied, and then a plan to solve the immediate problem is formulated [3]. It is obvious that this kind of planning is a passive planning and can only solve short-term or immediate problems. In order to achieve more effective long-term development, an overall regional or national program to relate all individual developments is needed.

Recently, the U. S. Army Corps of Engineers has been trying to change the approach of water resources development planning to planning-programming-budgeting systems (PPBS). As its name suggests, it is an effort to tie forward planning to budgeting via programming. This system is used as a mechanism for assigning priorities to proposed Corps' projects. The priority which a project receives is a function of a basin's needs and equity term for a given area. The needs of a basin are determined from the Corps' own estimates of needed water resources development. 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. In the current practices of this system, priorities are assigned 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 regional funds should be allocated to those programs for which priority can be estimated.

The attempt of allocating funds to projects which have established priority is a right approach to planning. It is also necessary to have a systematic method for making this attempt more effective.

Present Development Evaluation Procedure

Currently, the evaluation of water resources development is based on a national income account by means of the benefit and cost ratio (B/C) analysis. This analysis uses the ratio of benefit produced by a project to the cost spent for the project. According to S.D. No. 97, benefits of a project are increases or gains in value of goods and services which result from conditions with the project, as compared with conditions without the project. Induced costs (all uncompensated, adverse effects caused by the construction and 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. Measure of water supply and water quality benefits are approximated by the cost of achieving the same results by the most likely alternative means that would be utilized in the absence of the project. Irrigation and navigation benefits are the net increase 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 value of the improvements as measured by the number of uses of the project times some unit value of the recreation.

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 ratio analysis seeks to overcome the shortcomings of the previous evaluation method which relies on measuring profits (net benefits) in public enterprises as the criteria for comparison of alternatives. The use of a ratio between benefits and costs, as opposed to a difference, is an attempt at approximating more closely the results of an analysis which employs benefits and costs.

The practice of using B/C analysis for development evaluation is a suitable approach when only an individual development is considered and not the whole system. But, when an overall regional or national system which may include many developments is considered, a single analysis is not enough for effective evaluation, especially when this analysis consists of only monetary terms. There are many other factors to be considered, for example, needs to be fulfilled and efficiency achieved. Hence, more objectives and criteria should be sought to make the evaluation more effective.

Recently, the Water Resources Council has attempted to rectify some of the inadequacies inherent in the current procedures of B/C analysis. And as a result of this, the Water Resources Council's Special Task Forces Report (commonly called the Blue Book) [4] has suggested the following additional account: a regional income account, an environmental account and a well-being account. The new regional income account would be similar to the national income account except that 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.

This approach of adding new accounts to evaluation procedures is in the right direction towards more effective planning. But it is also obvious that new methods for measuring these or any other new accounts are needed.

Conclusion

The practice of considering water resources development in isolation and the problems in development evaluation procedure are a result of changes in the philosophy of federal expenditures. In the past, only economic analysis was considered in development planning. It was usually the policy of the federal government to fund water-related projects only if their benefits exceeded their costs. As time went on, more and more aspects of water resources development were taken into account. Today the policy of the government is that every conceivable aspects of impact, from economic to social to ecological, should be taken into account. The current problems are not due to ill-conceived concepts; they are due to continual modification of sound methods to the point where basic revision is needed [3].

As stated earlier, an effective evaluation procedure is only a means to attain a more effective development planning. Sometimes when the subject of evaluation is mentioned, it is linked to the approach of cost-effectiveness. Cost-effectiveness generally is referred to methodology used to optimize objectives under various constraints or alternatives [5]. In the past, the benefit and cost ratio analysis used in water resources development evaluation was mostly based on monetary measurement. As far as the current policy in water resources development planning is concerned, multiple objectives must also be considered in the planning. With the introduction of the multiple objectives, some objectives may not be able to be measured in monetary terms. Therefore, any cost-effectiveness methodology used for water resources development planning evaluation should be extended beyond the measurement of monetary value to include other types of measurements. Especially when priorities of some of the objectives are considered, the method should also be able to include weights for the priorities in the formulation of the analysis. For example, if in some regions the development of water supply is regarded to be more urgent than recreational development, then priorities for water supply development should be accounted in the analysis; or, if a region needs more development than other regions, then priority should be given to this region. Anyhow, any analysis used should be able to consider different objectives and measurements besides the economic factors based on monetary value.

Hence, a fresh approach which will respond to the current and probably future philosophy should be sought. In summary, to deal with the present problems, the new approach should at least be able to relate all individual developments under the overall system, to recognize proper priorities, and to augment new criteria and objectives to make the evaluation process more effective and, thus, more beneficial to water resources development. Decision theory and game theory, which are sometimes used as cost-effectiveness techniques, and the heuristic gaming approach and their possible applications were studied and they will be discussed in the following.

Decision Theory and Its Application to Evaluation Problem

While reviewing the present practices of water resources development planning evaluation it was found that decision-making plays quite an important role in the whole process. This led to a brief study of the decision theory and its possible application to evaluation problems.

Decision theory, in general, is an approach for systematic and effective decision-making. In order to illustrate its principle a simple decision theory model by Kline [6] is shown in Fig. 1.1. The main purpose of this model is to establish effective or system-worth criteria for system engineering. As it is shown in the figure, the model consists of a series of steps. A sub-model which establishes standards, solution methods, and evaluation criteria is first constructed before initial information is fed into this sub-model. Next, alternative solutions are sought, and then analyzed or tested. Results from analysis are appraised by evaluation criteria at the evaluation step which will lead to the final decision and thus generate new information. If any obtained decision being unsatisfactory, the optimization loop will make it possible to change the previously established standards in the sub-model

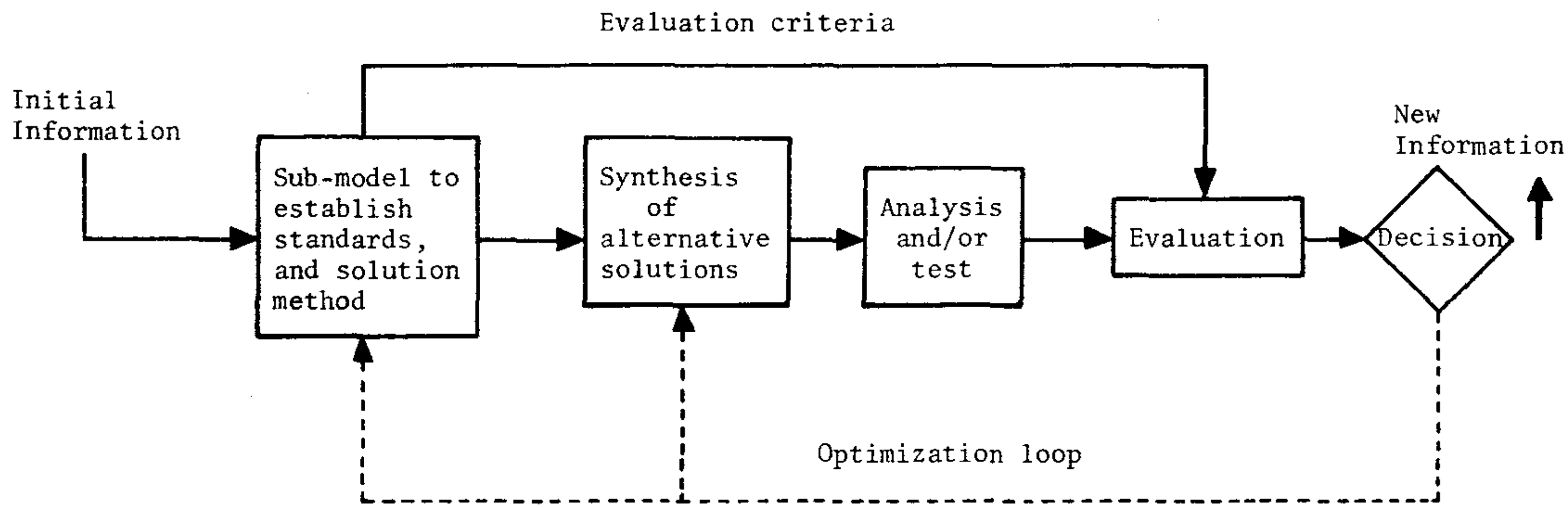

Figure 1.1. A decision theory model.

and to obtain an alternative solution. Of course, every time the optimization loop is used, it means a repetition of the whole evaluation process.

Evaluation is usually a key step in a decision-making process. Its primary purpose is to provide data in meaningful form to help a decision to be made. A decision is always a choice among alternatives, each of which will lead to a specific outcome. Evaluation is designated to help reducing the uncertainty of the outcome; or it may be looked at as a means for increasing the confidence level of the occurrence of a desired outcome.

It is believed that decision theory could be used as a proper means for leading to a more effective evaluation procedure for water resources development planning because the purpose of evaluation for water resources development planning is the same as those suggested by the evaluation in decision theory. Furthermore, when implementing concepts of decision theory in the present study, one can consider it to be a way of evaluating the worth of benefits received for the resources used and not simply a benefit-cost ratio analysis which is suggested in the present concept of water resources development evaluation procedure.

In the decision-making process, an analytical method is usually needed to support effective systematic evaluation. For example, linear programming and dynamic programming are used to help decision making by optimizing the objectives under a set of constraints. Reid, Lawrance, and Law's "A Model for the Allocation of Funds for the Development of Water Resources" [3] is an example of using integer and linear programming to support decision making. Raser [7] mentioned that mathematical theory of games, which is simply a set of statements about values and the logical consequence of basing decision on these values, is an excellent source of ideas for implementing decision theory. It will be noticed in the next section that game theory also has other features common to water resources development problem. Therefore, the reasons and possibility of using game theory concepts in formulating an evaluation procedure will be explored next.

Game Theory and Its Application to Evaluation Problem

Theory of games is a study of conflict of interests. The modern mathematical approach to conflict of interests is generally attributed to Von Neumann and Morgenstern for their publication - "Theory of Games and Economic Behavior" [8]. This publication has been furnishing people with limited mathematical training an opportunity to understand the motivation, the reasoning, and the conclusion of game theory. Hence, a growing interest in the scientific study of interest conflict resulted in the last several decades. As a reflection of this trend, one finds today that the study of interest conflict, both among individuals and among institutions, is one of the more dominant concerns of at least several academic departments, for example, economics, sociology, political science, and other areas to a lesser degree [9].

The mathematical theory of games was originally created to provide a new approach to economic problems, Von Neumann and Morgenstern did not construct a theory simply as an appendage to take its place on the periphery of economics as an afterthought. On the contrary, they felt that "the typical problems of economic behavior become strictly identical with the mathematical notions of suitable games of strategy." [9]. Example of interest conflict can be easily found in economic situations. Bilateral monopoly (one buyer and one seller) and oligopoly (a few sellers) are typical examples of interest conflict [10]. Other situations of interest conflict can always be arranged into a format of a competitive game. In this game, each competitor is competing for results or solutions beneficial to himself by using different strategies, though the possibility of getting proper solutions is mainly dependent upon the game arrangement and the complexity of the original situation.

Water resources development planning evaluation is fundamentally an ecomomic problem with an interest conflict nature; and, hence, it is amenable to the mathematical theory of games. Very often in the process of evaluation, comparisons are constantly made among alternatives which could be different regions, various levels of spending, several benefit categories, long-term and short-term effects, etc. These alternatives, or other components of development planning can be arranged into competitive games in which solutions are derived by using particular solution methods. These solutions can then be used as recommendation in the final decision making process.

While discussing decision theory and its application to evaluation problems, it was concluded that an analytical method is needed to support effective evaluation. Now, since some characteristics common to water resources development problems and game theory concepts have been recognized and application of game theory to development evaluation also seems to be possible, a competitive evaluation model aimed at more effective resources development planning based on game theory concepts will be developed in this study. An alternative to the analytical game theory approach, heuristic gaming, will be discussed first.

Heuristic (Operational) Gaming Approach to Water Resources Development Problem

Heuristic gaming is an alternative for analytical approach in the study of interest conflict problem. Sometimes when a complex competitive environment can not be cast into a formal mathematical model, the situation may be simulated as a heuristic game, in which human players enter the simulation system, act according to certain rules of thumb, and begin to manipulate the units and relationship in the structure. Raser [7] stated that heuristic gaming was once referred to as a "messing around" in science, but "messing around" is a legitimate way to increase knowledge. Anyhow, heuristic gaming does provide a powerful research tool for generating information and may enable one to shorten the influential road for some types of decision making. As a consequence, heuristic gaming has been used widely in many different fields, to name a few, war games, management and business games, political science and international relations games, games in sociology, games in education, games in psychology, etc.

At an earlier stage of this study, thoughts were given to adapt a heuristic gaming approach for solving water resources planning problem. As a result of this, a water resources development game was set up. This game was a simulation of a river basin. Different aspects of activities on a river basin were formulated into the simulation. The game was played several times. Although the game provided useful insights into the way water resources are developed in a river basin, it was not suitable to be used for studying complicated and large-scale development planning problems. With further planning and detailed simulation, heuristic gaming approach may possibly be used in future research. At the present moment, the theoretically justified game theory concepts will be employed to develop the competitive evaluation model in this study.

Objectives of the Competitive Evaluation Model

As stated earlier, the main objective of the competitive evaluation model is to establish a more effective evaluation methodology for helping water resources development planning. To achieve the main objective, a set of sub-objectives of the model is also explicitly defined in the following :

1. To be able to identify the following situations in water resources development:

a. The overall system of water resources development as well as individual or local development.

b. The relationship of water resources developments in different locations or regions.

c. The inter-relationship between different purposes or goals of water resources development.

d. Priorities among different purposes and locations of water resources development.

2. To be able to recognize the competitive nature of water resources development.

3. In addition to the measurements of benefit and cost used in the present evaluation procedure, to be able to augment new measurements, for example, effectiveness, long-term and short-term needs, etc.

4. To be able to provide systematic and specific recommendations for the decision-maker in order to benefit water resources development.

5. The model proposed must also be simple enough to be practically applicable.

The last sub-objective of the model is specially mentioned here because very often these days theoretical techniques introduced for some analysis are so ideally and esthetically developed that their application may not be too realistic after all.

Structure of the Model

The competitive evaluation model is mainly a collection of sets of games. The structure of the model is quite simple. As it is shown in Fig. 1.2, in the model there are several sets of games. Each set of games represents an evaluation criterion. In other words, all comparison information is centered around a particular evaluation measurement within a set. Each set has its individual games which supply comparison information. Each individual game has several components which include players, strategies, payoffs, etc. A great portion of the effort for this study was spent in the development of these individual game components because they are the backbone of the model. The main purpose of this model will be to collect and interpret comparison information from games in each set and then to use this information to formulate recommendations for decision making.

To be more specific about what the model does, the general idea of the model's application in evaluation of water resources development planning will be discussed here. In the verification of the model, several evaluation criteria, which categorize the sets of games, are introduced. These criteria are the measurements of the percent of effectiveness, the percent of needs met, the long-term total objective , and the short-term objective comparisons of water resources development planning between different water resources basins in the United States. The detail of these criteria will be explained later. Under each criterion which heads a set of games, games between different water resources basins were arranged so that comparison information among various types of development in different basins can be obtained. Of course, all comparison information are generated from individual games and they are collected and

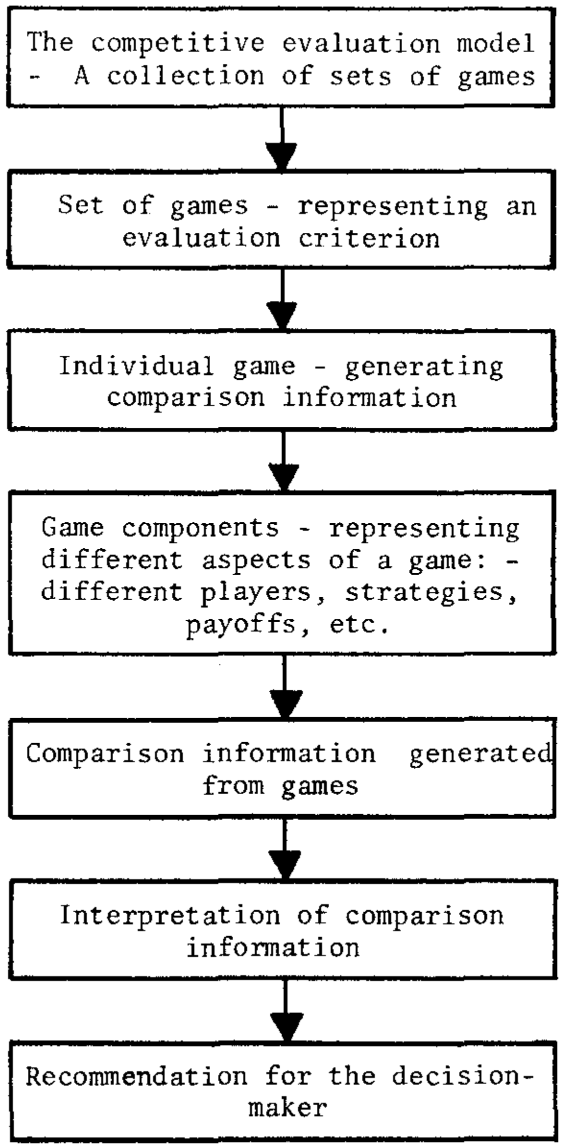

Figure 1.2. Structure of the competitive evaluation model.

interpreted under each evaluation criterion. This information could be used to formulate recommendations for decision making. The model made no effort to show how exactly water resources should be developed in the United States; it only offers the decision-maker the comparisons of various types of development planning between basins under different evaluation criteria.

Since all comparison information is obtained from individual games which are based on game theory concepts, a brief review of game theory concepts will be done next before discussing the development of the model.

CHAPTER II

REVIEW OF GAME THEORY CONCEPTS

It was mentioned in the introduction that the competitive evaluation model was developed by using game theory concepts. Therefore, a review of some basic game theory concepts will be done in this chapter.

Generally, game theory is the study of conflict of interests. Conflicting situations between two or more opponents are usually arranged into a competitive game. These opponents are referred to as the players of the game. The alternative actions which the players can maneuver in the process of a game are called strategies. During or at the end of a game, the payments transferred from one player to another, or simply received by a player, are called payoffs. The summation of payoffs a player receives during the game is designated as the value or solution of the game. The values of a game can be positive or negative depending on whether one gains or loses.

Luce and Raiffa [9] state that a game usually assumes one of the following three forms: the extensive form, the normal form, and the characteristic function form. To illustrate a conflict situation the extensive form employs game tree diagrams to show the step by step competition between the competitors. A payoff matrix which arranges payoffs of a game into a rectangular array in rows and columns is usually used in the normal form. Due to the fact that payoff matrix illustrates a competitive situation better than other methods, normal form is generally favored in studying basic game theory concepts. Characteristic function form very often involves theoretical mathematical functions, and hence is more complicated.

To study theory of games, one can divide the topics according to whether it is zero-sum or non-zero-sum, and according to the number of players in a game. A game is called zero-sum if the sum of payoffs which all players receive at the end of the game is equal to zero. Non-zero-sum is the opposite of zero-sum; i.e., the payoffs received by all players at the end of a game do not sum up to zero. The zero-sum nature of a game indicates a strictly competitive situation between the players of the game whereas non-zero-sum implies that there may still be some co-operative characteristics remaining for the opponents. Since two-person zero-sum, two-person non-zero-sum, and n-person games are the basic types of games, each of them will be discussed separately in the following.

Two-person Zero-sum Games

Two-person zero-sum games play a central role in the whole theory of games. In each game, the gain of one player signifies an equal loss to the other player. Usually the outcomes of the game are expressed in terms of the payoffs of one player. A payoff matrix for a two-person zero-sum game is shown in Fig. 2.1. In this matrix, the players of the game are represented by A and B. Player A has m strategies while player B has n strategies. Player A's strategies

Player B's Strategies

Player A's Strategies	B_1	B_2	B_3	$\cdots$	B_j	$\cdots$	B_n
A_1	a_{11}	a_{12}	a_{13}	$\cdots$	a_{1j}	$\cdots$	a_{1n}
A_2	a_{21}	a_{22}	a_{23}	$\cdots$	a_{2j}	$\cdots$	a_{2n}
A_3	a_{31}	a_{32}	a_{33}	$\cdots$	a_{3j}	$\cdots$	a_{3n}
$\vdots$	$\vdots$	$\vdots$	$\vdots$		$\vdots$		$\vdots$
A_i	a_{i1}	a_{i2}	a_{i3}	$\cdots$	a_{ij}	$\cdots$	a_{in}
$\vdots$	$\vdots$	$\vdots$	$\vdots$		$\vdots$		$\vdots$
A_m	a_{m1}	a_{m2}	a_{m3}	$\cdots$	a_{mj}	$\cdots$	a_{mn}

Figure 2.1. Payoff matrix of two-person zero-sum game.

are designated as A_1, A_2, ..., A_i, ..., A_m, whereas player B's strategies are those of B_1, B_2, ..., B_j, ..., B_n. If player A chooses the ith row strategy A_i and player B chooses the jth column strategy B_j, then the payoffs, in this case designated in terms of player A's payoffs, are indicated by the payoff coefficients which are a_{ij} for player A and $-a_{ij}$ for player B.

The objective of a game is for each player to choose his strategies so that the outcome of a game will be most beneficial to himself. Since both players are trying to get the most gains, the solution of a game is usually the value upon which both players would agree.

Different techniques can be used to solve two-person zero-sum games. Several solution methods will be mentioned. They mainly belong to either the use of pure strategy or mixed strategies. Since the detail procedures of these solution methods can be found in the references and most of them were found not to be suitable for direct use in the competitive evaluation model, they will not be discussed at length here. A dominance property which raises some problem later on in the development of the competitive evaluation model will also be mentioned here.

Pure Strategy

Pure strategy usually indicates that a player who may have several strategies in a game will use only a single prescribed strategy to obtain a final solution. Dresher [11] stated that pure strategy can be used to solve games with a saddle point. A saddle point is a point in the payoff matrix and it will lead to a solution which satisfies both players of the game. When using pure strategy to solve games, the minimax (or maximum) criterion is usually employed to pick out the strategies. The criterion expressed a conservative attitude which guarantees the best of the worst results. The two corresponding strategies used by each player are called "optimal" strategies. The saddle point is given by the common entry to these "optimal" strategies. The payoff in this common entry is called the "optimal" value of the game. "Optimality" here signifies that neither player is tempted to change his strategy since his opponent can counteract by selecting another strategy which will yield a worse payoff than the one given him through the minimax (or maximum) criterion.

Mixed Strategies

For games without saddle point, the two players can not use pure strategies to reach the optimal value. This is true since each player can improve his outcomes by selecting a different strategy.

The failure of the pure strategies to give an optimal solution to a game has led to the idea of using mixed strategies [14]. Each player, instead of playing his pure strategies only, will play all his strategies according to a predetermined set of ratios. The general concept of mixed strategies is described in the following. Let X_1, X_2, ..., X_i, ..., X_m and Y_1, Y_2, ..., Y_j, ..., Y_n be two sets of ratios, such that

$$\sum_{i=1}^{i=m} X_i = 1$$

and

$$\sum_{j=1}^{j=n} Y_j = 1 \tag{2.1}$$

where $X_i \geq 0$ and $Y_j \geq 0$ for all i and j. If player A has strategies A_1, A_2, ..., A_i, ..., A_m, and player B has strategies B_1, B_2, B_j, ..., B_n, then for the mixed strategies, player A will use strategy A_1 a fraction X_1 of the time, strategy A_2 a fraction X_2 of the time, strategy A_i a fraction X_i of the time and so on, and player B will use strategy B_1 a fraction Y_1 of the time, strategy B_2 a fraction Y_2 of the time, and strategy B_j a fraction Y_j of the time and so on. The ratios X_i and Y_j may be regarded as the probabilities by which players A and B select their i^{th} and j^{th} pure strategies, respectively. The solution of a game employing mixed strategies is defined as the following:

$$\begin{aligned} \text{Game value} &= \sum_{i=1}^{i=m} X_i \cdot a_{ij} \\ &= \sum_{j=1}^{j=n} Y_j \cdot a_{ij} \end{aligned} \tag{2.2}$$

where a_{ij} are payoff coefficients.

There are several methods for solving mixed strategies in two-person zero-sum games. According to Williams [12], the "Oddment" method can be used for solving games with small dimensions. Graphical methods [13] which usually gives vivid illustration can be used to solve two-person zero-sum games. For games of any dimensions, Taha [21] states that linear programming can be used to obtain solutions.

As stated earlier, the solution of a game is usually called the value of a game. This value is the outcome upon which all players agree. The theory of two-person zero-sum games is unusual in that it enables one to find solutions which are universally accepted. In actual problems that arise in every day life, competitive games usually do not lead themselves to straightforward answers. This indicates that using two-person zero-sum game approach to solve real life problem is very unrealistic.

Dominance Property

When solving games, Karlin [15] states that the so called "dominance property" should be taken into account. This property occurs when one or more of the strategies of either players can be deleted because they are inferior to the remaining ones and hence will never be employed. In such cases, it is said that the deleted strategies are dominated by superior ones. The superiority of a strategy is usually shown by the payoff coefficients of a game. For example, a strategy A_s is superior to another strategy A_t if and only if the followings hold true for their payoff coefficients:

$$a_{sj} \geq a_{tj} \qquad \text{for all } j,$$

where a_{sj} = payoff coefficients for strategy A_s,

a_{tj} = payoff coefficients for strategy A_t, and

j is the sub-script indicating the other player's strategy.

The dominance property can be used to reduce the size of games and hence the computation effort involved. But if a game has two dominant superior strategies, one for each player, it will be resolved into a simple competition between the two superior strategies. This is one of the problems which arised in developing the payoff matrix for games in the competitive evaluation model. To deal with such problems, a new algorithm was developed in this study. It will be discussed later.

Two-person Non-zero-sum Games

A non-zero-sum game is different from a zero-sum game in that payoffs of the game are denoted for both players. This is necessary because the gain of one player may not be the loss of another player. A payoff matrix for a two-person non-zero-sum game is shown in Fig. 2.2. This matrix is almost the same as the one shown for two-person zero-sum game except that payoffs are shown for both players. Each entry of the payoff matrix includes two items, the first one a_{ij} for player A and second one b_{ij} for player B.

Two-person zero-sum games come up in many different contexts, but they always have the same basic structure. By looking at the payoff matrix, one can pretty well tell "the whole", This is not the case in non-zero-sum games. Besides the payoff matrix, there are many "rules of the game" that markedly affect the character of the game, these rules must be spelled out before one can talk about the basis of the payoff matrix alone.

Methods for solving two-person non-zero-sum games have been introduced by different people. Nash [16] offeres a method. He regarded non-zero-sum game as bargaining problem, and stated that

Player B's Strategies

Player A's Strategies

	B_1	B_2	$\cdots$	B_j	$\cdots$	B_n
A_1	(a_{11},b_{11})	(a_{12},b_{12})	$\cdots$	(a_{1j},b_{1j})	$\cdots$	(a_{1n},b_{1n})
A_2	(a_{21},b_{21})	(a_{22},b_{22})	$\cdots$	(a_{2j},b_{2j})	$\cdots$	(a_{2n},b_{2n})
.	.	.		.		.
.	.	.		.		.
.	.	.		.		.
A_i	(a_{i1},b_{i1})	(a_{i2},b_{i2})	$\cdots$	(a_{ij},b_{ij})	$\cdots$	(a_{in},b_{in})
.	.	.		.		.
.	.	.		.		.
.	.	.		.		.
A_m	(a_{m1},b_{m1})	(a_{m2},b_{m2})	$\cdots$	(a_{mj},b_{mj})	$\cdots$	(a_{mn},b_{mn})

Figure 2.2. Payoff matrix of two-person non-zero-sum game.

the task is to give a formal definition of a bargaining problem and to solve it. His approach is to select a starting point which is agreed by all the players for bargaining, and proceed from there to arrive at a set of solutions.

Davis [17] offers a method which employs techniques used for solving two-person zero-sum games to solve non-zero-sum game. His method suggests that by isolating the payoffs of the other player, game value is obtained for one player. This is done for both players. And, then, these two game values are used as the lower limits leading to outcomes upon which both players will agree. This method is essentially the same as the one suggested by Nash except that the bargaining point is analytically calculated. Most of the methods introduced by others are similar to the ones discussed here.

Davis [17] states that the outcomes of two-person games may depend on the ways of communication, the effect of imperfect information, the effect of restricting alternatives, whether threats are allowed, binding agreement and side payment, etc. Von Neumann and Morgenstern [8] argue that the actual selection of an outcome of a two-person non-zero-sum game depends upon certain psychological aspect of the players. They contend that further speculation in this direction is not of a mathematical nature, at least not with the present mathematical abstraction.

In conclusion, for most non-zero-sum games with any complexity, there is no universally accepted solution; that is, there is no single strategy which is clearly preferably to the others, nor is there a single clear-cut, predictable outcome. Therefore, one will have to be content with something less than the unequivocal solution one obtained for zero-sum games.

N-person Games

Due to the complexity of games, studies on n-person games are admitted to be less satisfactory than two-person games. As the name suggested, n-person games involve more players in a game. The first problem encountered in n-person games is the difficulty of arranging the conflicting situation between players into a proper competitive formulation. Then, there are many more factors to be considered, for example, the problem of coalitions between players, the superadditivity properties of payoffs, individual rationality among players, etc.

Different methods have been attempted for solving n-person games, yet so far they are all unsatisfactory. One particular method introduced by Churchman, Ackoff and Arnoff [18] uses coalition formation between players to simplify the problem into two-person games and proceed from there. Since there are a number of players in each game, different coalitions will lead to different solutions. From the start, Von Neumann and Morgerstern [17] gave up any hope of finding a single payoff solution for all n-person games. They asserted that the only reasonable solution is a variety of alternatives, which will probably all express some general principles but nevertheless differ among themselves in many particular respects. They also felt that the existence of many alternatives, far from being a defect of the theory, is in fact an indication that the theory has the flexibility necessary to deal with the wide diversity one encounters in real life.

Summary

Generally, in the application of game theory, after identifying the opponents and their strategies of a conflicting situation, a competitive game is first formulated. Next, payoffs derived from using different strategies by each player are sought. In the case of two-person zero-sum games, the solution of a game is then obtained by employing a particular solution method. In other cases, for example, two-person non-zero-sum games or n-person games, a solution set which includes different alternatives is sought and, then, special alternatives are selected and applied to the specially required situation. In conclusion, two-person games are usually easier to handle and solutions are more readily accepted than the more complicated n-person games which, so far, often depend on coalition formation to obtain solutions.

Scope of Games in the Competitive Evaluation Model

Games in the competitive evaluation model are developed by using some game theory concepts mentioned in this chapter. Due to the fact that n-person games are usually quite complex and do not give a solution which would please all players, it was decided to use only the simple *two-person games* throughout the model. Since games in the model are used for the purpose of obtaining comparison information which will later be used to formulate recommendations for the evaluation of water resources development planning, the strictly competitive situation between opponents of zero-sum games is not the nature of games in the model. Hence, games considered in the model will all be *non-zero-sum* and payoffs will be denoted for both players of a game. The normal form of a game which employs *payoff matrix* to indicate the competition will be used in the model, because payoff matrix summarizes all payoffs of a game into a single matrix and thus clearly illustrates the whole conflicting situation.

A new algorithm was developed to solve games in the model. This was done because the two-strategy (one for each player) dominance problem occurred consistently during the development of the payoff matrix of games in the model and none of the existing solution methods seems to be suitable for solving games in such situation. Although the new algorithm is completely different from the existing solution methods, it is still based on the method of solving two-person non-zero-sum games by isolating one player's payoffs and then obtaining a solution for the other players. The detailed development of this new algorithm will be explained in the next chapter as is the development of the model itself.

CHAPTER III

General Development of the Competitive Evaluation Model

The objectives of this study and the competitive evaluation model were stated in Chapter I. In Chapter II, a brief review of the basic game theory concepts was done. The purpose of this chapter is to describe the development of the competitive evaluation model. It will be done in a very general format. The more detailed application of the model to the evaluation of water resources development planning will be discussed in the next chapter.

General Description of the Model

The model is basically a collection of sets of games. Since the purpose of the model is for evaluation of water resources development planning, each set of games represents an evaluation criterion. The number of sets in the model is depended on the number of evaluation criteria determined by the decision-maker. To bring out the emphasis on a particular evaluation criterion, an objective priority weighting factor can be applied to the results of a set of games.

Each set has a number of games which are used to generate comparison information . In this study, the comparison information was specially aimed at water resources development in different water resources basins in the United States. Within each set of games, a game, or basin, priority weighting factor can be used to bring out the priority of a game. To be more specific, this factor is intended for sounding out the development priority of a certain water resources basin.

Games in a set are actually the main component of the model. These games are developed using game theory concepts. Many of the components of games in this model are terms from traditional game theory, for example, player, strategy, payoff matrix, payoff coefficient, etc. A new term, the utility number of a strategy (UNS), and a new algorithm for solving games are the special features of the games in this model. In this study, players of games are used to represent water resources basins in the United States and their strategies are various types of water resources development. Strategies of a player also have their weighting factor and they are used, in this model, to bring out the special needs of certain types of water resources development in a basin, for example, the urgent need of flood control or irrigation development in a particular basin.

Solutions for each game are first found. They are compared within a set of games before being compared with solutions from other sets of games. All solutions are then interpreted and used as guideline to establish recommendation for the decision-maker in the evaluation of water resources development planning.

Sets of Games in the Model

Each set of games in the competitive evaluation is headed by an evaluation criterion. The purpose of these criteria is to measure the objectives of various types of water resources development in different water resourses basins in the United States. The number of sets of games in the model is quite flexible and is decided by the decision-maker. In other words, the number of evaluation criteria allowed in the model is not restricted in the sense that if a decision requires more detailed analyzed information, then more sets of games should be included in the model. Usually it is the case that the more sets of games are considered, the more information will be generated for the decision-maker assuming that the information thus obtained is not redundant or overlapping. This unrestrictiveness of the number of sets of games in the model is introduced to compensate the past practice of using only benefit and cost ratio analysis as the single criterion in the evaluation procedure of water resources development. Earlier it was stated that new objectives of water resources development should be explored. Using this concept of permitting flexible number of evaluation criteria, whenever new objectives need to be considered, their results of evaluation can always be added to the original evaluation results.

In this study, four evaluation criteria which will be discussed in the next chapter, are introduced. They are the measurements of the long-term total objective, the short-term objective, the percent of effectiveness, and the percent of needs met. These evaluation criteria are introduced only for demonstration purpose and by no means are they representing a complete evaluation.

In each set of games, there are individual games which are the source of the comparison information. Therefore a great portion of the remaining of this chapter will be devoted to the development of the individual games in the model.

Games in the Model

Games are the main component of the competitive evaluation model. The objective of games in the model is to generate comparison information between players. This is a little different from the traditional use of games which usually only denotes competition between two opponents. Hence, it may be more appropriate to call the competition of a game in this model the comparison, or even more precisely related to this model, the competitive evaluation. However, all these terms have been and will be used interchangeably throughout this report.

Earlier, the general concepts of games have been discussed. Terminology of traditional game theory will be retained in this study. Nevertheless, it is possible that interpretation of these terms, or components, of games may be different from their traditional meaning. Besides, some new terms have been introduced. The greatest change for game in this model is the use of a new algorithm to replace the traditional method for solving games. Each component and the new algorithm will be discussed in the following.

Players of Games

Since games in the competitive evaluation model are used for obtaining comparison information, players of a game naturally represent the two parties for whom comparisons are being sought. No fixed rule is set for the selection of players or the number of their appearances. Players can always be arranged into a competitive game if comparison information between them is needed. Of course, whenever two players appear in the same game, they should at least have some common characteristic or some common ground to be compared. In this study, the players of games are used to represent water resources basins in the United States.

Since only two-person games are used in this model, if comparisons between more than two players are needed, they can only be derived indirectly from repeated competitions. One way of doing this is to arrange one player as the standard player so that all other players can compete with this particular player to obtain all the comparisons needed between all players. This is the method used in this study.

The Basic Payoff Matrix

The format of game payoff matrix in the competitive evaluation model is basically the same as the one shown earlier for two-person non-zero-sum games except that one more term is added to the matrix. This additional term, the utility number of a strategy (UNS), and the development of the matrix will be explained later. Figure 3.1 shows the basic payoff matrix of a game in the model. A and B represent the two players of the game. Player A has m strategies designated by A_i's, for $i = 1, 2, \ldots, m$; whereas player B's n strategies are designated by B_j's, for $j = 1, 2, \ldots, n$. Associated with each strategy, there is a specific utility number (UNS). For example, U_{ai} is the utility number for player A's strategy A_i, and U_{bj} is the utility number for player B's strategy B_j. The subscripts ai and bj of the utility numbers are used to indicate that the utility numbers belong to strategies A_i and B_j, respectively. The coefficients of the payoff matrix (CPM) are shown in the same

Player B's Strategies and Utility Numbers (UNS)

Player A's Strategies and Utility Numbers (UNS)

		B_1	B_2		B_j		B_n
	UNS	U_{b1}	U_{b2}		U_{bj}		U_{bn}
A_1	U_{a1}	(a_{11},b_{11})	(a_{12},b_{12})	...	(a_{ij},b_{ij})	...	(a_{1n},b_{1n})
A_2	U_{a2}	(a_{21},b_{21})	(a_{22},b_{22})	...	(a_{2j},b_{2j})	...	(a_{2n},b_{2n})
.							
.							
.							
A_i	U_{ai}	(a_{i1},b_{i1})	(a_{i2},b_{i2})	...	(a_{ij},b_{ij})	...	(a_{in},b_{in})
.							
.							
.							
A_m	U_{am}	(a_{m1},b_{m1})	(a_{m2},b_{m2})	...	(a_{mj},b_{mj})	...	(a_{mn},b_{mn})

Figure 3.1. Payoff matrix of games in the competitive evaluation model.

way as those shown earlier for two-person non-zero-sum games; i.e., the first term aij of the payoff coefficient (aij, bij) belongs to player A and the second one, bij, belongs to player B.

Strategies of Games

Any player of a game in the competitive evaluation model will have a number of strategies to be manipulated. Usually in game theory, a strategy is a complete description of how one will behave under every possible circumstance; it has no connotation of cleverness. Since games in the model are used for obtaining comparison information between players under a particular evaluation criterion, strategies will represent different aspects on which comparisons are needed to be made. In this study, outcomes of various types of water resources development, for example, development of flood control, irrigation, navigation, etc., will be used as the strategies when comparison information between water resources basins are sought.

In this model, it is assumed that the number of strategies available to a player is finite. For instance, in the payoff matrix shown earlier, player A has m strategies and player B has n strategies. The number of strategies a player can have is totally depended on the types of games one is involved.

In the same game or in the same set of games, it is necessary that strategies used by each player are similar in nature although they may not be identical or equivalent in number. Otherwise comparison will not be able to be made. But it is permissible for players to have different types of strategies in different setsof games; i.e., players can have one type of strategy in games under an evaluation criterion and other types of strategy in games under another evaluation criterion.

The Utility Number of Strategy (UNS)

The utility number of strategy shown earlier in the basic payoff matrix of games in this model is used to measure the absolute payoff or outcome of a strategy under a certain evaluation criterion. This newly introduced term is not usually indicated in conventional game payoff matrix. Although the derivation of the utility number of a strategy may involve the consideration of its relationship with the utility numbers of the other strategies of the same player or even those of the opponent, the magnitude of the utility number of a strategy is only relevant to this particular strategy. Utility number is not a relative payoff derived after considering two strategies belonging to two different players like the payoff coefficient which will have its derivation explained in the next section. In other words, the derivation of the utility number of a strategy is usually independent of other strategies.

A strategy may have several UNS's, each one of them being the measurement of the absolute payoff or outcome of this strategy under a particular criterion. For example, in this study, various types of water resources development are designated as strategies for the basin-players and under each evaluation criterion there is a special utility number for each type of development.

The derivation of the UNS's is difficult to be clearly explained unless the strategy and the evaluation criterion are definitely defined. Hence, it will be more explicitly explained in the next chapter in the application of the competitive evaluation model for evaluation of water resources development planning when all the strategies and evaluation criteria are definitely defined.

Utility number is one of the main input of games in the competitive evaluation model. It will be used to procure payoff coefficients of a game.

Coefficients of the Payoff Matrix (CPM)

To develop the coefficients of the payoff matrix (CPM) for a game so that they will be reflecting real life situation and quantitatively usable in the competitive evaluation model has been a time consuming effort. In game theory texts, the derivation of the CPM's has seldom been clearly explained. In some cases, the coefficients were just arbitrarily arranged into the matrix without even considering whether they reflect any reasonable real life situation. Hence, it was necessary in this study to develop a method for obtaining payoff coefficients for games in the competitive evaluation model.

So far in the development of games for the model, the main information available in the payoff matrix is the utility number (UNS), or the absolute payoff, of each strategy, and it was intended to use them to procure the coefficient of the payoff matrix (CPM). As it was stated earlier, utility number of a strategy is a measure of the outcome for a strategy and it is only relevant to this particular strategy. But a CPM is usually the resultant derived from two strategies belonging to the two different players of a game. Therefore, it is necessary to use the utility numbers of two strategies, each one belonging to a player of a game, to obtain a payoff coefficient.

An earlier attempt was to use the difference of two utility numbers as the payoff coefficients. For instance, if U_{ai} is the utility number for player A's strategy A_i and U_{bj} is the utility number for player B's strategy B_j, then the payoff coefficients corresponding to strategies A_i and B_j are as follows:

$$a_{ij} = U_{ai} - U_{bj} \text{ for player A,}$$

and

$$b_{ij} = U_{bj} - U_{ai} \text{ for player B.}$$

This can be interpreted as if U_{ai} and U_{bj} represent the benefit gains for strategies A_i and B_j, respectively, then a_{ij} is the net benefit gain for player A's strategy A_i over those of player B's strategy B_j. This method of calculating CPM is in agreement with the practice of evaluating water resources development by finding the net benefits, although in this case the benefit obtained from using one player's strategy over those of another player's strategy is calculated instead of the difference between the benefit and the cost.

The practice of comparing outcomes of two strategies is essential in the competitive evaluation model. But the approach of using the differences of two utility numbers as payoff coefficients led to the fact that player A's payoff coefficient a_{ij} would be equal to the negative of player B's payoff coefficient b_{ij}. This indicates that the net gain of one player is equal to the net loss of another, then a zero-sum game appeared. At the same time, since payoff coefficients a_{ij} and b_{ij} have the same units as utility numbers U_{ai} and U_{bj}, game values from different games will have different units attached to them. Thus, it would be quite difficult to combine results from different games for further comparison.

Finally it was decided that payoff coefficients should be the ratios of two utility numbers instead of their differences. And the payoff coefficients are defined as follows:

$$\begin{cases} a_{ij} = \dfrac{U_{ai}}{U_{bj}} \text{ and } b_{ij} = \dfrac{U_{bj}}{U_{ai}}, & \text{if } U_{ai} \neq 0 \text{ and } U_{bj} \neq 0 \\ a_{ij} = 0 \text{ and } b_{ij} = 0, & \text{if } U_{ai} = 0 \text{ or } U_{bj} = 0 \end{cases} \tag{3.1}$$

where a_{ij} = the payoff coefficient for player A by using strategy A_i,

b_{ij} = the payoff coefficient for player B by using strategy B_j,

U_{ai} = utility number for player A's strategy A_i,

and U_{bj} = utility number for player B's strategy B_j.

The reason for using the ratio of two utility numbers of different strategies belonging to the two opponents of a game as the payoff coefficients has its root in benefit-cost analysis which, as it was mentioned earlier, has been used for evaluation of water resources development. Although in the benefit-cost analysis the ratio is between the benefit and the cost, whereas the ratio in the present case is between two utility numbers which could represent two benefit gains, two costs, or some other measurements.

This approach for obtaining payoff coefficients also has the following advantages:

(i) The comparisons of game values from different games will be made possible. Since utility numbers U_{ai} and U_{bj} in a particular game always have the same units, the division of U_{ai} by U_{bj} or vice versa will make the payoff coefficients a_{ij} and b_{ij} an unitless quantity which in turn will be used to obtain unitless game values. Thus, game values from a set of games or from different sets of games can later be combined for further comparisons to give systematic recommendations for the decision-maker.

(ii) The division of one utility numbers by another will also achieve the purpose of competitive evaluation. In the process of obtaining payoff coefficients, one player is using another player's utility number as an evaluation or measuring basis to arrive at one's payoff coefficient. For example, player A's payoff coefficient a_{ij}, which is equal to U_{ai}/U_{bj}, can be interpreted as the gain for player A by using strategy A_i per unit gain for player B by using strategy B_j; and player B's payoff coefficient b_{ij}, which is equal to U_{bj}/U_{ai}, indicates the gain for player B by using strategy B_j per unit gain for player A by using strategy A_i. From this practice of obtaining payoff coefficients through mutually competitive measuring of utility numbers, the competitive nature of games in the competitive evaluation model is once again emphasized.

Although the method used to obtain payoff coefficients has its advantages, a problem which brings difficulty in obtaining solutions for a game also arises from the method. It is the dominance problem and it will be discussed next.

Dominance Problem

Due to the method used to develop payoff coefficients for games in the competitive evaluation model, the dominance problem occurs for both player's strategies in every game. The dominance problem, as it was stated earlier, occurs when one or more strategies of either players of a game can be deleted because they are inferior to the remaining ones and hence will never be employed. It is said that the deleted strategies are dominated by the superior ones. The superiority of a strategy is usually shown by its payoff coefficients. In this model, utility numbers are used to measure the absolute payoffs of a strategy and payoff coefficients are derived from utility numbers. Hence the dominance of a strategy originates from utility numbers. For example,

$$\text{if} \quad U_{as} \geq U_{at} \ ,$$

$$\text{then} \quad a_{sj} = \frac{U_{as}}{U_{bj}} \geq \frac{U_{at}}{U_{bj}} = a_{tj} \qquad \text{for all } j,$$

where U_{as} = utility number for player A's strategy A_s,

U_{at} = utility number for player A's strategy A_t,

U_{bj} = utility number for player B's strategy B_j,

a_{sj} = payoff coefficient for strategy A_s,

a_{tj} = payoff coefficient for strategy A_t,

and j is the sub-script indicating player B's strategy. In this example, the dominance of strategy A_t by strategy A_s is shown by their payoff coefficients ($a_{sj} \geq a_{tj}$) which originate from utility numbers ($U_{as} \geq U_{at}$).

The dominance problem happened to games in this model is also the two-strategy dominance case. The two-strategy dominance is the situation in which two strategies, one from each player, are superior to all other strategies and thus it will resolve a game into a simple competition between these two superior strategies. For example, considering all the utility numbers U_{ai} for player A's strategies A_i in a game, if $U_{as} > U_{ai}$ for all i such that $i \neq s$, then strategy A_s which has utility number U_{as} will dominate all other strategies of player A; for the same reason, considering all utility numbers U_{bj} for player B's strategies B_j, if $U_{bt} > U_{bj}$ for all j such that $j \neq t$, then all strategies B_j of player B will be dominated by strategy B_t which has utility number U_{bt}. Hence, both player A and B have a superior strategy, A_s for player A and B_t for player B, which dominated all their other strategies, and the game is resolved into a competition between these two strategies, A_s and B_t.

Consequently, the two-strategy dominance problem has led to the development of a new algorithm for solving games in the competitive evaluation model. Following the traditional meaning of games and their solution methods, the occurrence of the two-strategy dominance indicates that each player will use only their superior strategies for competing in a game, i.e., the use of pure strategy. Since games in this model are arranged for obtaining comparison information between water resources basins through the use of different types of water resources development as strategies, the occurrence of two-strategy dominance will mean the comparison between only two types of water resources development which are represented by the two strategies with the highest utility numbers. But it was not intended to use one single superior development (strategy) to claim that all other developments (represented by other strategies in the game) of the same basin are better or worse than those of another basin; and this is just what the two-strategy dominance suggested in ordinary solution methods of games. Therefore, the conventional solution method for games will not be used and a new algorithm for solving games will be developed in this study to meet the purpose of games in the competitive evaluation model.

Game Solution Method

The Originally Intended Method

According to the original plan, if payoff coefficients could be developed without the occurrence of the two-strategy dominance problem, it was intended to apply techniques used for solving two-person zero-sum games to solve all the two-person non-zero-sum games in this model. Because there are generally no argument concerning the validity of solutions in two-person zero-sum games, and, thus, solutions derived are satisfied by all players of a game.

A method proposed earlier for solving games in this model was to find game value for a player by only considering his own payoff coefficients in the matrix. In other words, by isolating the other player's payoff coefficients in the matrix, game values are obtained for each player of a two-person non-zero-sum game by using solution methods for two-person zero-sum games. Thus, there will be two game values from every game, one for each player. These two game values of a non-zero-sum game represent what the minimum or guaranteed gain a player will get by using pure or mixed strategies.

Since the purpose of games in this model is to obtain information generated from the comparison of different strategies, these game values can serve as an indication or quantitative measurement of the comparison.

With the occurrence of the two-strategy dominance problem which reduces a game into a competition between two single superior strategies instead of the intended comparisons between different strategies, the intended plan of using solution method applied to two-person zero-sum game to solve all two-person non-zero-sum games in the model had to be abondoned. Some other means for solving games in the model must be sought.

Basic Reasoning of the New Algorithm

The problem to be dealt with in here now is to acquire game values which would give a better representation of what different strategies with their associated utility numbers indicate. These games values also should not be the result of a competition between two superior strategies, i.e., all strategies should participate in the derivation of the game values. Consequently, a new algorithm for solving games in the competitive evaluation model was developed.

The new algorithm is based on the concept of average expected value. In decision theory the question involved in the course of actions is always the choice of a proper decision from a number of alternatives which usually represent variety of circumstances. To help with the decision making, the statistical method of expectation or average value is very often used to give quantitative representation of each alternative. Average expected values are usually calculated from the linear combination of the products of different expected values and their corresponding probabilities. For example, if x_i's, for i = 1, 2, ..., m, are a series of values expected to happen and $p(x_i)$ are the probabilities associated with each of these x_i's, then the average expected value is calculated by the following formula:

$$\text{Average expected value } E(X) = \sum_{i=1}^{i=m} p(x_i) \cdot x_i \ ,$$

where $0 \leq p(x_i) \leq 1$. The proposed new algorithm is based on this concept of average expected value. Payoff coefficients which are derived from utility numbers of strategies will be considered as the expected values and a number representing the occurrences of the strategies will take the place of the probabilities. The new algorithm has in some way a resemblance to Eq. (2.2) used to compute game solution for mixed strategies shown earlier in Chapter II.

The New Algorithm

The new algorithm can be stated as the following:

$$\begin{aligned} V_{A-B} &= \frac{1}{P} \sum_{i=1}^{i=m} \left(\frac{1}{Q} \sum_{j=1}^{j=n} a_{ij}\right) \\ &= \frac{1}{PQ} \sum_{i=1}^{i=m} \sum_{j=1}^{j=n} a_{ij} \\ V_{B-A} &= \frac{1}{Q} \sum_{j=1}^{j=n} \left(\frac{1}{P} \sum_{i=1}^{i=m} b_{ij}\right) \\ &= \frac{1}{PQ} \sum_{j=1}^{j=n} \sum_{i=1}^{i=m} b_{ij} \end{aligned} \qquad (3.2)$$

where V_{A-B} = game value for player A when the opponent is player B,

V_{B-A} = game value for player B when the opponent is player A,

a_{ij} = payoff coefficients for player A,

b_{ij} = payoff coefficient for player B,

P = the number of rows which have at least one non-zero entry of the CPM's,

Q = the number of columns which have at least one non-zero entry of the CPM's.

This new algorithm for solving games in the competitive evaluation model is based on the concept of average expected values. The game value for a player is simply the sum of all his payoff coefficients divided by the number of non-zero payoff coefficients.

Although this algorithm is quite different from the originally intended method, i.e., to solve a two-person non-zero-sum game by using techniques usually applied to two-person zero-sum games, yet the original plan of obtaining one's game value by isolating another player's payoff coefficients is still being adopted. For example, none of player B's payoff coefficients b_{ij} are used in the process to obtain game value V_{A-B} for player A; in other words, only player A's payoff coefficients are used in calculating game value V_{A-B} for player A.

Several advantages of this new algorithm are stated in the following:

(i) All strategies participate in the final derivation of game values. This is what originally intended before this algorithm was developed. The development of this new algorithm was due to the occurrence of the two-strategy dominance problem in the payoff matrix which has resolved a game into a competition between two superior strategies and thus has discredited all the deleted strategies. But the new algorithm of taking average expected values as game solutions does consider all strategies simultaneously.

(ii) The new algorithm allows players with different types of strategies or even unequally numbered strategies to launch a competition or a comparison. This may answer the question of the necessity of going through all these many steps to find the average expected values as a result of comparison instead of just comparing the identical strategies of the two players. Because in some cases when two players have different types of strategies or unequally numbered strategies, the one-to-one comparison is impossible. But the new algorithm permits comparisons to be made in both cases.

(iii) The new algorithm affords a quantitative measurement of a comparison, the game values, which, actually, can be considered as the summary of numerous comparisons between individual strategies. This can be deemed as the step of providing data in a more meaningful and simpler form to help decision-making.

Strategy Priority Weighting Factor

In the new algorithm used to obtain game values, all the entering payoff coefficients are considered to be equally weighted. This means that no matter how large or small a payoff coefficients is, it is always considered to be at the same level of importance as any other payoff coefficients. Since payoff coefficients are derived from utility numbers of strategies, the consideration of all payoff coefficients as equal entry would also indicate that all strategies are of the same importance. But in application, if each strategy represents a type of water resources development and certain types of development may more desperately be needed, then a weighting factor for bringing out this priority is necessary. Essentially this weighting factor allows a decision-maker familiar with a certain player's strategies to inject this judgement into the model by assigning relative importance to the player's strategy.

Since strategy priority weighting factor is developed on strategy basis, the utility number of a strategy will be multiplied by this factor before it can be used to procure payoff coefficients. This is done as follows:

$$U_{ai}' = U_{ai} \cdot \phi_{ai}$$

where U_{ai}' = the weighted utility number for strategy A_i of player A,

U_{ai} = ordinary utility number for strategy A_i of player A,

ϕ_{ai} = strategy priority weighting factor for strategy A_i of player A.

With the introducing of the strategy priority weighting factor, the derivation of payoff coefficients will be modified as follows:

$$a_{ij} = \begin{cases} \dfrac{\phi_{ai} \cdot U_{ai}}{\phi_{bj} \cdot U_{bj}} = \dfrac{U_{ai}'}{U_{bj}'}, & \text{if } U_{ai} \neq 0,\ U_{bj} \neq 0, \text{ and } \phi_{bj} \neq 0, \\ 0 & \text{if } U_{ai} = 0, \text{ or } U_{bj} = 0, \text{ or } \phi_{bj} = 0, \end{cases} \tag{3.3}$$

where a_{ij} = payoff coefficient for player A,

U_{ai}' = weighted utility number for player A's strategy A_i,

U_{bj}' = weighted utility number for player B's strategy B_j,

U_{ai} = utility number for player A's strategy A_i,

U_{bj} = utility number for player B's strategy B_j,

ϕ_{ai} = strategy priority weighting factor for player A's strategy A_i,

and

ϕ_{bj} = strategy priority weighting factor for player B's strategy B_j.

Each player of a game should have different priorities and, thus, different weighting factors, for different strategies. These factors should be derived objectively and under careful consideration with all the factors for different players being interrelated and evaluated on the same criteria. This is necessary since game values obtained later from each game or set of games will all be considered simultaneously in the decision-making process.

In the case that objective priority weighting factors for each strategies can not be obtained and that the risk of using the subjective and biased weighting factors does not want to be taken, it is better to assume that all the strategies are in the same level of importance, i.e., to assume all the priority weighting factors being equal to one, instead of using biased factors and leading to biased solutions.

Analysis of Games

Although the methods used for obtaining payoff coefficients and game values of a game in the competitive evaluation model are quite simple and straightforward, yet several things concerning games must be pointed out now.

First, while using the concept of two-person non-zero-sum games, it is necessary to identify the players of each game. Since evaluation of water resources development is the main objective of this model and comparison information obtained from game arranged between water resources basins are used to support evaluation, players are arranged into games if comparison information between them is needed. With a systematic arrangement, players can appear repeatedly in different games either with same opponent or with different opponents. If the same players are to appear in different games or different sets of games, the purpose of each game or set of games should be clearly defined. The grouping of players should also be done very carefully so that confusion will not occur later on when solutions are considered in the final decision making process.

In the development of the payoff matrix, strategies of each player and the associated utility numbers are pursued first. Strategies used by each player in a particular game should be in the related categories. It is not necessary that the two players of a game have the same number of strategies. Because it is always possible to make the two players have the same number of strategies by filling in strategies with zero utility number which in turn will produce payoff coefficients with zero value to be deleted during the calculation of game values.

The determination of utility numbers for a strategy is a very important step for a game. The magnitude of the utility number will influence the outcome of a game greatly. Any increase of utility number for a strategy will not only magnify the payoff coefficients for this player, it will also reduce the values of the payoff coefficients for the opponent. For example, if utility number U_{a1} for player A's strategy A_1 is increased, then all player A's payoff coefficients a_{1j}'s, which are equal to U_{a1}/U_{bj}, will also be increased, because all a_{1j}'s are now derived from a large U_{a1}. At the same time, all player B's payoff coefficients b_{1j}'s, which are equal to U_{bj}/U_{a1}, will be decreased, because U_{bj}'s are now divided by a large U_{a1} to arrive at the values of b_{1j}'s. But it should be remembered that if one player tries to increase his game value by increasing the utility number associated with a particular strategy and thus the derived payoff coefficients, the other player can also do the same thing. Therefore, it is quite important to keep it in mind that the determination of utility numbers should be done carefully and objectively. Fortunately, after the competitive measuring or evaluation used in the process to obtain payoff coefficients, i.e., the dividing of an utility number of a player by the utility numbers of the other player's strategies to obtain payoff coefficients, the effect of a biased utility number on the overall game value is reduced.

Summary

Games in the model are used to obtain comparison information between players. In the present case, these players will be water resources basins in the United States. The structure of a game in the model is shown in Fig. 3.2. All games in the model are two-person non-zero-sum. No fixed rule is used to limit the selection

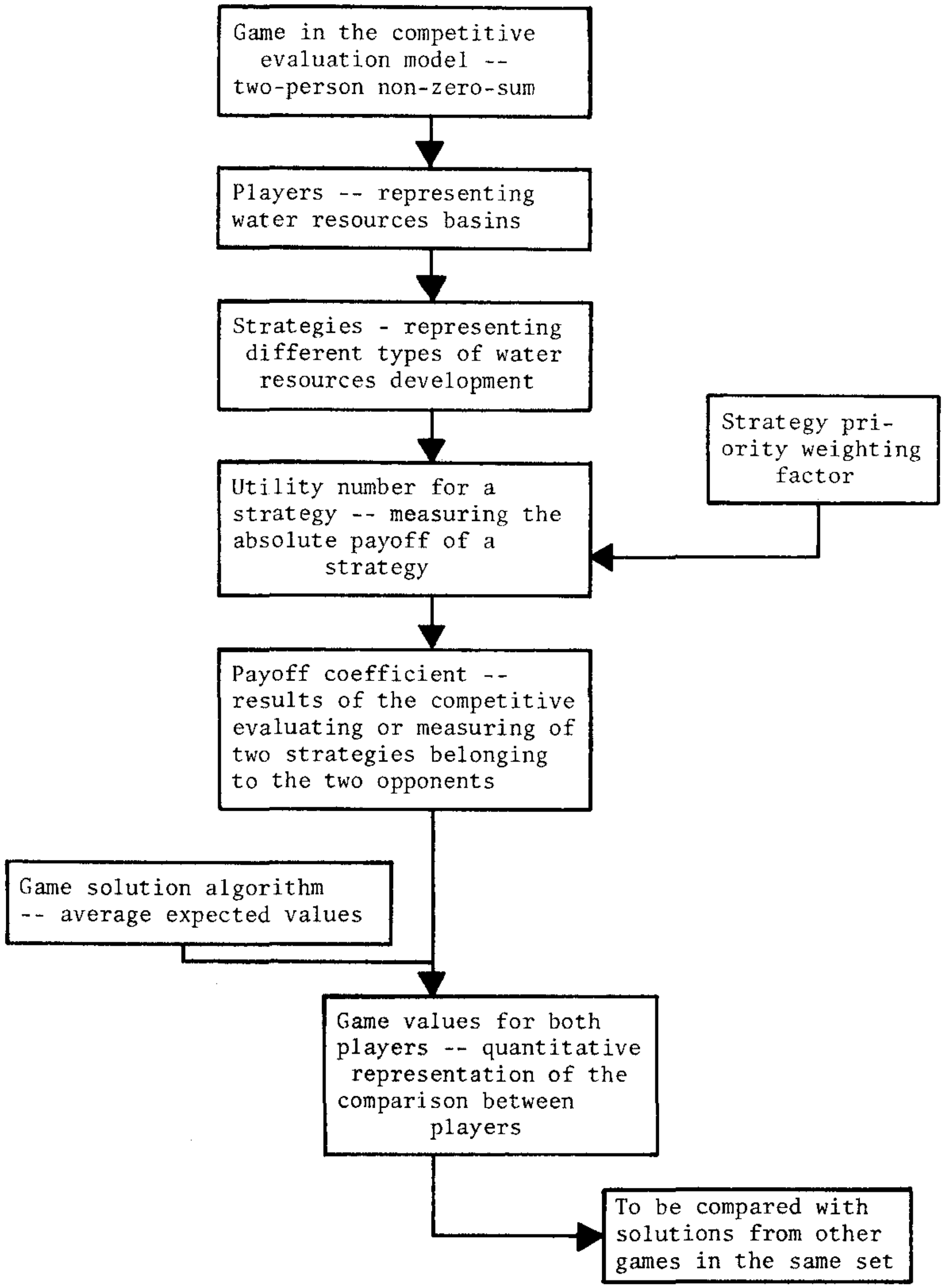

Figure 3.2. The structure of the game in the competitive evaluation model.

of players. Players are initiated into a game whenever comparison information between them is needed and they have some common ground to be compared.

The basic payoff matrix of games in the model is essentially the same as the traditional two-person non-zero-sum games', i.e., the gain of one player does not indicate the equal loss of the other player and payoff coefficients need to be designated for both players. The only exception in the payoff matrix for games in the model is the addition of a new term, the utility number of a strategy (UNS).

Strategies are the basic tools for competition or comparison. It is intended to use various types of water resources development as strategies for the basin-players.

To quantify the effect of a strategy, or development, an utility number is introduced as the measure of the absolute payoff for a strategy. A strategy may have different utility numbers in different sets of games. Utility numbers are used to procure payoff coefficients of the matrix.

The process of procuring payoff coefficients emphasizes the concept of competitive evaluation. Because one player's utility number is measured, evaluated, or divided, by another player's utility numbers of different strategies to derive the values of payoff coefficient. But this process also produced a new problem, the two-strategy dominance, which resolves a game into the competitive between two superior strategies, one for each player. Consequently, the traditional solution methods for solving games have to be abandoned due to the occurrence of this two-strategy dominance problem. And a new algorithm based on average expected values was developed.

The new algorithm is quite simple, but it supplies a method for obtaining game values with the participation of all strategies and a summary of data in a meaningful and simpler form to help decision making. A strategy weighting factor was introduced to bring out the priority of a strategy, or a development in water resources. Game values of a game will later be compared with all other game values from the same set of games.

More Weighting Factors

A strategy priority weighting factor which is used to bring out the priority for certain types of water resources development within a river basin was discussed earlier in this chapter. Two more weighting factors, the game or basin priority weighting factor and the objective priority weighting factor, will be introduced here.

Game or Basin Priority Weighting Factor

The game priority weighting factor is actually used to bring out the priority for development of a water resources basin and therefore, may also be called the basin priority weighting factor. Since games are used to generate comparison information between basin-players, if a weighting factor is applied to the game values of a basin-player, it certainly will bring out the priority for development of a basin. The game values for a basin-player will be multiplied by this weighting factor and it is defined as follows:

$$V'_{A-B} = \theta_A \cdot V_{A-B} \tag{3.4}$$

where V_{A-B}' = weighted game value for player A when the opponent is player B,

V_{A-B} = original game value for player A when the opponent is player B,

θ_A = game or basin priority weighting factor for basin-player A.

An experimental basin priority weighting factor for water resources basins in the United States was developed in this study and it will be discussed more lengthily in the next chapter. The development of this factor is based on the existing data regarding to the regional federal income taxes paid, population, and population and per capital income.

Objective Priority Weighting Factor

This weighting factor is introduced to point out the relative importance of different evaluation criteria. Since the number of evaluation criteria used in this model is unrestricted and is decided by decision-maker, all the evaluation criteria introduced may not be of the same importance viewed by the decision-maker. In other words, some comparison information under certain evaluation criteria may be valued more than those under other evaluation criteria, then a weighting factor is necessary for bringing out their relative importance. This factor will be applied to all game values in the same set of games, i.e., under the same evaluation criterion, and it is defined as follows:

$$V^{i'} = \lambda_i \cdot V^i \qquad (3.5)$$

where $V^{i'}$ = weighted game value from the set of games under the evaluation criterion i,

V^i = original game value from the set of games under the evaluation criterion i,

λ_i = objective priority weighting factor for the evaluation criterion i.

Since the four evaluation criteria introduced in this study are purely for demonstration purpose, no effort was made to find their objective weighting factors, and thus, these factors will all be assumed to be equal to one in this study.

Operation of the Model

The relationship between the components of the competitive evaluation model and their equivalent parts in game theory terminology is shown in Fig. 3.3. Figure 3.4 shows the structure and the operation of the model. The terms used for the components of the model and their game theory originals may have been used interchangeably all throughout this study. No effort was made to distinguish when a term is restrictively a component of the model or just a game theoretic term in the model. However, Fig. 3.3 will help to illustrate the whole relationship.

The model is mainly a collection of sets of two-person non-zero-sum games. Sets of games are used to represent evaluation criteria decided by the decision-maker. In other words, each set of games is headed by an individual evaluation criterion. All these evaluation criteria can be considered as equal entries of the model. Otherwise, if any of them, viewed by the decision-maker, is more

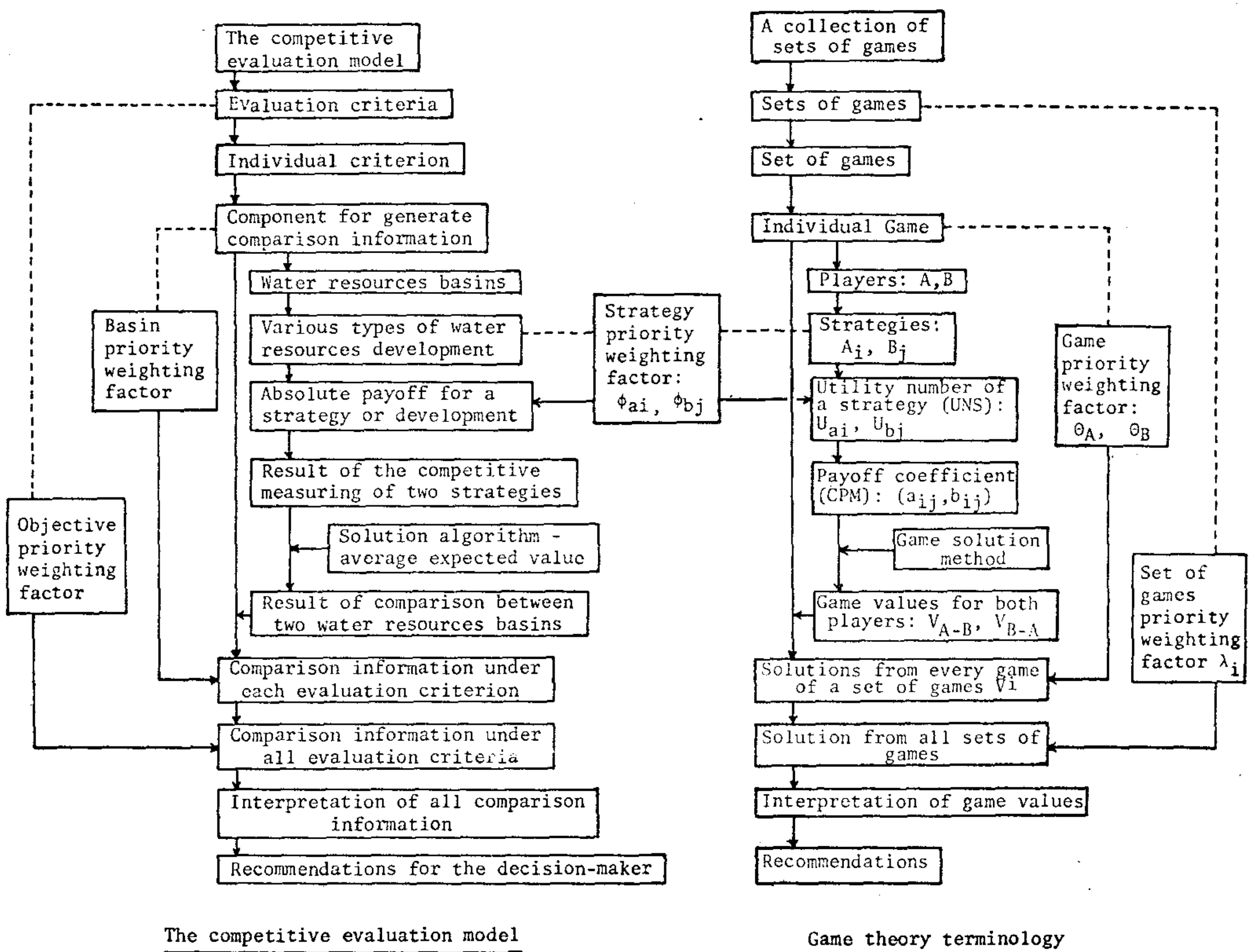

Figure 3.3. The relationship between the components of the competitive evaluation model and their equivalent parts in game theory terminology.

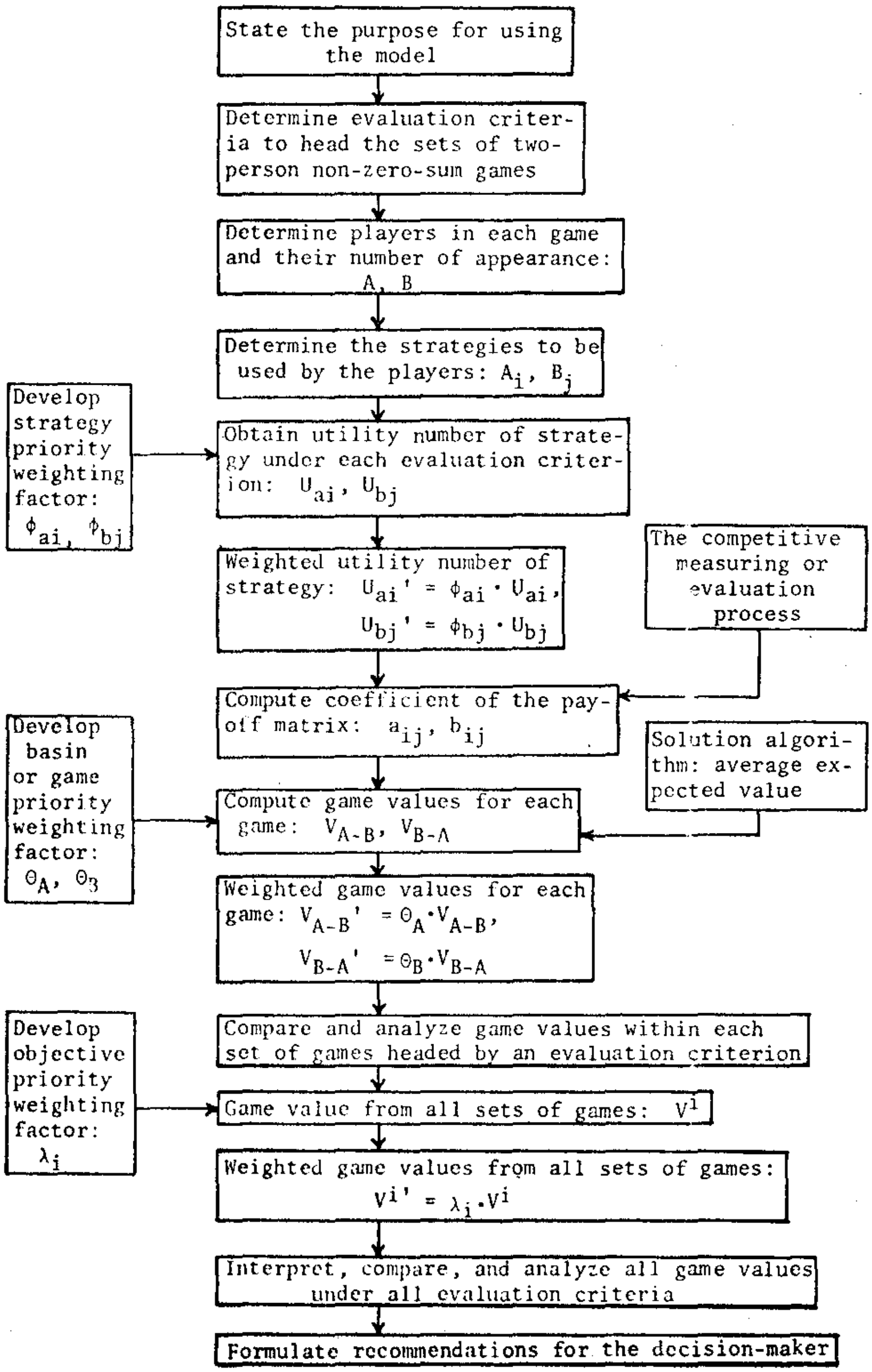

Figure 3.4. Operation of the competitive evaluation model.

important than the others, then the objective priority weighting factor for a set of games is introduced. This factor, if introduced, is multiplied to all game values in a set of games.

Under each evaluation criterion there is a series of games used to obtain comparison information . Each individual game is arranged for two opponents representing water resources basins in the United States when comparison information between them is needed. The traditional game strategies are used to represent various types of water resources development. All types of water resources development or strategies can be considered to be equally important; if not, the strategy priority weighting factors are used to show the preferences. These factors are multiplied to the newly introduced term, the utility number of a strategy, which measures the absolute payoff of a strategy. Utility number of a strategy is used to procure payoff coefficients by a competitive evaluation method which employs two utility numbers of two strategies belonging to the two opponents through a mutual measuring to obtain payoff coefficients. A new algorithm of taking average expected value , developed in this study to replace the traditional game solution method due to the occurrence of the two-strategy dominance problem, is used to calculate game values or solutions for both players of a game to show the result of a comparison.

All game values derived within each set of games reflect the comparisons between water resources basins under a certain evaluation criterion. Some of the basins may have established more priorities for development than the others, then, the game or basin priority weighting factors are used to bring out these priorities. These factors are multiplied to the game values in each set of games.

Solutions or game values representing all needed comparisons between basins from all sets of games are then compared and interpreted. And consequently, they will be used to draw recommendations to be considered in the decision-making process.

Conclusion

The structure of the competitive evaluation model is very simple and flexible. The model is just an aggregation of games which are grouped in sets and are used to obtain comparison information for the decision-maker. There is no limitation on the number of sets of games, the number of games in a set, or even the number of players in the model. Evaluation criteria represented by sets of games, game for generating comparisons, and players representing water resources basins can always be initiated into the model by the decision-maker whenever they are deemed necessary.

The mathematical techniques used in the model is quite straight forward. No complicated calculation is involved in the model. Even the traditional game solution methods which sometimes increase the complexity of a game are omitted in favor of a simple algorithm of taking average expected value as the solution for games.

The special feature of the model is the emphasis of the competitive evaluation or comparison all throughout the model. The routine of arranging players into games whenever comparison information between them is needed is an indication of this feature. In the process to obtain payoff coefficients, two utility numbers of two strategies belonging to the two opponents of a game are mutually measured and evaluated is another emphasis of this feature. Comparing solutions from games in each set of games and solutions from all sets of games is also an emphasis of this feature.

The development of the model presented in this chapter is in a very general format. This was specially planned so that this model, with some modification, can always be used in areas other than water resources. The emphasis in this chapter is the general development of the model. Due to the absence of some detail explanation of how to implement this model, sometimes the model might seem to be quite abstract. This is specially true in the final steps of the model, the interpretation of the data obtained and the formulation of the recommendation, which can only be explained clearly and easily if data have been fed into the model and results of comparisons have been obtained. It is planned in the next chapter to emphasize the detail application of the model to the evaluation of water resources development planning, then the application of the competitive evaluation model can be more clearly and easily explained.

CHAPTER IV

THE APPLICATION OF THE COMPETITIVE EVALUATION MODEL FOR WATER RESOURCES DEVELOPMENT PLANNING

The approach of using the competitive evaluation model for water resources development planning will be illustrated in this chapter. The model was used to find the comparisons of water resources development planning between different water resources basins in the United States. Four evaluation criteria were introduced to head the sets of games arranged between the water resources basins and the player representing the whole nation while various types of water resources development were employed as strategies by the players. Results of comparisons were interpreted and used as guidelines for forming recommendations for the decision-maker. The inputs of the model and the results will be discussed in the following.

Sets of Games - Evalaution Criteria

Sets of games in the model are headed by evaluation criteria. Four evaluation criteria were introduced in this study. They measure the long-term total objective, the short-term objective, the percent of needs met, and the percent of effectiveness. Based on the availability of data, these evaluation criteria were only introduced for demonstration purposes and by no means do they represent a complete evaluation. If more data were available, other evaluation criteria could always be introduced. Each one of the evaluation criteria will be discussed separately in the following.

The Long-term Total Objective

The long-term total objectives are used to define the extent of long-range needs in a region. In other words, these objectives indicate the water resources development in a region when this region is fully developed under the present standard and they may be modified from time to time through comprehensive planning. These objectives for each individual location are usually defined by people who know the region well. They may be the maximum possilbe development or any degrees of development ranging from no new development to maximum development.

The ideal long-term total development objective usually should be defined under the assumption that no constraint is enforced. Of course, this assumption can only be applied when the objectives of physical development are being defined. It would be quite difficult to define some other direct or indirect development objectives under such an assumption. Because some development, for instance, the well-being objectives which will be described later, can be developed without bounds. The long-term total physical development objectives defined under the no-constraint assumption show how a region should have been developed when there is no capital or any other type of limitation existing. Although this no-constraint assumption is quite ideal, it is helpful to find the most ideal and the most favorable development needed in a region.

Although other types of long-term total objectives were also considered, only the long-term total physical development objective was used in this study. In the "Procedure for Evaluation of Water Resources and Related Land Resources Projects" [4], several categories of national and regional development objective were listed. For example, the national income account objective measures the national income increases from employment, growth in productivity, economic stability; the regional income account objective measures the economic activities by national income accrual, and related economic activity; the environmental account objective measures specified objective such as preservation of natural areas, preservation of cultural areas, achieving quality standards, and protection and rehabilitation of resources; and the well-being account objective measures the specified objective such as security of life, security of health, national defense, inter-personal income distribution, and interregional income distribution. All these measurements of development objectives may be used as possible evaluation criterion for a single project, but with their unlimited horizon, it is difficult to use them in defining the total objective of a region at the present time. So far the only feasible measurement of long-term total objectives in a region was the measurement of the physical development which was used in this study.

By using the long-term total objectives as an evaluation criterion in the model, it is possible to determine the long-term planning of a region and how this region stands when it is compared to other regions or to the whole nation. Thus the decision-maker will know which regions need the most development, and priority may then be considered for them.

In order to make comparisons possible, the measurements of all long-term total development objectives defined in this study were converted into a unified monetary term. This was done because different types of water resources development are usually measured in different units. For example, flood control is measured in acres, whereas municipal and industrial water supply is measured in gallons/day and agriculture water supply is measured in acres. The conversion method used in this study was to convert the total objectives in all types of development, whether they were measured in acres, gallons, or any other units, into a monetary measurement. This monetary measurement is a product of the output units and a mean value. The output units were those defined for the long-term total objective. The mean value calculated the benefit in dollar per unit of development output. Every benefit category in different regions had its own mean value. These two figures, the total output units in each type of development and the respective mean value of benefit estimated in dollars, were then multiplied together to give the dollar value of the total objective in each type of development in each region.

Data used to determine the long-term total objectives were collected from data obtained by the U. S. Army Corps of Engineers. The regional objectives defined by the Corps were assumed to be the long-term total objectives of a region and they were multiplied by their respective mean values of benefit in dollar value to convert to monetary terms. These data are shown in Appendix II. The validity of these data was not questioned since the only interest in using them was to verify the model developed. Data used in the following evaluation criteria were also from the same source.

The Short-term Objective

The evaluation of short-term planning is also important in a decision making process. The long-term total objectives, which show the development of a region when it is fully developed under the present standard, are usually just a gross estimation. The short-term objectives define what are needed for a region in a certain relatively short time limit. Since they are the immediate needs, short-term total objectives can be defined more directly and more precisely than the long-term total objectives.

In this study, a five year short-term objective was used. Data of project output for the years from 1972-1976 defined by the Corps were assumed to be the short-term objective of a region.

In order to make comparison possible, short-term development objectives were also converted into monetary term. The output units of the five year (1972-1976) short-term objectives of various development in different basins and their direct total benefit in dollar are shown in Appendix II. In a few cases, the short-term development objective may exceed the long-term total objective in output units because sometimes it was more economical to develop at one time more units than the amount estimated for long-term planning by the present standard.

The Percent of Effectiveness Measurement

Another new evaluation criterion introduced in this study is used to measure the percent of effectiveness. Earlier, the long-term total and short-term objectives were discussed. The measurement of the percent of effectiveness is based on the measurements of these two objectives and is defined as the following:

$$\text{The percent of effectiveness} = \frac{\text{Unit outputs of the Short-term objective}}{\text{Unit outputs of the long-term total objective}} \times 100\% \,. \qquad (4.1)$$

The long-term total and short-term objectives of development in a region measure the direct needs of various types of development. The percent of effectiveness measures the percentage of the immediate short-term needs of various types of physical development in a region meeting the long-term total development objectives. The results of this measurement will supply information for decision making. For instance, if the goal of a decision is to have development established uniformly towards resources completion in various regions, then the regions which have the lower percent of effectiveness should receive higher priorities for development. If it is decided to have certain region completely developed before considerations are given to other regions, then priorities for development should be given to the regions with the highest measurement in the percent of effectiveness. In both cases, it is obvious that the measurement of the percent of effectiveness is very much dependent on the previously defined long-term and short-term objectives.

The Percent of Needs Met Measurement

The percent of needs met measurement is similar to the measurement of the percent of effectiveness. The latter takes into account the percentage of the short-term physical development objectives meeting the long-term total objectives and all the measurements are based on physical development output units. The percent of needs met measurement is based on the estimated benefit units, measured in monetary value, derived from various developments. It is defined as follows:

$$\text{The percent of needs met} = \frac{\text{Dollar benefit of the short-term objective}}{\text{Dollar benefit of the long-term total objective}} \times 100\% \,. \qquad (4.2)$$

It might be questioned whether the percent of needs met and the percent of effectiveness were the same measurement with different names. It seems that the only difference between these two measurements is that both the dollar benefit measurements of the short-term and long-term total objectives in the percent of needs met are just derived by multiplying the unit outputs of the short-term or the long-term total objectives by a mean value. Actually these two measurements are different. Firstly, the dollar benefit value of the long-term total objective is obtained by multiplying the objective by the corresponding regional mean value according to different developments. The dollar benefits of short-term objective are computed a little differently. Since benefits of short-term objective are expected in the near future, they are calculated directly from the outputs and hence are more precise when compared to the estimation of the dollar benefits of the long-term total objective which are more or less a gross approximation. Secondly, the percent of effectiveness only measures the physical units of achievement, but sometimes objectives may involve the same units of physical development while the intensity of the use is changed and, thus, the change of the benefit value derived. Thirdly, it is also possible that the development units of the short-term objective may exceed the long-term total objective but the outcome of benefit does not reach what is required. In other words, the quantity, which is measured by the physical development units, has been achieved but not the quality, which is measured by the benfits derived. Therefore, the measurement of the percent of needs met which is based on the monetary measurement of the benefit derived is necessary and it offers a different dimension of evaluation approach from those indicated by the measurement of the percent of effectiveness.

Although the measurement bases of the percent of needs met and the percent of effectiveness are different, one in monetary outputs and one in physical outputs, the interpretations of the results of the two measurements are similar. For example, as it was illustrated for the measurement of the percent of effectiveness, if a decision is made to develop basins uniformly towards the goal of reaching the basins' total long-term total objectives in dollar value, then priorities for new development or for increasing the intensity of certain development should be given to regions with the lower figure in the percent of needs met measurement.

Conclusion

The evaluation criteria introduced here are a little different from the traditional water resources development evaluation methodology which usually use the benfit and cost ratio analysis. Although benefits in dollar still dominate the measurements used in these newly introduced criteria, they were used differently from the traditional benefit and cost ratio analysis. The costs of different categories of development were not mentioned in any of the evaluation criteria introduced so far. It was not because cost is not an important factor. It was due to the fact that complete data of some of the regions were not available at the time when the model was being tested. If cost data are available, it is always possible to include new evaluation criteria in order to obtain comparison information of various water resources development in different basins based on costs.

Several other evaluation criteria were also under consideration earlier, for example, the mean value comparison of the benefits of various types of development in different regions, the measurement of dollar benefit per unit short-term development, the percent of needs met per unit output measurement, the percent of effectiveness per unit output measurement, etc. It was due to the lack of available data or the lack of compatible measurement unit that the time consuming effort of data collecting had to be abandoned in favor of spending more time in developing the general model.

Therefore the evaluation criteria introduced so far were not the only possible ones but they were the ones which were used to illustrate the application of the model based on the availability of the existing data. Any time when data are available, other evaluation criteria or measurement can always easily be included in the model.

Players of Games - Water Resources Basins in the United States

In planning water resources use and development, Senate Document No. 97 (S.D. No. 97) states that all viewpoints - national, regional, State and local - shall be fully considered and taken into account in planning. Regional, State, and local objectives shall be considered and evaluated within a framework of national public objectives and available projections of future conditions and needs. Similarly, available projections of future conditions and needs of regions, States, and localities shall be considered in plan formulation.

With the above policies in mind, when the competitive evaluation model is used for the evaluation of water resources development planning, it is necessary to have players representing viewpoints of different level of interests.

S. D. No. 97 [2] also indicates that river basins are usually the most appropriate geographical units for planning the use and development of water and related land resources in a way that will realize fully the advantage of multiple use, reconcile competitive uses through choice of the best combination of uses, coordinate mutual responsibilities of different agencies and levels of government and other interests concerned with resource use. Planning use of water and related land resources, therefore, shall be undertaken by river basins, groups of closely related river basins, or other regions.

The United States Water Resources Council presently uses twenty geographic water regions or basins, which are shown in Table 4.1 and Fig. 4.1, and one-hundred-ten subregions or sub-basins in planning. Seventeen of the twenty regions are in the contiguous United States. The other three are Alaska, Hawaii and Puerto Rico.

Since this research was limited by the data collected, eighteen water resources regions were employed as players of games in verifying the competitive evaluation model. These eighteen regions are shown in Table 4.2. They are almost identical with the regions defined by the United States Water Resources Council except that the region Tennessee was deleted and that the regions Upper Colorado and Lower Colorado were combined into the Colorado region. The nation was also used as a player representing the whole United States. These players will be called the basin-players or the nation-player.

At the present time, only players representing the basin-level were employed in the verification of the model. If more detailed study concerning the development within a basin or region is needed, players representing sub-basin level can also be introduced into the model.

REGION
Alaska
Arkansas-White-Red
California
Columbia-North-Pacific
Great Basin
Great Lakes
Hawaii
Lower Colorado
Lower Mississippi
Missouri
North Atlantic
Ohio
Puerto Rico
Rio Grande
Souris-Red-Rainy
South Atlantic-Gulf
Tennessee
Texas-Gulf
Upper Colorado
Upper Mississippi

Table 4.1. Water resource regions in the United States.

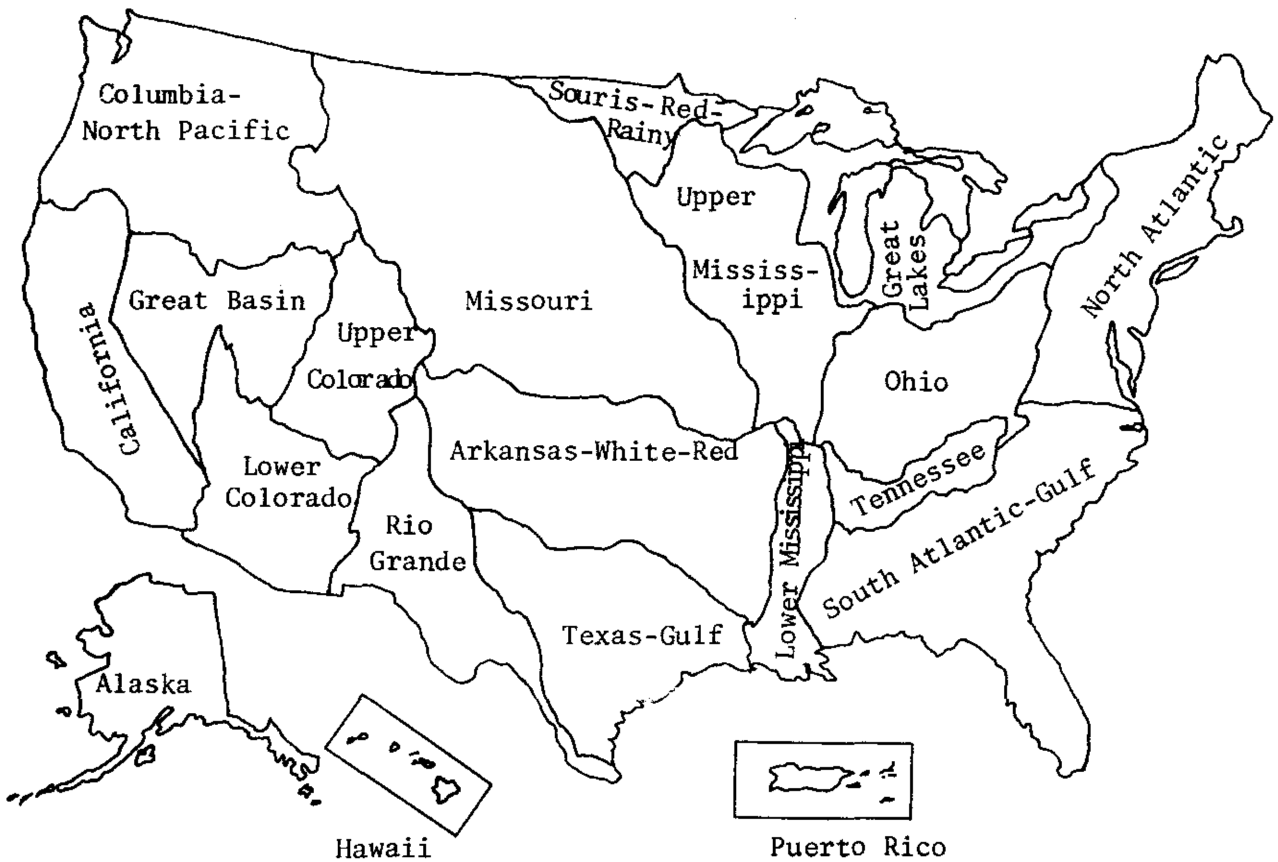

Figure 4.1. Water resource regions in the United States.

Basin Code No.	Regions: basin-players
0	Nation
1	Alaska
2	Arkansas-White-Red
3	California
4	Colorado
5	Columbia-North Pacific
6	Great Basin
7	Great Lakes
8	Hawaii
9	Lower Mississippi
10	Missouri
11	North Atlantic
12	Ohio
13	Puerto Rico
14	Rio Grande
15	Souris-Red-Rainy
16	South Atlantic-Gulf
17	Texas-Gulf
18	Upper Mississippi

Table 4.2. Players of games representing water resources regions in the competitive evaluation model.

Appearance of Players

To make the selection of players in each set of games more systematic and the comparison information obtained sufficient, it was decided that all eighteen basin-players representing different water resources regions and the nation-player will all appear in each set of games. This meant that all players will be evaluated under every evaluation criterion.

Games were arranged for every basin-player and the nation-player in each set of games. This led to the comparison information between the nation and every region. The comparisons between regions were indirectly obtained from the comparisons between the nation and each region.

To obtain comparison information between basin-players directly from games arranged between them is also possible although it was not practiced in this study. One way to do this is to arrange two-person games between all basin-players. But the results are quite complicated. For example, if there are ten basin-players, the number of two-person games between all basin-players will be 45* and they will lead to 90 game values, two for every two-person non-zero-sum game. Thus the procedure to analyze the results will be quite complicated. Another way to obtain comparison information between basins directly is to set up a standard basin-player and, then, to seek game values between this standard basin-player and all other

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*Considering combination between 10 objects taking two at a time, there will be $C_2^{10} = \frac{10!}{2!8!} = 45$ combinations.

players. For example, if ten basin-players are being considered, one as the standard player, then there will be 9 games and 18 game values. The latter method is obviously simpler than the one mentioned earlier. This method of establishing a standard player was used in this study but with the nation-player as the standard player instead of a basin-player.

The selection of the standard-player should be done objectively. The standard player could be an average basin. The word "average" is applied to whatever evaluation criterion is under consideration. For instance, if the measurement of the long-term total objective is being considered, then the basin with medium long-term total objectives could be used as the standard player. Although it might not be easy to decide which basin would be the best one to be used as the standard basin, by a careful consideration of the objective of the special evaluation criterion, it will not be too difficult to find the one to serve as the standard player.

An earlier attempt in this research was to select the basin-player representing the Arkansas-White-Red region as the standard player. It was because there were more data available from this region. Later the nation-player was used as the standard player because information thus obtained can be more easily analyzed. Since the main purpose was to illustrate the use of the competitive evaluation model, the selection of the standard player would not be too important here.

If further study within a water resources region is pursued, the games between sub-regions or between a region and its sub-regions can also be arranged. Of course, the more players that are initiated into the model, the more information will be obtained. Therefore, it is important to decide first to what extent the research will be carried out, then the number of players and the number of their appearances can be determined.

Strategies - Different Types of Development Represented by Benefit Categories

Various types of water resources development were employed as strategies by the players in games formulated in this model. These developments actually are categorized according to the benefits derived from them.

Senate Document No. 97 (S.D. No. 97) [2] defines benefits as the increases or gains, net of associated or induced costs, in the value of goods and services which result from conditions with the projects, as compared with conditions without the project. Benefits include tangibles and intengibles and may be classed as primary and secondary. Due to the availability of data, only primary benefits will be considered in this research.

S. D. No. 97 [2] has defined the types of primary benefits and standards for their measurement. They are as follows:

(i) Domestic, municipal, and industrial water supply benefits - Improvements in quantity, dependability, quality, and physical convenience of water use. The amount water users should be willing to pay for such improvements in lieu of foregoing them affords an appropriate measure of this value.

(ii) Irrigation benefits - The increase in the net income of agricultural protection resulting from an increase in the moisture content of the soil through the application of water or reduction in damages from drought.

(iii) Water quality control benefits - The net contribution to public health, safety, economy, and effectiveness in use and enjoyment of water for all purposes which are subject to detriment or betterment by virtue of change in water quality. The net contribution may be evaluated in terms of avoidance of adverse effects which would accrue in the absence of water quality control, including such damage and restrictions as preclusion of economic activities, corrosion of fixed and floating plant, loss or downgrading of recreational opportunities, increased municipal and industrial water treatment costs, loss of industrial and agricultural production, impairment of health and welfare, damage to fish and wildlife, siltation, salinity intrusion, and degradation of the esthetics of enjoyment of unpolluted surface waters, or, conversely, in terms of the advantageous effects of water quality control with respect to such items. In situations where no adequate means can be devised to evaluate directly the economic effects of water quality improvements, the cost of achieving the same results by the most likely alternatives may be used as an approximation of value.

(iv) Navigation benefits - The value of the services provided after allowance for the cost of the associated resources required to make the service available.

(v) Electric power benefits - The value of power to the users is measured by the amount that they should be willing to pay for such power.

(vi) Flood control and prevention benefits - Reduction in all forms of damage from inundation (including sedimentation) of property, disruption of business and other activity, hazards to health and security, and loss of life, and increase in the net return from higher use of property made possible as a result of lowering the flood control hazard.

(vii) Land stabilization benefits - Benefits accruing to landowners and operators and the public resulting from the reduction in the loss of net income, or loss in value of land and improvements, through the prevention of loss or damage by all forms of soil erosion including sheet erosion, gullying, flood plain scouring, streambank cutting, and shore or beach erosion, or, conversely in terms of advantageous effects of land stabilization.

(viii) Drainage benefits - The increase in the net income from agriculture lands or increase in land values resulting from higher yields or lower production costs through reduction in the moisture content of the soil, and the increase in the value of urban and industrial lands due to improvement in drainage conditions.

(xi) Recreation benefits - The value as a result of the project of net increase in the quantity and quality of boating, swimming, camping, picnicking, winter sports, hiking, horseback riding, sightseeing, and similar outdoor activities.

(x) Fish and wildlife benefits - The value as a result of the project of net increase in reacreational, resource preservation, and commercial aspects of fish and wildlife.

(xi) Other benefits - Any other benefit categories not included in the above categories.

Although the general description of the primary benefits derived from water resources development is stated in S. D. No. 97 [2], the detailed explanation and measurement were absent from that document. The U. S. Army Corps of Engineers [19] has defined a more detailed list of benefit categories. It is shown in Appendix I. All the benefit categories are listed with an explanation of the definition and a code number. Most of the categories also list the measurement unit. This list of benefit categories can be considered as a detailed sub-division of what was defined in the S. D. No. 97. For example, the flood control benefit defined in the S. D. No. 97 was sub-divided according to whether the flood damage reduction is in urban area or in rural area, and according to whether it is the existing development or the future development, etc. In verifying the competitive evaluation model, these benefit categories were used as strategies by the players in each game. Data were collected according to these benefit categories for each basin, and they are shown in Appendix II.

The Utility Number of A Strategy (UNS)

The utility number of a strategy (UNS) is used to measure the absolute payoff or outcome of a strategy under certain evaluation criterion. Since four evaluation criteria were introduced in this study, each strategy which represents a category of benefits obtained from the water resources development will have four UNS's, each one being derived under a particular evaluation criterion. Basically, these UNS's were directly or indirectly derived from the development objectives. The development output units of the long-term total objective and the five year (1972-1976) short-term objective, the long-term regional mean value of benefit per unit of development, and the total benefit values of the five year (1972-1976) short-term objective were collected from data obtained by the U. S. Army Corps of Engineers and are shown in Appendix II. These data were used to calculate the UNS's under all four evaluation criteria.

The UNS's under each evaluation criterion are shown in Appendix III. The UNS's under the long-term total objective criterion are measured in monetary term. They are calculated by multiplying the development output units of the long-term total objective of a region according to benefit categories by their respective regional mean values of benefit in dollar per unit of development. The UNS's under the short-term development objective are also measured by monetary value and they were the total benefit value of the five year (1972-1976) short-term objective shown in Appendix II.

The UNS's under the measurement of the percent of effectiveness were obtained through Eq. (4.1) by using data of the development output units of the long-term total objective and the five year

(1972-1976) short-term objective shown in appendix II. The UNS's under the measurement of the percent of needs met were obtained through Eq. (4.2) by using data of the long-term total objective in monetary term and the five year (1972-1976) short-term objective in monetary term shown in Appendix III.

The strategy priority weighting factor which was introduced in the last chapter was not developed here for strategies employed by the players. Because information which would lead to assign priorities to strategies was not collected. Thus, all strategies were considered to be in the same level of importance. In other words, all these factors were assumed to be equal to one. Hence, the original UNS's were used, instead of the weighted UNS's which would have been obtained by multiplying the original UNS's by the priority weighting factors, when these UNS's were used to procure the coefficients of the payoff matrix (CPM's).

Game Payoff Matrix and Its Coefficients

The game matrix is used to show payoffs corresponding to different strategies. Under each evaluation criterion introduced in this study, a game was arranged between the nation-player and a basin-player. An example of the payoff matrix of these games is shown in Fig. 4.2. The main entries of the matrix are the coefficients of the payoff matrix (CPM's) corresponding to different strategies and their respective utility numbers of strategy (UNS's). Because all games were two-person non-zero-sum, each entry of the CPM's is comprised of two figures, one for each player.

B.C. = Benefit category code shown in Appendix I. UNS = Utility number of strategy.

	B.C	B11	B41	B51	B52	B53	B63	B64
B.C	UNS	42.900	5.700	25.900	3.000	0.300	8.600	0.500
A11	19.00	(0.443,2.258)	(3.333,0.300)	(0.734,1.363)	(6.333,0.158)	(63.333,0.016)	(2.209,0.453)	(38.000,0.026)
A12	12.80	(0.298,3.352)	(2.246,0.445)	(0.494,2.023)	(4.267,0.234)	(42.667,0.023)	(1.488,0.672)	(25.600,0.039)
A17	4.80	(0.112,8.938)	(0.842,1.188)	(0.185,5.396)	(1.600,0.625)	(16.000,0.063)	(0.558,1.792)	(9.600,0.104)
A19	40.10	(0.935,1.070)	(7.035,0.142)	(1.548,0.646)	(13.367,0.075)	(133.667,0.007)	(4.663,0.214)	(80.200,0.012)
A25	30.40	(0.709,1,411)	(5.333,0.188)	(1.174,0.852)	(10.133,0.099)	(101.333,0.010)	(3.535,0.283)	(60.800,0.016)
A26	13.20	(0.308,3.250)	(2.316,0.432)	(0.510,1.962)	(4.400,0.227)	(44.000,0.023)	(1.535,0.652)	(26.400,0.038)
A31	35.50	(0.828,1.208)	(6.228,0.161)	(1.371,0.730)	(11.833,0.085)	(118.333,0.008)	(4.128,0.242)	(71.000,0.014)
A32	2.00	(0.047,21.450)	(0.351,2.850)	(0.077,12.950)	(0.667,1.500)	(6.667,0.150)	(0.233,4.300)	(4.000,0.250)
A34	21.80	(0.508,1.968)	(3.825,0.261)	(0.842,1.188)	(7.267,0.138)	(72.667,0.014)	(2.535,0.394)	(43.600,0.023)
A41	10.20	(0.238,4.206)	(1.789,0.559)	(0.394,2.539)	(3.400,0.294)	(34.000,0.029)	(1.186,0.843)	(20.400,0.049)
A51	11.70	(0.273,3.667)	(2.053,0.487)	(0.452,2.214)	(3.900,0.256)	(39.000,0.026)	(1.360,0.735)	(23.400,0.043)
A52	6.10	(0.142,7,033)	(1.070,0.934)	(0.236,4.246)	(2.033,0.492)	(20.333,0.049)	(0.709,1.410)	(12.200,0.082)
A53	3.60	(0.084,11.917)	(0.632,1.583)	(0.139,7.194)	(1.200,0.833)	(12.000,0.083)	(0.419,2.389)	(7.200,0.139)
A54	11.40	(0.266,3.763)	(2.000,0.500)	(0.440,2.272)	(3.800,0.263)	(38.000,0.026)	(1.326,0.754)	(22.800,0.044)
A61	7.90	(0.184,5.430)	(1.386,0.722)	(0.305,3.278)	(2.633,0.380)	(26.333,0.038)	(0.919,1.089)	(15.800,0.063)
A63	5.40	(0.126,7.944)	(0.947,1.056)	(0.208,4.796)	(1.800,0.556)	(18.000,0.056)	(0.628,1.593)	(10.800,0.093)
A64	11.60	(0.270,3.698)	(2.035,0.491)	(0.448,2.233)	(3.867,0.259)	(38.667,0.026)	(1.349,0.741)	(23.200,0.043)
A67	11.90	(0.277,3.605)	(2.088,0.479)	(0.459,2.176)	(3.967,0.252)	(39.667,0.025)	(1.384,0.723)	(23.800,0.042)
A71	16.70	(0.389,2.569)	(2.930,0.341)	(0.645,1.551)	(5.567,0.180)	(55.667,0.018)	(1.942,0.515)	(33.400,0.030)
A72	**14.20**	**(0.331,3.021)**	**(2.491,0.401)**	**(0.548,1.824)**	**(4.733,0.211)**	**(47.333,0.021)**	**(1.651,0.606)**	**(28.400,0.035)**

Figure 4.2. Game payoff matrix. Player A (Nation) vs. Player B (Alaska Basin)
Evaluation Criterion: Percent of Effective Measurement.

The CPM's were derived from the UNS's by using Eq. (3.1). Although the competitive evaluation formulation used to calculate the CMP's is relatively straightforward as the number of strategies employed by the players increases, the process to obtain the CPM's becomes more tedious. For instance, if two players each have ten strategies, then there are two hundred CPM's to be computed, one hundred for each player. Most of the basin-players used in this study had at least several strategies in each game while the nation-player had even a greater number of strategies. Therefore, all the computations of the CPM's were done by computer. The CPM's of a game were later used to derive game values for each players of a game.

Game Solutions

Game solutions, or game values, are the indications of the comparisons between the players. Game values for each player were computed by using Eq. (3.2). This equation was based on the concept of the average expected value. Just as with the computation of the CPM's, game values were computed by computer in this study. Basin game values of all games under each evaluation criteria are shown in Table 4.3. These game values were from the sets of games headed by the four evaluation criteria: the long-term total objective, the five years (1972-1976) short-term objective, the measurement of the percent of effectiveness, and the measurement of the percent of needs met. The basin code numbers used in the table were shown earlier in Table 4.2. Only basin game values from each game are

Table 4.3. Original basin game values from the sets of games headed by all four evaluation criteria.

Basin Code No.	EVALUATION CRITERION Long-term Total Objective	Five-year (1972-1976) Short-term Objective	Percent of Effectiveness	Percent of Needs Met
1	1.201	0.518	1.472	2.042
2	1.426	1.215	4.543	2.326
3	3.234	0.534	2.321	1.601
4	2.132	0.204	0.775	0.516
5	2.032	1.819	1.644	1.383
6	0.363	0.156	1.356	0.833
7	1.414	0.400	2.369	2.926
8	0.345	0.190	5.161	5.432
9	0.881	0.429	3.021	2.069
10	0.909	0.976	4.610	3.296
11	3.468	2.580	2.406	3.096
12	5.075	4.203	1.760	2.175
13	0.166	0.248	4.372	3.893
14	0.152	0.057	2.977	1.279
15	0.057	0.143	3.046	2.432
16	2.603	1.368	4.787	3.029
17	1.739	0.952	3.035	3.691
18	1.980	1.681	2.901	5.041

shown in the table. Because in the present case, the only interest was in seeking the comparisons between basins and, hence, the game values for the nation-player were disregarded.

These game values were the ones obtained directly from the coefficients of the payoff matrix (CPM's) before any weighting factors were applied to them. A basin, or game, priority weighting factor was developed in this study. This weighting factor will be applied to the original game value before the game value can be used as a basis to formulate recommendations for the decision-maker.

Basin Priority Weighting Factor

An experimental basin priority weighting factor was developed in this study. This factor was based on several criteria developed and used by the U. S. Army Corps of Engineers in formulating water resources programs. [20] These criteria are listed below.

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

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

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 priority. Table 4.4 shows the priority allocated to different basins in percent based on these criteria.

Table 4.4. Priority allocated to different basins** (Percent of Total)

Code No.	Region	Criterion: Federal Income Taxes Paid	Criterion: Population	Criterion: Population & per Capital Income
1	Alaska	*	*	*
2	Arkansas-White-Red	3	4	4
3	California	10	11	10
4	Colorado	1	1	2
5	Columbia-North Pacific	3	3	3
6	Great Basin	*	1	1
7	Great Lakes	18	10	10
8	Hawaii	*	*	*
9	Lower Mississippi	1	3	4
10	Missouri	4	4	4
11	North Atlantic	34	23	21
12	Ohio	8	10	10
13	Puerto Rico	*	1	2
14	Rio Grande	1	1	1
15	Souris-Red-Rainy	*	*	*
16	South Atlantic Gulf	6	11	12
17	Texas-Gulf	3	5	5
18	Upper Mississippi	7	10	9
	The Nation	100%	100%	100%

*0.5 percent or less.

**By U. S. Army Corps of Engineers

To derive the basin priority weighting factors, all three criteria mentioned here were considered to be equally important. The sum of percentages from each criterion for each basin was calculated. The basin priority weighting factors were then obtained from the sums. These factors were defined to be numbers ranging between one and two. A region shows no priority based on these criteria will have a weighting factor one; and the basin has the most priority will have a weighting factor two. The following equation can be used to calculate this factor:

$$\text{Basin Priority Weighting Factor } \theta_i \text{ for basin i} = 1 + \frac{S_i}{C} , \qquad (4.3)$$

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

In this study since all sums of percentages were less than one-hundred, the constant C was assumed to be equal to one-hundred. The values of θ_i varies linearly and directly with respect to the sums of percentages. The derived priority weighting factor for all eighteen basins and their sums of percentages from the three criteria are shown in Table 4.5.

The derived basin priority weighting factors were then applied to the original game values by following Eq. (3.4), according to basins. The weighted basin game values from the sets of games headed by all four evaluation criteria are shown in Table 4.6.

Game Values and Recommendations

Game values from the sets of games headed by the four

Table 4.5. Basin priority weighting factors.

Basin Code No. i	Sum of the Percentages of the Three Criteria S_i	Basin Priority Weighting Factor
1	0	1.00
2	11	1.11
3	31	1.31
4	4	1.04
5	9	1.09
6	2	1.02
7	38	1.38
8	0	1.00
9	8	1.08
10	12	1.12
11	78	1.78
12	28	1.28
13	2	1.02
14	3	1.03
15	0	1.00
16	29	1.29
17	13	1.13
18	26	1.26

Table 4.6. Weighted basin game values from the sets of games headed by all four evaluation criteria.

	EVALUATION CRITERION			
Basin Code No.	Long-term Total Objective	Five-year (1972-1976) Short-term Objective	Percnet of Effectiveness	Percent of Needs Met
1	1.201	0.518	1.472	2.042
2	1.583	1.349	5.043	2.583
3	4.237	0.700	3.041	2.097
4	2.217	0.212	0.806	0.537
5	2.215	1.983	1.792	1.507
6	0.370	0.159	1.383	0.850
7	1.951	0.552	3.269	4.038
8	0.350	0.190	5.161	5.432
9	0.951	0.460	3.263	2.235
10	1.018	1.093	5.163	3.691
11	6.173	4.592	4.283	5.508
12	6.496	5.380	2.253	2.784
13	0.169	0.253	4.459	3.971
14	0.157	0.059	3.066	1.317
15	0.057	0.143	3.046	2.432
16	3.358	1.765	6.175	3.907
17	1.965	1.075	3.430	4.171
18	2.495	2.118	3.655	6.352

evaluation criteria were used as bases for drawing recommendations for the decision-maker. Since the main objective was to find the comparisons of water resources development planning between water resources basins, only the basin game values will be considered in here. The nation-player only served as an intermediary for obtaining indirect comparison information between basins, its game values were disregarded in the present case. If games were arranged between basins and direct comparison information between basins was being sought, then both player's game values should be examined. Since the four evaluation criteria used here were only for illustration purposes, no attempt was made to normalize game values from different sets of games into a unified scale. All game values will retain their original values except being adjusted by the basin priority weighting factor, and they will be analyzed separately for each set of games.

In all games used in this study, the basin-players were competing with the same player, the nation-player, this made all the basin game values within each set of games comparable. The weighted game values from different set of games given in Table 4.6 are also shown as graphs in Fig. 4.3 through Fig. 4.6.

Game Values Under the Long-Term Total Objective Criterion

Figure 4.3 shows the weighted basin game values for the set of games headed by the long-term total objective evaluation criterion. This criterion was used to measure needs of the long-term

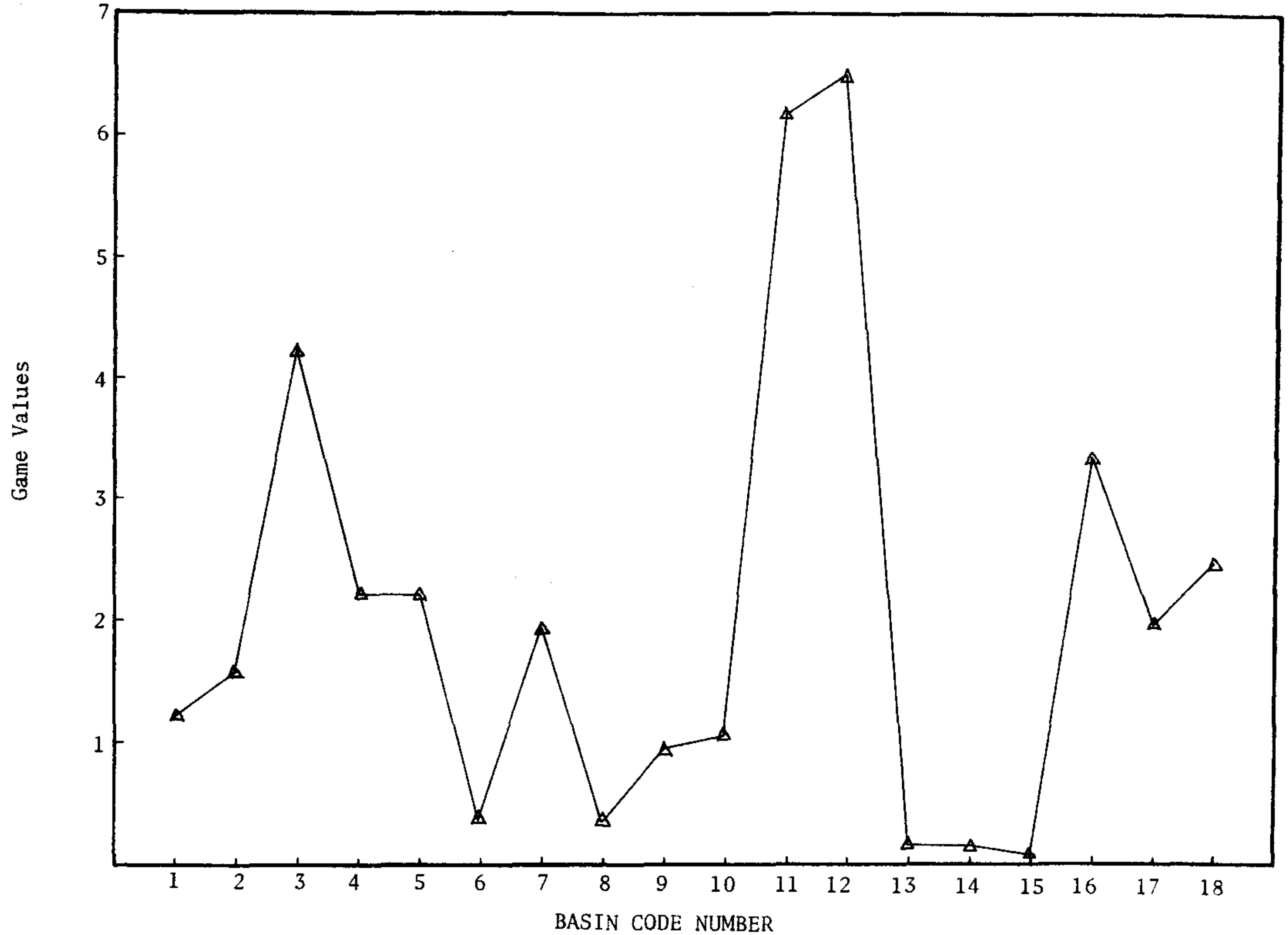

Figure 4.3. Basin game values (weighted) from the set of games headed by the long-term total objective evaluation criterion.

water resources development in a basin. Game values from the competitive evaluation model under this evaluation criterion indicated the competitively measured averages of the long-term development needs of different benefit categories in a basin. These averages were obtained by the two main processes used in this model, the competitive measuring of the UNS's to obtain the CPM's and the game value computation of taking average expected value . In the competitive measuring process, the national totals by benefit categories were used as measurement standard. From the computation algorithm, the average of the long-term development needs of all benefit categories were derived. The game values were generally not the indications of the sums of all the long-term development needs. Those sums can be more easily and directly calculated by adding all the monetary values of different developments in a basin.

A large game value under this evaluation criterion means that a larger number of the benefit categories needs are still in the position of needing great development. For example, basin No. 12 shown in Fig. 4.3 had the largest game value, 6.496. An observation of this basin's UNS's of the long-term total objective in monetary term indicated that the UNS's under all eight benefit categories were quite large. Hence it was natural to expect a large average, indicated by a large game value, of the long-term development needs of different benefit categories for the basin. The basin with the next largest game value, 6.173, shown in Fig. 4.3 was basin No. 11 which had most of its thirteen benefit categories possessing large UNS's under the long-term total objective. Basin No.

11 had the largest sum of long-term development needs in monetary value, $790,593,000; whereas those of the Basin No. 12 was the second largest, $695,894,000. These two rankings were just reversed in the game value ranking. Hence it is not true that the basin with the largest sum of long-term development needs in monetary value would also have the largest game value.

A small game value means that the various types of benefit categories do not have large long-term development needs. For instance, the basin with the smallest game value, 0.057, shown in Fig. 4.3 was basin No. 15 and its UNS's of long-term total objective were also quite small for all six benefit categories when compared to those belonging to basins No. 12 and No. 11. Incidently, basin No. 15 also had the smallest sum of long-term development needs, $6,447,000, among all basins.

Sometimes, it is also possible that a basin has a large game value while the majority of the benefit categories need little development and only a few of the benefit categories with extremely large UNS's under the long-term total objective showing the needs for greater development. In this case, it is said that the strong needs for development of these few benefit categories have overshadowed the minor needs of the other benefit categories. For example, considering basin No. 3 with the number three ranking in game values, 4.237, shown in Fig. 4.3, most of its UNS's under the long-term objective were not too large, but few benefit categories with extremely large UNS's had contributed to the large game value for this basin.

In summary, if a decision were made to develop basins in such a way that basins having higher percentages of benefit categories which need more intensive development should receive special consideration, then the basins with large game values should be especially considered. In the present case, it was basin No. 12 with the highest priority, followed by basin No. 11, then basin No. 3, etc.

Game Values Under the Five Year (1972-1976) Short-term Objective Criterion

The weighted basin game values from the sets of games headed by the five year (1972-1976) short-term objective evaluation criterion are shown in Fig. 4.4. The interpretations of game values under the short-term objective and the long-term objective criteria are similar except that one is for short-term planning and one is for long-term planning. Game values under the five year (1972-1976) short-term objective evaluation criterion indicate the competitively measured averages of short-term development needs of all benefit categories in a basin.

If a decision were made to fulfill the development needs for basins in such a way that basins having higher percentage of benefit categories which need more intensive development in the five years (1972-1976) period should receive priorities, then the basins with the large game values should be especially considered. From Fig. 4.4, it is obvious that basin No. 12 had the largest game value, followed by basin No. 11, and then by basin No. 5, with basin No. 14

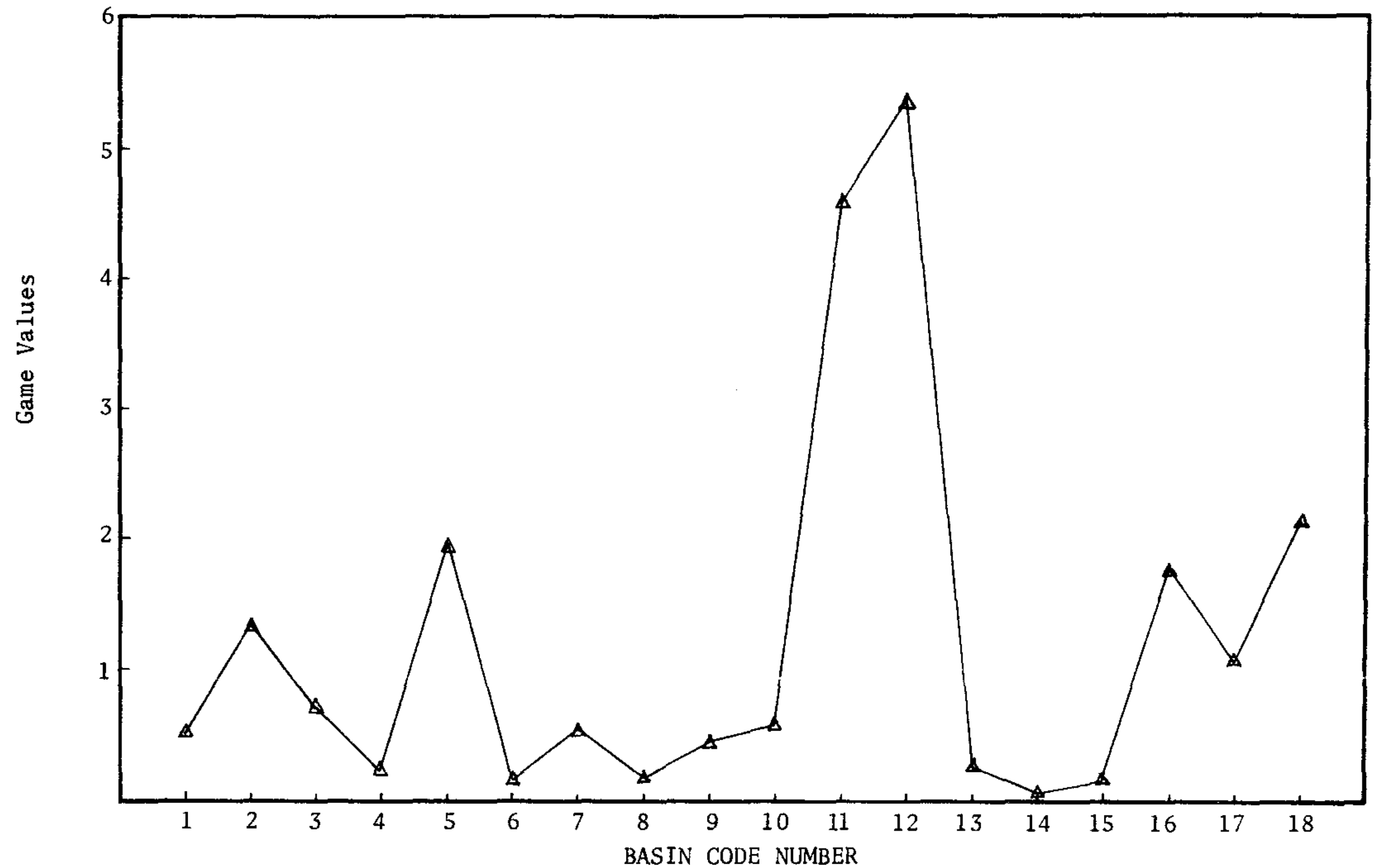

Figure 4.4. Basin game values (weighted) from the set of games headed by the five year (1972-1976) short-term objective evaluation criterion.

having the smallest game value. This ranking of game value was not identical with those under the long-term objective. This is an indication that the needs for long-term and short-term development were different in each basin although it was not unusual for some basins, like basin No. 12, to have greater needs for development both in long-term and short-term objectives than other basins.

Game Values Under the Percent of Effectiveness Criterion

The weighted basin game values from the set of games headed by the percent of effectiveness evaluation criterion are shown in Fig. 4.5. The percentage of short-term development needs in physical output units meeting the long-term total development objective is measured by the percent of effectiveness criterion. It should be mentioned again that the measurement here is a relative measurement, a relationship between the short-term and the long-term objectives. It is not the absolute measurement like the long-term or short-term objective. Game values under this evaluation criterion indicate the average of these percentages of different benefit categories in a basin. A small game value for a basin means that there is a large number of benefit categories which needs further development in order to reach the defined long-term total objective in a basin. A large game value would indicate that most of the benefit categories in a basin having their developments close to the long-term needs. Therefore, if a decision is made to develop basins uniformly towards resources completion, then the basins with smaller

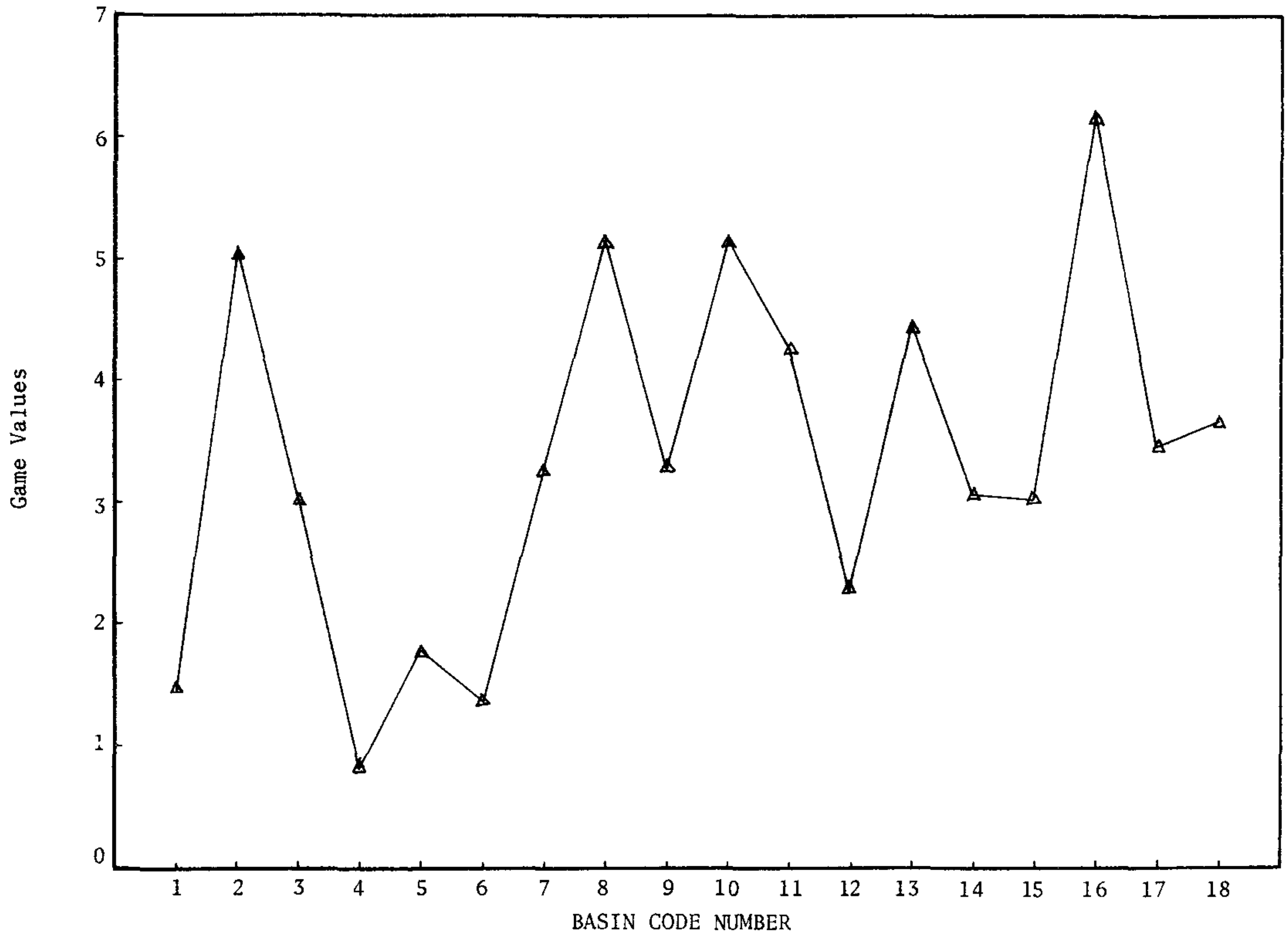

Figure 4.5. Basin game values (weighted) from the set of games headed by the percent of effectiveness evaluation criterion.

game values should be considered specially. Otherwise, if it was decided to develop certain basins completely first, then basins with large game values are the ones to be given development priorities.

The ranking of game values shown in Fig. 4.5 was quite different from those shown earlier for the long-term or the short-term objectives. It is obvious that basin No. 16, with game value, 6.175, was the basin which, in an average among different benefit categories, had its short-term development needs closer to the long-term objective than other basins shown in Fig. 4.5. Basin No. 4, with game value 0.806, was the basin which still needs great development to reach the long-term objective.

Game Values Under the Percent of Needs Met Criterion

The percent of needs met evaluation criterion measures the percentage of the dollar benefit of short-term objective meeting the dollar benefit of long-term objective. The game values under this criterion indicate the averages of these percentages of different benefit categories in a basin. The percent of needs met criterion is similar to the percent of effectiveness criterion, except that the measurement bases are different, one in monetary value and the other in physical output units. However, the interpretations of game values under these two evaluation criteria are quite similar. A small game value for a basin under the percent of needs met criterion means that there is a large number of benefit categories which needs new development or needs to increase the development intensity in order to reach the defined long-term total objective measured by derived benefits in dollar value. A large game value would indicate that most of the benefit categories in a basin having their development closer to the long-term needs expressed in dollar value, when it is compared to the basin with a small game value.

The weighted basin game values from the set of games headed by the percent of needs met evaluation criterion are shown in Fig. 4.6. The pattern of game value ranking in this figure was quite similar to those shown earlier under the percent of effectiveness criterion for some of the basins. For example, basin No. 4, which had a small game value, 0.805, under the previous criterion, also had a small game value under this criterion. This meant that, measuring by an average among all benefit categories, basin No. 4's needs of short-term development objective, both in the number of output units and in the dollar benefit values of these development, were far from the long-term total objective defined for this basin when they were compared with other basins. Therefore, if it was decided to have all the basins progressing toward the long-term total development objective uniformly, then basin No. 4 should be given special attention for development.

For some other basins, the rankings of their game values under the two evaluation criteria were quite different. For instance, basin No. 16, which had a large game value, 6.175, under the percent of effectiveness criterion, had a moderate game value, 3,907, under the percent of needs met criterion. This indicated that the short-term development needs of basin No. 16, in an average among all benefit categories, had reached closer to the long-term objective in the number

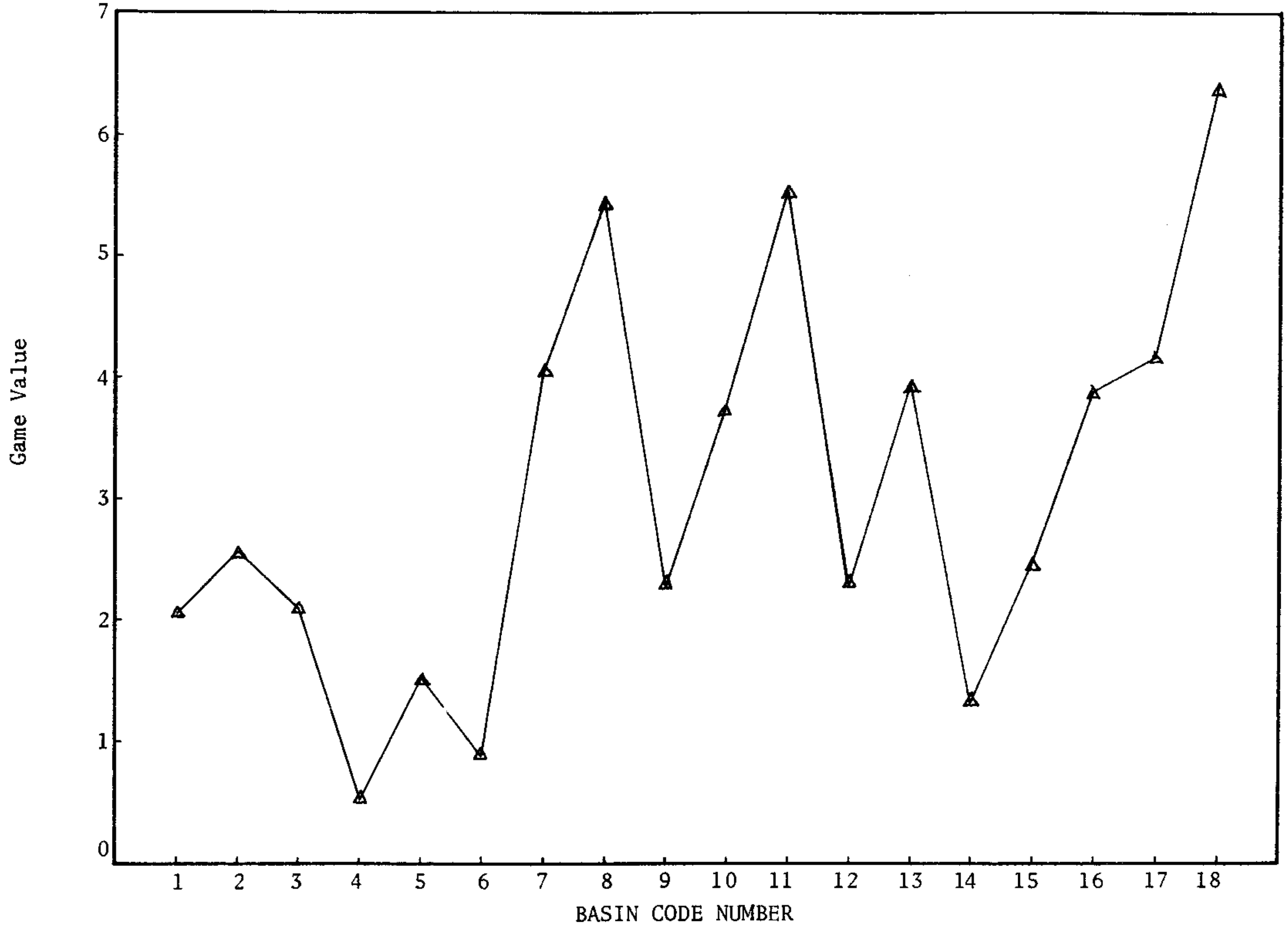

Figure 4.6. Basin game values (weighted) from the set of games headed by the percent of needs met evaluation criterion.

of output units, but the intensity for use measured in dollar benefit value still needs more improvement when this basin was compared with other basins. Hence, it is a matter for the decision-maker to decide whether the objective of getting more unit outputs of development close to the long-term objective or the objective of reaching the use of intensity required by the long-term planning is to be favored, then priority can be assigned for basin development.

Game Values from All Sets of Games

After analyzing game values separately for each set of games headed by an evaluation criterion, game values from all sets of games were supposed to be compared and analyzed together so that decision could be made basing on this final analysis. As it was stated earlier that the four evaluation criteria introduced here were just for illustration purposes, no effort was made to normalize game values from all sets of games to a unified scale so that rigorous comparisons and analysis of the game values could be done while all criteria were considered simultaneously.

Since all games were arranged between the nation-player and different basin-players, in the competitive measuring process, used to obtain the coefficients of the payoff matrix (CPM's) which were later used to calculate the game values, the national total had served as measuring standard . This practice had made game values from all sets of games in a relatively similar scale. The weighted basin game values from all four evaluation criteria are shown in Fig. 4.7. This figure would give a vague comparison of all the game values.

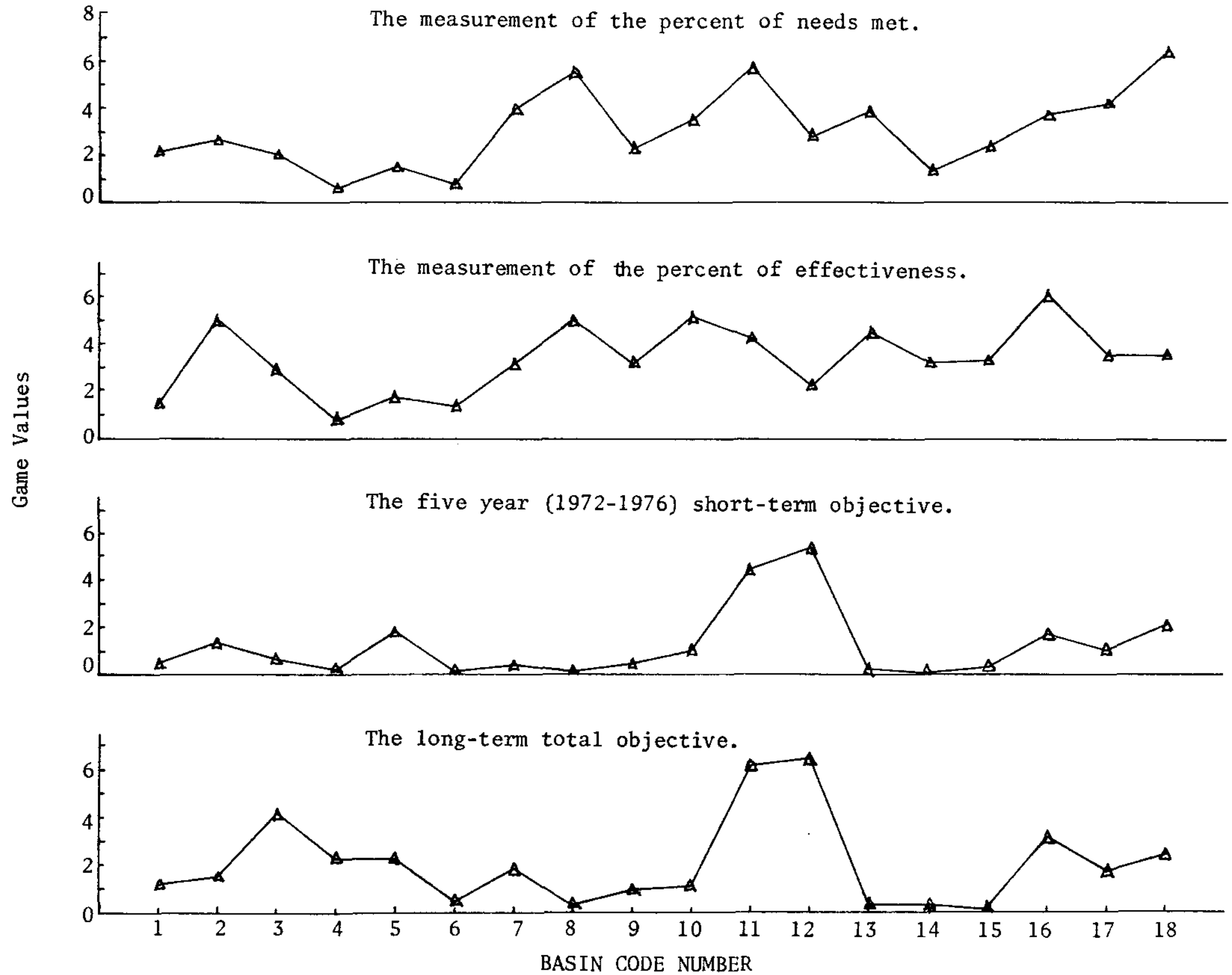

Figure 4.7. Basin game values (weighted) from all four evaluation criteria.

Since there could be many combinations of objectives based on the four evaluation criteria which had been used earlier to analyze game values from each set of games, it was not attempted to analyze any basin's game values under all evaluation criteria simultaneously. Because of this, the objective priority weighting factor, which was originally designed to bring out the relative importance of different criteria, was not developed here. Finally, any analysis of game values would have to be referred back to the previous discussion of game values under different evaluation criteria.

Sensitivity Analysis

Some sensitivity analyses of the results of games were done here. First, it was the comparison of the original and the weighted basin game values which are shown in Fig. 4.8. As it can be seen in the figure, most of the basins had their game values staying in a similar ranking for the original and the weighted game values. A few basins had their original game value rankings raised after the basin priority weighting factors had been applied to them. For example, under the percent of effectiveness evaluation criterion, basin No. 11 which had its game value, 2.406, exceeded by ten basins with game values ranging from 2.901 to 5.161; but the weighted game value of basin No. 11, 4.283, which was exceeded by the game values of only five basins ranging from 4.459 to 6.175, had a big jump in game value ranking. This means that the influence of the basin priority weighting factor sometimes was quite large for some basins. Hence, it further emphasizes that the development of the weighting

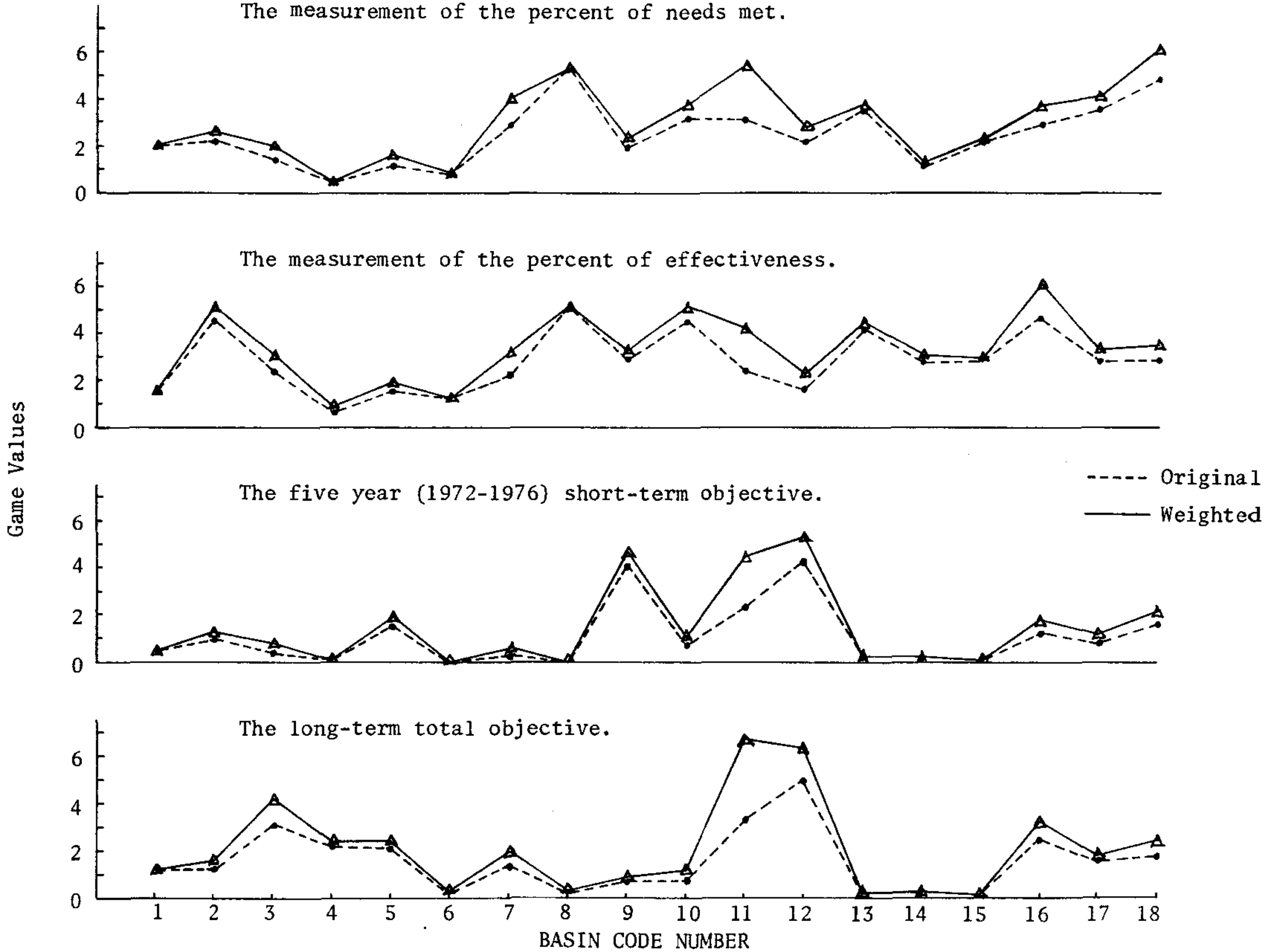

Figure 4.8. The original and the weighted basin game values from all four evaluation criteria.

factors should be done objectively and carefully.

As far as the number of strategies employed by each basin-player was concerned, it hardly had any effect on the game values. A simple proof of this was that for a basin which had used the same number of strategies in games under all evaluation criteria, its game values rankings in each set of games fluctuated under different evaluation criteria.

The number of strategies with large or small utility numbers (UNS's) would affect the game values. After all, the UNS's were used to procure the CPM's which in turn were used to calculate the game values, an average among different strategies. Hence if more strategies with large UNS's were employed by a basin-player, the game value would be larger for this basin. As was mentioned in the previous chapter, if a basin was trying to raise the magnitude of its game values by adding more benefit categories with large UNS's into a game, other basin could also do the same thing. But this would destroy the whole purpose of an objective evaluation of planning. On the other hand, large game values can also be obtained by eliminating benefit categories with small UNS's, but then, these eliminated benefit categories would not be included in the whole development plan and they would also be eliminated from any consideration for further development. Again it indicates that to increase the magnitude of a game value by manipulating the inclusion or the omission of benefit categories with large or small UNS's would not result in objective evaluation.

The limited sensitivity analyses done here were just for demonstration purposes. In an actual evaluation process, more detailed and rigorous sensitivity analyses should be done.

Summary

The model developed earlier was applied to the evaluation of water resources development planning in this chapter. The model was used here to find the comparison information of water resources development planning between different water resources basins in the United States, so that recommendations for development can be obtained. For illustration purposes, four evaluation criteria which measure the long-term total objective, the five year (1972-1976) short-term objective, the percent of effectiveness, and the percent of needs met, were introduced to head the sets of game in this model. Eighteen water resources basins in the Untied States were designated as basin-players of the model so that comparison information of water resources development planning between these basins could be obtained. The nation as a whole was also introduced as a player, the nation-player, to serve as an intermediary for obtaining indirect comparisons between these basins. A game was arranged for each basin-player and the nation-player in each set of games headed by an evaluation criterion. Strategies employed by each player were various types of water resources development represented by benefit categories. The benefit categories, which can be considered as a detailed subdivision of the primary benefit categories stated in S. D. No. 97, used in this research were defined by the U. S. Army Corps of

Engineers. The data used here to calculate the utility numbers of strategies (UNS's) were collected from data obtained by the U. S. Army Corps of Engineers. The UNS's were calculated for each player's strategies under every evaluation criterion. No strategy priority weighting factor was developed in this study. The UNS's were used to procure the coefficients of the payoff matrix (CPM's) and the computation was done by computer. The game solutions, or values, were obtained from the CPM's by using the algorithm of taking the average expected value and the computation was also done by computer. An experimental basin priority weighting factor was developed based on three guidelines, the federal income taxes paid, population, and population and per capita income. This weighting factor was applied to the original game values. The weighted basin game value were finally analyzed under each evaluation criterion. And recommendations, based on the game values, for developing basins were discussed. No attempt was made to analyze any game value when all four evaluation criteria were considered simultaneously, and, hence, no objective priority weighting fact was developed. Finally, an illustration of a simple sensitivity analysis was done. To better illustrate the application of the competitive evaluation model, the verification of the model done in this chapter was summarized in Fig. 4.8 as a sample application of the model for water resources development planning.

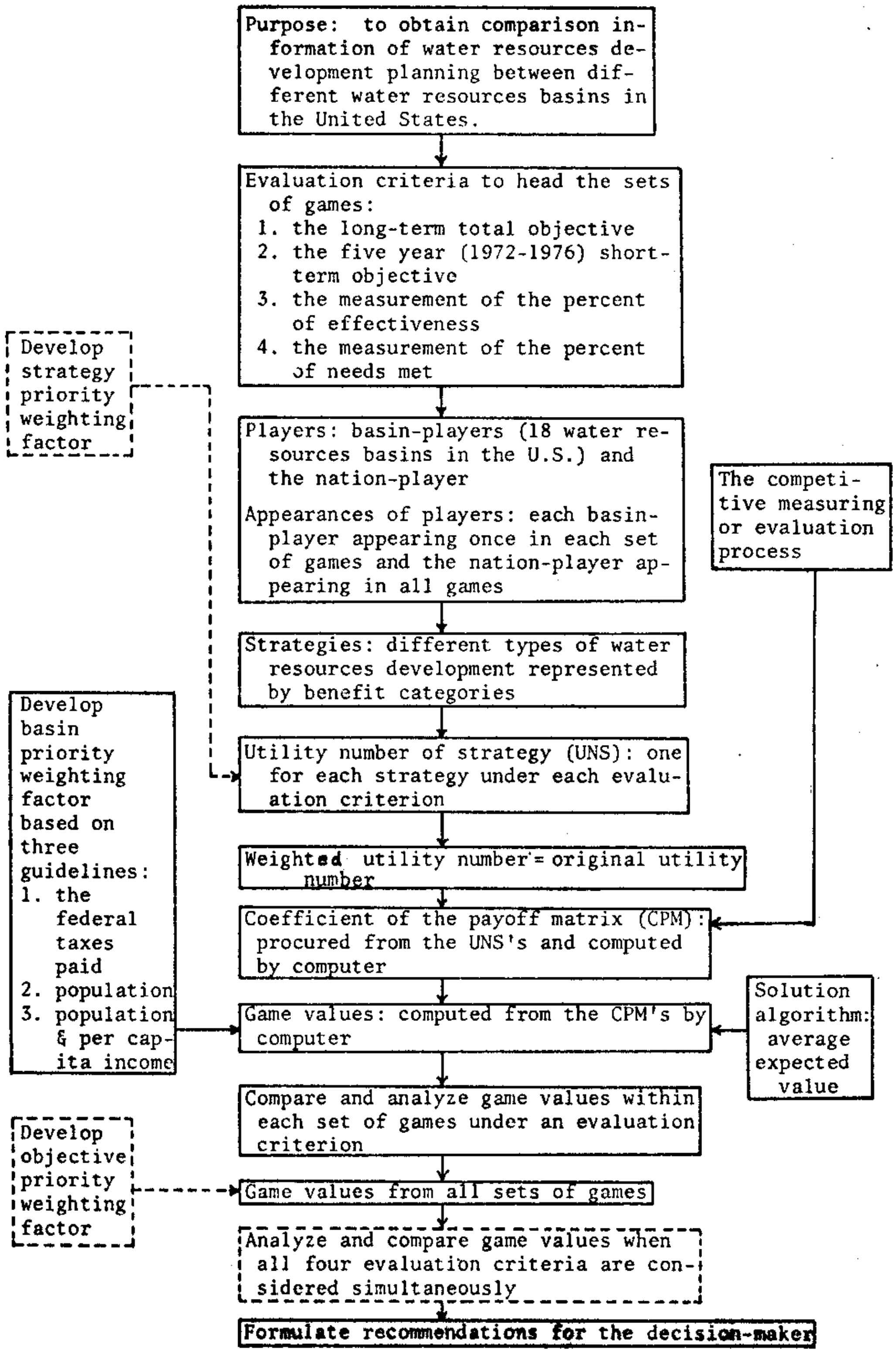

Figure 4.9. Sample application of the competitive evaluation model for water resources development.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

A new approach for the evaluation of water resources development planning has been presented through the model developed in this study. This new approach was contemplated for solving some of the problems existing in the present practices of water resources development planning. Two of the problems were the considering of individual development as an isolated entity and the using of the benefit and cost ratio as the only analysis in the evaluation process. The development of the model originated from game theory concepts. The principal tactics employed in the model are the competitive measuring and evaluation. As it was stated earlier, the main objective of this model is to establish a more effective evaluation methodology for assisting water resources development planning. A set of the sub-objectives of the model was also defined earlier. How these sub-objectives have been accomplished in this model will be discussed briefly.

Review of the Sub-objectives of the Model

Several special situations in water resources development were presumed to be identified in this model. First, it is the overall system of water resources development as well as any individual or local development. Since games used to obtain comparison information in the model can be arranged for any two parties from whom comparison information is needed, games arranged between the player representing the whole system and the players representing individual developments would certainly supply information of the whole system and its components. In the verification of the model, the nation-player representing the whole nation was introduced to serve as the standard player for obtaining indirect comparisons between the basin-players and, thus, all the UNS's of a basin-player were competitively measured by the UNS's of the nation-player in games; this showed that the national situation was considered to be the overall system while the developments in individual basins were considered to be local development. Although micro-analysis of the development in an individual basin was not done in the verification of the model, it can be done by using this model if it is needed. For example, if the comparison of different types of development in an individual basin is needed, games can be arranged between the players representing different types of development in a region with different evaluation criteria being designated as strategies, and game values obtained can then be used to indicate the comparisons between different types of development. Actually, the model is capable of handling comparisons at any level of detail available or desirable.

Secondly, the relationship of water resources development in different locations or regions can be identified in this model. As a matter of fact, this sub-objective was especially emphasized in the development of the model. Games in the model are arranged for obtaining comparison information of water resources development in different basins; this is a strong indication that this relationship has been identified. This sub-objective really shows that water resources development planning in a basin is not considered in isolation but it is compared with developments in other basins. In the verification of the model, comparison information between different basins was obtained indirectly from games between the nation-player and basin-players; i.e., the nation-player was assumed to be the norm and a comparison between any individual and the norm also provide a inter-subsystem comparison. This was done because when the nation-player was introduced as the standard player, game values obtained can be more easily analyzed. Even though comparisons were only made at the basin level in the verification of the model, if further comparisons between sub-regions in a basin are needed, the model can also be used to derive them.

Thirdly, the inter-relationship between different purposes or goals of water resources development is identified in the model. In the verification of the model, strategies employed by the player of game were used to represent different purposes or different benefit categories of development. The algorithm developed to calculate game value anticipates the participation of all strategies; this is an indication that different purposes of development are inter-related by contributing to the magnitude of the game value. As stated earlier, comparisons between different purposes of development can also be obtained through this model although it was not illustrated in the verification of the model.

One more situation to be identified in the model is the priority among different purposes and locations of water resources development. Weighting factors were introduced to bring out these priorities. The strategies priority weighting factor was designed for bringing out the relative importance of different types of water resources development in a basin although in the verification of the model this weighting factor was not developed for any strategy employed by the basin-player and the factor was assumed to be equal to one, i.e., all types of development were considered to be in the same level of importance in a basin when comparisons were made between basins. The development priority for different locations was indicated by the basin priority weighting factor. In the verification of the model, an experimental basin priority weighting factor was developed based on three guidelines - federal income taxes paid, population, and population and per capital income of the region. Game values for a basin were multiplied by the respective basin priority weighting factors before the game values were analyzed; and hence the development priority for different locations was identified.

Another sub-objective of the model is that the model should be able to recognize the competitive nature of water resources development. No doubt that this sub-objective has been achieved in the model. The entire model was developed based on the competitive concept of game theory. As it was mentioned in the conclusion of Chapter III, the special feature of the model is the emphasis of the competitive evaluation or comparison throughout the model. The arrangement of games to obtain comparison information between water resources basins, the competitive measuring or evaluation process used to derive the CPM's, and the comparing of solutions from games in each set of games, all are indications that the model is able to recognize the competitive nature of water resources development.

In addition to the measurements of benefits and costs used in the present evaluation process, another sub-objective of the model was to argument new measurements. As a result of this, four evaluation criteria were introduced for illustration purposes, these new criteria measure the long-term total objective, the short-term objective, the percent of needs met, and the percent of effectiveness. Although some other measurements were also considered, they were not used in the verification of the model. Further research may enable more measurements to be introduced.

The model has another sub-objective that is to provide systematic and specific recommendations for the decision-maker in order to benefit water resources development planning. This sub-objective can be considered as an emphasis of the main objective of the model. Actually the whole model is a process to achieve this sub-objective. In the model, data of different types of water resources development in various basins are collected. Game values are then obtained from games arranged through these data. These game values are then formulated. Basically this whole process was intended to summarize a large quantity of data and rearrange it into a simpler and more meaningful form to provide systematic and specific recommendations for the decision-maker.

The last sub-objective of the model is that the model developed should be simple enough to be practically applicable. This sub-objective is unquestionably accomplished. First, although the model was developed by using game theory concepts, the competitive measuring process used to procure the CPM's and the algorithm used to calculate game values are all quite straightforward. Secondly, the structure of the model is also very simple and flexible; it is simply a collection of sets of games. Therefore, there are no complicated techniques involved in implementing the model.

The sub-objectives of the model defined earlier have basically been accomplished. The model also has some other advantages which are either originally intended or obtained as a by-product from the development of the model and they will be discussed next.

General Advantages of the Model

First of all, the structure of the model is quite flexible and is formulated in a modular fashion, so that new modules may be added or existing ones replaced or modified at minimal expense. For instance, any number of evaluation criteria can be introduced if it is deemed necessary. The number of games in each set of games is unrestricted as well as the number of the players or the appearances of each player. Also no restriction is enforced on what the player should represent or what kind of strategies should be employed. All these are arranged and decided by whoever is using the model.

The model is not an optimization formulation which would indicate how exactly water resources development should be planned. On the other hand, the results of games from the model is a summary of a large quantity of data presented in a simple and meaningful form which can be used to formulate recommendations for the decision-maker. A budget allocation model developed earlier by Reid, Lawrence, and Law [3] is the type of model which would show the decision-maker the optimal solutions for planning water resources development; a summary of that model is included in Appendix IV for reference. Anyhow, very often in the decision making process, it is better to consider evaluation results as recommendations other than direct and optimized answers. Because in the case that some optimized solutions are not satisfied by the decision-maker, there exists the tendency that the whole set of the optimized solutions might be totally disregarded. Results from the competitive evaluation model do not give straightforward answers for the decision-maker but they do offer some analytical outcomes to be used to formulate recommendations or guidelines for the decision-maker.

As stated in the development of the computation algorithm, the new model allows players with different types of strategies or even unequally numbered strategies to launch a comparison. Hence, in some cases when comparison is needed for two parties with different types or unequally numbered aspects (though these aspects must belong to the same general categories) and the one-to-one comparison is impossible, the model still permits comparison to be made.

If comparison between non-quantifiable benefits or other objectives is needed, the model is also capable of handling it. In the development of the model, the coefficients of the payoff matrix were derived in such a way that all of them will be in unitless measurements and, thus, they will lead to unitless game values so that game values from different games can be compared. Therefore, if utility numbers can be assigned to the non-quantifiable objectives, then the non-quantifiable objectives of two different players can be compared through a game arranged between them. And the game values thus obtained can also be compared with other unitless game values from the comparisons between the quantifiable objectives. Of course, this can only be done after a methodology for assigning utility numbers to the non-quantifiable objectives has been developed.

As a matter of fact, being able to introduce more measurements and objectives, whether quantifiable or non-quantifiable, besides the economic factors based on cost and benefit, is the main advantage of the evaluation method used in this model, as compared with the benefit and cost ratio analysis which is traditionally used in water resources development evaluation.

Limitations of the Model and Recommendations for Further Research

The competitive evaluation model was developed by using game theory concepts. Although applications of game theory have been shown in other areas, for instance, military, business, management, political science, etc., the idea of using game theory concepts to develop a methodology for the evaluation of water resources development planning is relatively new if it is not the first try. Since few references can be found for direct and ready adaption of game theory concepts to the evaluation of water resources development planning, a major portion of this research was devoted to the development of the general model. As a result of this, although the main objective of the model has been essentially fulfilled, the application of the model is limited by the fact that a great deal more work is still needed before this model can be considered as a workable model with practical use for the evaluation of water resources development planning.

To achieve practical application of this model for the evaluation of water resources development planning, it is necessary to define more detailedly the evaluation criteria used to head the sets of games in the model. The four evaluation criteria introduced in this study were only for illustration pruposes and they do not make up a complete evaluation. More evaluation criteria should be introduced and also justified if a complete evaluation is required. This means that more aspects related to water resources development should be considered, for example, cost, social objectives, ecological objectives, etc.

Several weighting factors were introduced in this model. The strategy priority weighting factor which is designed to bring out the priorities of various types of development in a basin was not developed in the verification of the model; hence, the development of this weighting factor should be considered in the future study. Although an experimental basin priority weighting factor was developed in this study, further sensitivity analysis of the effect of this factor on the game value should be done. The objective priority weighting factor introduced in the model for bringing out the relative importance of different evaluation criteria was not developed. When the set of complete evaluation criteria has been defined and comparison of game values from different sets of games is needed, it is necessary to develop the objective priority weighting factor.

Only a limited post-sensitivity analysis of the effect of the UNS's magnitude on the game value as well as a limited post-sensitivity analysis of the whole model have been done in this study. Hence, more effort should be spent in these areas if future research is pursued.

Another possible improvement of the model is to develop a methodology for comparing or combining game values from different evaluation criteria. Although all the CPM's and game values shown in the verification of the model were computed by computer, it would be more effective if comparisons of these game values could also be made directly by computer. This could be another area for future research.

Although the competitive evaluation model was formulated with its application in the evaluation of water resources development planning in mind, the development of the model was done in a very general format and, thus, the structure of the model is general enough to permit handling evaluation in other areas. For example, this model could be used to handle evaluation in transportation development planning by obtaining comparison information from games arranged between players representing different regions while different modes of transport or different transport facilities being employed as strategies in the competition. The model could also be used to handle evaluation in fields like housing, education, public health, urban planning, or a combination of such fields.

CHAPTER VI

SUMMARY

The main purpose of this study was to develop a more effective evaluation methodology for assisting in water resources development planning. The new model was contemplated for solving some of the problems existing in the present practices of water resources development planning. Two of the principal problems associated with the present practices were the considering of individual development as isolated entity and the using of the benefit and cost ratio as the only analysis in the evaluation process. A study of some cost-effectiveness techniques, decision theory and game theory, and the heuristic (operational) gaming approach as well as their possible applications for water resources development planning evaluation led to the development of the model. The model was finally developed by stressing game theory concepts. The principal tactics employed in the model are the competitive measuring between benefit categories and the competitive evaluation of the outcomes.

The model is basically a collection of sets of games. Its structure is quite flexible. Each set of games is headed by an individual criterion. All evaluation criteria can be considered as equally weighted entries of the model; otherwise, an objective priority weighting factor can be used to bring out the relative rankings among criteria. Under each evaluation criterion, there is a series of games used to obtain comparison information between different types of water resources development in different locations. All games are formulated in a two-person non-zero-sum game format. When comparison is needed, individual game can be arranged for two players, which can be used to represent two water resources basins while traditional game strategies being used to represent various types of water resources development. In general, strategies are used to designate different aspects on which comparison is needed to be made. All strategies can be considered to be equally important; if not, a strategy priority weighting factor can be used to show the preference. By using a competitive measuring process, the utility number of a strategy (UNS), which measures the absolute payoff of a strategy, is used to procure the coefficients of the payoff matrix (CPM) which in turn are used to compute game values by employing the algorithm of taking average expected value. These game values are then multiplied by their respective basin priority weighting factor before they are compared and analyzed, and, then, used as bases for formulating recommendations to be considered in the decision making process.

In the verification of the model, four evaluation criteria which measure the long-term total objective, the five year (1972-1976) short-term objective, the percent of effectiveness, and the percent of needs met, were introduced to head the sets of games in the model. Eighteen water resources basins in the United States were designated as basin-players so that the comparison information of water resources development planning between these basins could be obtained. The nation as a whole was also introduced as a player, the nation-player, to serve as an intermediary for obtaining indirect comparisons between these basins. A game was arranged for each basin-player and the nation-player in each set of games headed by an evaluation criterion. Strategies employed by each player were various types of water resources development represented by benefit categories. No strategy priority weighting factor was developed. Data were collected so that utility numbers of different strategies (UNS) under each of the four evaluation criteria can be obtained. These UNS's were used to procure the coefficients of the payoff matrix (CPM) which in turn were used to compute the game values. All the computations of the CPM's and game values were done by computer. An experimental basin or game priority weighting factor was developed and applied to the original game values. The weighted game values were then compared and analyzed under each evaluation criterion. Based on these game values, recommendations for water resources development planning in basin level were discussed. No attempt was made to analyze any game value when all four evaluation criterion were considered simultaneously, and, hence, no objective priority weighting factor was developed. Finally, an illustration of a simple sensitivity analysis was done.

To support the main objective, some sub-objectives of the model have also been accomplished. These sub-objectives enable the model to identify the overall system of water resources development as well as the individual or local development, the relationship of developments in different locations, the inter-relationship between different purposes of development, and the priorities among different purposes and locations of development. The model also recognizes the competitive nature of water resources development and augments some new measurements. The structure of the model is quite simple as well as the computation techniques involved. The model is not an optimization formulation which would indicate how exactly water resources should be planned. The model as a whole provides a new approach to obtain systematic and specific recommendations for the decision-maker.

The main advantage of the evaluation method used in this model, as compared to the benefit and cost ratio analysis which is traditionally used in water resources development evaluation, is that more measurements and objectives, whether quantifiable or non-quantifiable, can be introduced in the evaluation process besides the economic factors based on benefits and costs. Although many details of this model are based on Senate Document No. 97, e.g., benefit categories and basic planning units - basins, the evaluation method used in this model is more an analytical approach. As compared to the present practices in planning, no water resources development is considered in isolation in this model; i.e., the relationships of any individual development with the overall system and with any other component of the system are considered.

The limitation of this model at the present is that detailed and practical application still needs further refinement. This means further research on the application of weighting factors, the assigning of utility number to non-quantifiable objective, detailed formulation of evaluation criteria further, post-sensitivity analysis, and the methodology for comparing and combining game values, etc.

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APPENDIX I

BENEFIT CATEGORIES

BENEFIT CATEGORIES

Code	Category	Output Units	Definition of Project Output
	[Control of Water Damage]		
11	Flood damage reduction, existing development, urban	10^3 Acres	Acreage, shown as urban in the City and County Data Book which receive protection from the proposed project.
12	Flood damage reduction, existing development, rural	10^3 Acres	Acreage, not designated as urban in the City and County Data Book which would receive protection from the proposed project.
13	Flood damage reduction, future development, urban		Financial benefits only for areas classified as urban in the City and County Data Book which would receive protection from the proposed project and on which development is expected to occur with or without construction of the proposed project.
14	Flood damage reduction, future development, rural		Financial benefits only for areas not designated as urban in the City and County Data Book which would receive protection from the proposed project, and on which development is expected to occur with or without construction of the proposed project.
15	Increased land use, urban		Financial benefits only for areas classified as urban in the City and County Data Book which would receive protection from the proposed project and on which development or higher level of use is expected to result from construction of the proposed project.
16	Increased land use, rural		Financial benefits only for areas not designated as urban in the City and County Data Book which would receive protection from the proposed project, and on which development or higher level of use is expected to result from construction of the proposed project.

Code	Category	Output Units	Definition of Project Output
	[Control of Water Damage]		
17	Drainage	10^3 Acres	Acreage, classified by Soil Conservation Service as a wetness problem area, which would be relieved of wetness problems through project construction.
18	Bank and channel stabilization	10^3 Acres	Acreage which would be preserved for beneficial use by provision of measures to restrict erosion and/or channel meander.
19	Beach Erosion	Miles	Miles of beach which would be preserved for beneficial use by provision of measures to restrict erosion or to restore eroded areas.
21	Hurricane damage reduction, existing development, urban	10^3 Acres	Acreage subject to inundation from the standard project hurrican, which would receive protection from the proposed project and is expected to qualify as urban in accordance with the definition furnished.
22	Hurricane damage reduction, existing development, rural	10^3 Acres	Acreage subject to inundation from the standard project hurricane, which would receive protection from the proposed project and is not expected to qualify as urban in accordance with the definition furnished.
23	Hurricane damage reduction, future development, urban		Financial benefits only for acreage subject to inundation from the standard project hurricane, which would receive protection from the proposed project and is expected to qualify as urban in accordance with the definition furnished and on which development is expected to occur with or without protective measures.

Code	Category	Output Units	Definition of Project Output
	[Control of Water Damage]		
24	Hurricane damage reduction, future development, rural		Financial benefits only for acreage subject to inundation from the standard project hurficane, which would receive protection from the proposed project and is expected to qualify as urban in accordance with the definition furnished and on which development is expected to occur with or without protective measures.
25	Flood damage reduction, tributaries existing development, urban	10 Acres	Acreage bounded by the confluence of two streams and subject to flooding from more than one direction, which wihtin the time frame used for projection of needs is expected to qualify as urban in accordance with the definition furnished. Acreage reported under this category consists of areas requiring protection provided by projects along both streams and duplicates acreage reported under flood damage reduction, urban.
26	Flood damage reduction, tributaries existing development, rural	10 Acres	Acreage bounded by the confluence of two streams and subject to flooding from more than one direction, which within the time frame used for projection of needs is not expected to qualify as urban in accordance with the definition furnished. Acreage reported under this category consists of areas requiring protection provided by projects along both streams and duplicates acreage reported under flood damage reduction, rural.
27	Flood damage reduction, tributaries future development, urban		Financial benefits only for acreage bounded by the confluence of two streams and subject to flooding from more than one direction, which

Code	Category	Output Units	Definition of Project Output
	[Control of Water Damage]		
27 (Cont'd.)			within the time frame used for projection of needs is expected to qualify as urban in accordance with the definition furnished and on which development is expected to occur with or without protective measures. Acreage reported under this category consists of areas requiring projection provided by projects along both streams and duplicates acreage reported under flood damage reduction, urban.
28	Flood damage reduction, tributaries future development, rural		Financial benefits only for acreage bounded by the confluence of two streams and subject to flooding from more than one direction, which within the time frame used for projection of needs is not expected to qualify as urban in accordance with the definition furnished and on which development is not expected to occur with or without protective measures. Acreage reported under this category consists of areas requiring protection provided by projects along both streams and duplicates acreage reported under flood damage reduction, rural.
	[Water Supply]		
31	Municipal and industrial water supply	MGD	Service yield of proposed project (dependable yield times reuse factor).
32	Agricultural water supply	10^3 Acres	Acreage which could be brought into productive use or would be more productive if the proposed project were constructed.
34	Water quality	MGD	Dependable yield of proposed project.

Code	Category	Output Units	Definition of Project Output
41	Commercial fisheries	Tons	Tons of increased catch
	[Recreation]		
51	General	10^3 uda	Annual user-days of water oriented recreation, not specifically reported under fish and wildlife or boating, expected to be satisfied by the proposed project after the initial five years of project operation.
52	Fish and wildlife	10^3 uda	Annual user-days of recreational fishing or hunting to be satisfied by the proposed project after the initial five years of project operation.
53	Boating-launched	10^3 uda	Annual user-days of recreational boating, using boats transported by trailer or car-top, to be satisfied by the proposed project after the initial five years of project operation.
54	Boating-berthed	Boats	Number of recreation boats which could be permanently or semi-permanently moored at facilities developed as a result of construction of the proposed project.
	[Navigation]		
61	Harbors	10^6 Tons Comm.	Projected annual tonnage to be benefitted as a result of and within five years of construction of proposed project.
63	Deep draft channels	10^6 Ton-Miles Comm.	Projected annual tonnage to be benefitted as a result of and within five years of construction of proposed project times length of proposed project.

Code	Category	Output Units	Definition of Project Output
64	Barge channels	10^6 Ton-Miles Comm.	Projected annual tonnage to be benefitted as a result of and within five years of construction of proposed project times length of proposed project.
65	Miscellaneous navigation benefits		Financial benefits attributed to reduced maintenance dredging, reducing delays, etc., will be reported under this category. No physical measure now required.
66	Deep draft locks	10^6 Tons	Projected total annual tonnage locked through the locks of the subject waterway, shown as the sum of the tonnage for each lock.
67	Shallow draft locks	10^6 Tons	Projected total annual tonnage locked through the locks of the subject waterway, shown as the sum of tonnage for each lock.
68	Navigation safety		Average annual benefits ($1000) resulting from reduction in accidents, elimination of vessel damage and cruising hazard, loss of cargo, cost of clean-up and related costs associated with providing safer navigation facilities. This does <u>not</u> reflect the value of loss of life or personal injury prevented.
	[Power]		
71	Power capacity-peaking	10^3 KW	Proposed project installation for peaking capacity.
72	Power capacity-base	10^3 KW	Proposed project installation for base load capacity.
73	Downstream Power Benefits		Financial benefits resulting from increased generation at downstream plants attributed to flow regulation by proposed project. No physical measure now required.

Code	Category	Output Units	Definition of Project Output
81	ARA Benefits		Financial benefits accruing to a geographical area as a result of the projects. In order for this category to be used it is necessary for the affected area to be designated as an EDA county by the Economic Development Agency.
82	Regional Development Benefits		Financial benefits accruing to a geographical area as a result of the project which stimulate or induce a growth in income not directly attributable to any other benefit category and which do not provide national benefits.
91	Other Financial Benefits		Financial benefits which are not attributable to any other official benefit category (i.e., mine drainage pollution abatement, dust reduction, etc.). A typed explanation sheet identifying the type benefit by project must be provided with the listing and punch cards when this category is used.

APPENDIX II

REGIONAL DEVELOPMENT OBJECTIVES

*The benefit categories corresponding to the code numbers indicated here are shown in Appendix I.

@The basic measurement units of different types of development according to benefit categories are shown in Appendix I.

Table I-0. National development objectives.

Strategies - Benefit Categories by Code Number*	Development Output Units of Long-term total objectives[@]	Development Output Units of Five Year (1972-1976) Short-term objectives	Long-term Regional Mean Values of Benefit per Unit of Development ($1000)	Total Benefit Values of Five year (1972-1976) Short-term Objectives ($1000)
11	1,849	350	406.23	74,508
12	24,998	3,201	25.20	35,329
17	7,927	377	2.75	2,707
19	1,068	428	17.0	7,613
25	15	4	91.0	239
26	8,183	1,082	5.13	3,543
31	6,404	2,275	12.29	34,836
32	7,580	153	15.43	6,066
34	24,948	5,446	6.99	42,022
41	647,878	65,960	0.08	8,033
51	1,554,311	181,944	0.94	118,340
52	156,139	9,584	1.23	17,040
53	94,059	3,358	1.76	5,419
54	613,070	69,719	0.21	11,724
61	708	56	105.18	19,623
63	4,575	243	27.24	8,945
64	36,415	4,112	8.65	77,309
67	21	3	147.61	2,847
71	18,143	3,033	19.32	51,255
72	3,780	536	30.11	11,959

Table II-1. Basin No. 1 (Alaska) development objectives.

Strategies - Benefit Categories by Code Number*	Development Output Units of Long-term total Objectives@	Development Output Units of Five Year (1972-1976) Short-term Objectives	Long-term Regional Mean Values of Benefit per Unit of Development ($1000)	Total Benefit Values of Five Year (1972-1976) Short-term Objectives ($1000)
11	28	12	661.500	8,482
41	44,500	25,400	0.068	2,241
51	239	62	1.200	256
52	830	25	1.360	36
53	1,646	5	2.000	11
63	582	50	119.850	265
64	95	1	86.788	192

Table II-2. Basin No. 2 (Arkansas-White-Red) development objectives.

Strategies - Benefit Categories by Code Number*	Development Output Units of Long-term total Objectives@	Development Output Units of Five Year (1972-1976) Short-term Objectives	Long-term Regional Mean Values of Benefit per Unit of Development ($1000)	Total Benefit Values of Five Year (1972-1976) Short-term Objectives ($1000)
11	26	34	436	3,758
12	2,346	771	24	7,503
17	248	62	8.449	598
31	1,134	157	14.824	2,508
32	148	23	55.152	1,551
34	4,787	3,583	6.278	19,476
41	483	280	0.209	35
51	45,409	5,047	0.980	4,434
52	2,065	1,116	1.042	943
53	3,680	54	1.407	96
71	3,586	85	19.154	1,411

Table II-3. Basin No. 3 (California) development objectives.

Strategies - Benefit Categories by Code Number*	Development Output Units of Long-term total Objectives@	Development Output Units of Five Year (1972-1976) Short-term Objectives	Long-term Regional Mean Values of Benefit per Unit of Development ($1000)	Total Benefit Values of Five Year (1972-1976) Short-term Objectives ($1000)
11	552	57	541.360	4,570
12	1,193	94	77.436	1,712
17	92	3	17.453	134
31	214	151	22.720	1,358
32	342	45	46.407	3,298
34	63,000	450	0.089	57
41	59,864	1,584	1.144	3,553
51	7,890	144	1.153	488
52	4,789	160	1.780	816
53	101,500	1,700	.487	786
71	50	50	36.160	1,808

Table II-4. Basin No. 4 (Colorado) development objectives.

Strategies - Benefit Categories by Code Number*	Development Output Units of Long-term total Objectives@	Development Output Units of Five Year (1972-1976) Short-term Objectives	Long-term Regional Mean Values of Benefit per Unit of Development ($1000)	Total Benefit Values of Five Year (1972-1976) Short-term Objectives ($1000)
11	190	12	115.630	763
12	2,934	28	23.845	219
32	48	6	167.170	995

Table II-5. Basin No. 5 (Columbia-North Pacific) development objectives.

Strategies - Benefit Categories by Code Number*	Development Output Units of Long-term total Objectives@	Development Output Units of Five Year (1972-1976) Short-term Objectives	Long-term Regional Mean Values of Benefit per Unit of Development ($1000)	Total Benefit Values of Five Year (1972-1976) Short-term Objectives ($1000)
11	69	5	426.180	988
12	522	83	47.745	3,445
17	287	2	8.966	10
19	86	5	35.238	299
51	72,048	235	1.469	396
52	7,950	95	2.795	250
54	29,782	1,432	0.195	145
64	1,256	6	20.038	1,094
71	5,305	2,509	10.064	38,742
72	975	536	19.269	11,959

Table II-6. Basin No. 6 (Great Basin) development objectives.

Strategies - Benefit Categories by Code Number*	Development Output Units of Long-term total Objectives@	Development Output Units of Five Year (1972-1976) Short-term Objectives	Long-term Regional Mean Values of Benefit per Unit of Development ($1000)	Total Benefit Values of Five Year (1972-1976) Short-term Objectives ($1000)
11	65	22	187.430	1,237
12	252	19	1.976	53
31	99	9	71.277	717
51	11,400	792	.987	790
52	1,570	30	1.250	40
53	650	95	1.030	130

Table II-7. Basin No. 7 (Great Lakes) development objectives.

Strategies - Benefit Categories by Code Number*	Development Output Units of Long-term total Objectives@	Development Output Units of Five Year (1972-1976) Short-term Objectives	Long-term Regional Mean Values of Benefit per Unit of Development ($1000)	Total Benefit Values of Five Year (1972-1976) Short-term Objectives ($1000)
11	45	22	436.000	3,512
12	55	1	32.900	9
19	321	38	2.677	340
31	82	6	28.059	103
34	1,929	84	12.129	318
41	1,925	1,032	0.122	146
51	135,147	4,962	0.956	4,088
52	12,572	972	1.780	1,503
53	5,768	355	6.860	204
54	28,553	15,366	0.091	2,589
61	20	4	57,442	1,131

Table II-8. Basin No. 8 (Hawaii) development objectives.

Strategies - Benefit Categories by Code Number*	Development Output Units of Long-term total Objectives@	Development Output Units of Five Year (1972-1976) Short-term Objectives	Long-term Regional Mean Values of Benefit per Unit of Development ($1000)	Total Benefit Values of Five Year (1972-1976) Short-term Objectives ($1000)
11	8	0.488	305.41	436
51	14,810	300	1.464	333
53	101	90	2.590	256
54	6,750	5,430	0.253	1,242
61	2	1	377.040	737

Table II-9. Basin No. 9 (Lower Mississippi) development objectives.

Strategies -Benefit Categories by Code Number*	Development Output Units of Long-term total Objectives@	Development Output Units of Five Year (1972-1976) Short-term Objectives	Long-term Regional Mean Values of Benefit per Unit of Development ($1000)	Total Benefit Values of Five Year (1972-1976) Short-term Objectives ($1000)
12	1,292	126	10.931	158
17	5,161	283	2.0	1,941
25	15	4	93 056	239
26	8,183	1,082	5.132	3,543
31	504	68	6.062	139
32	759	79	2.722	222
34	393	168	1.747	322
51	42,407	350	1.431	350
52	2,430	202	1.700	620
63	218	89	31.679	2,291
64	877	920	7.092	4,996

Table II-10. Basin No. 10 (Missouri) development objectives.

Strategies - Benefit Categories by Code Number*	Development Output Units of Long-term total Objectives@	Development Output Units of Five Year (1972-1976) Short-term Objectives	Long-term Regional Mean Values of Benefit per Unit of Development ($1000)	Total Benefit Values of Five Year (1972-1976) Short-term Objectives ($1000)
11	54	39	514.200	6,577
12	617	191	34.826	3,703
31	107	42	6.750	586
34	423	71	12.060	1,102
51	20,064	6,986	1.000	5,130
52	4,330	1,642	0.921	1,449

Table II-11. Basin No. 11 (North Atlantic) development objectives.

Strategies - Benefit Categories by Code Number*	Development Output Units of Long-term total Objectives@	Development Output Units of Five Year (1972-1976) Short-term Objectives	Long-term Regional Mean Values of Benefit per Unit of Development ($1000)	Total Benefit Values of Five Year (1972-1976) Short-term Objectives ($1000)
11	231	28	749.280	13,817
12	1,600	32	79.622	2,766
19	351	201	15.505	4,707
31	951	370	12.184	6,212
34	4,290	564	9.607	8,804
41	57,220	21,865	0.069	2.143
51	258,203	107,441	0.551	45,334
52	13,071	636	1.278	1,339
53	28,227	234	1.740	1,207
54	200,340	29,240	0.150	6,069
61	88	29	104.44	5,431
63	2,167	104	4.291	6,389
71	4,251	89	23.943	1,955

Table II-12. Basin No. 12 (Ohio) development objectives.

Strategies - Benefit Categories by Code Number*	Development Output Units of Long-term total Objectives@	Development Output Units of Five Year (1972-1976) Short-term Objectives	Long-term Regional Mean Values of Benefit per Unit of Development ($1000)	Total Benefit Values of Five Year (1972-1976) Short-term Objectives ($1000)
11	265	22	226.940	7,279
12	3,809	239	28.900	5,160
31	768	451	19.510	12,497
34	8,976	504	6.064	8,335
51	166,167	7,941	1.360	15,594
52	38,532	421	544	890
53	17,785	1,235	1.162	2,504
64	11,190	3,020	11.449	54,195

Table II-13. Basin No. 13 (Puerto Rico) development objectives.

Strategies - Benefit Categories by Code Number*	Development Output Units of Long-term total Objectives@	Development Output Units of Five Year (1972-1976) Short-term Objectives	Long-term Regional Mean Values of Benefit per Unit of Development ($1000)	Total Benefit Values of Five Year (1972-1976) Short-term Objectives ($1000)
11	4	2	938.360	2,825
12	18	5	413.160	15
31	50	29	28.436	759
52	20	9	1.495	7
61	1	0	524.59	320

Table II-14. Basin No. 14 (Rio Grande) development objectives.

Strategies - Benefit Categories by Code Number*	Development Output Units of Long-term total Objectives@	Development Output Units of Five Year (1972-1976) Short-term Objectives	Long-term Regional Mean Values of Benefit per Unit of Development ($1000)	Total Benefit Values of Five Year (1972-1976) Short-term Objectives ($1000)
11	14	10	436.000	348
31	23	2	19.259	148
51	4,228	193	0.435	173
52	423	60	3.117	54

Table II-15. Basin No. 15 (Souris-Red-Rainy) development objectives.

Strategies - Benefit Categories by Code Number*	Development Output Units of Long-term total Objectives@	Development Output Units of Five Year (1972-1976) Short-term Objectives	Long-term Regional Mean Values of Benefit per Unit of Development ($1000)	Total Benefit Values of Five Year (1972-1976) Short-term Objectives ($1000)
11	3	3	576.000	1,972
12	586	313	3.176	677
17	392	24	1.448	26
51	400	29	1.473	29
52	166	3	1.214	5
53	93	7	1.444	6

Table II-16. Basin No. 16 (South Atlantic-Gulf) development objectives.

Strategies - Benefit Categories by Code Number*	Development Output Units of Long-term total Objectives@	Development Output Units of Five Year (1972-1976) Short-term Objectives	Long-term Regional Mean Values of Benefit per Unit of Development ($1000)	Total Benefit Values of Five Year (1972-1976) Short-term Objectives ($1000)
11	176	22	113.820	2,435
12	3,439	865	5.168	1,088
19	142	174	34.230	2,049
31	1,522	770	4.068	2,291
34	1,276	370	4.639	1,903
51	323,651	30,493	1.149	23,580
52	5,375	1,149	1.384	1,955
53	11,270	205	1.596	141
54	73,585	6,761	0.121	129
61	18	18	459.200	8,323
64	1,521	50	8.287	720
71	300	300	22.658	7,339

Table II-17. Basin No. 17 (Texas-Gulf) development objectives.

Strategies - Benefit Categories by Code Number*	Development Output Units of Long-term total Objectives@	Development Output Units of Five Year (1972-1976) Short-term Objectives	Long-term Regional Mean Values of Benefit per Unit of Development ($1000)	Total Benefit Values of Five Year (1972-1976) Short-term Objectives ($1000)
11	76	42	244.040	3,976
12	5,576	107	11.323	782
17	268	6	3.927	131
31	455	184	12.326	5,611
34	88	65	9.816	637
41	5,000	2,554	.164	430
51	261,028	4,247	.557	7,342
52	14,740	2,022	1.032	5,929
61	29	4	186.220	3,681
64	3,526	61	4.554	1,634

Table II-18. Basin No. 18 (Upper Mississippi) development objectives.

Strategies - Benefit Categories by Code Number*	Development Output Units of Long-term total Objectives@	Development Output Units of Five Year (1972-1976) Short-term Objectives	Long-term Regional Mean Values of Benefit per Unit of Development ($1000)	Total Benefit Values of Five Year (1972-1976) Short-term Objectives ($1000)
11	12	10	510.22	6,045
12	640	266	23.441	7,119
51	136,714	8,422	.812	4,408
52	43,155	1,035	1.399	1,479
64	11,988	54	1.739	14,414
67	21	3	147.62	2,847

APPENDIX III

UTILITY NUMBER OF STRATEGY (UNS) UNDER EACH EVALUATION CRITERION

*The benefit categories corresponding to the code numbers indicated here are shown in Appendix I.

Table III-0. National utility number of strategy (UNS) under each evaluation criterion.

Strategies - Benefit Categories by Code Number*	EVALUATION CRITERION: Long-term total objective in monetary term ($1000)	Five year (1972-1976) Short-term objective in monetary term ($1000)	Percent of Effectiveness Measurement	Percent of Needs met Measurements
11	751,137	74,508	19.0	9.9
12	629,988	35,329	12.8	5.6
17	21,863	2,707	4.8	12.4
19	18,170	7,613	40.1	41.9
25	1,377	239	30.4	17.4
26	42,001	3,543	13.2	8.4
31	78,756	34,836	35.5	44.2
32	117,022	6,066	2.0	5.2
34	174,403	42,022	21.8	24.1
41	52,491	8,033	10.2	15.3
51	1,463,435	118,340	11.7	8.1
52	192,349	17,040	6.1	8.9
53	166,152	5,419	3.6	3.3
54	130,963	11,724	11.4	9.0
61	74,471	19,623	7.9	26.4
63	123,272	8,945	5.4	7.3
64	315,253	77,309	11.6	24.5
67	3,100	2,847	11.9	91.8
71	350,551	51,255	16.7	14.6
72	113,835	11,959	14.2	10.5

Table III-1. Basin No. 1 (Alaska) utility number of strategy (UNS) under each evaluation criterion.

Strategies -Benefit Categories by Code Number*	EVALUATION CRITERION			
	Long-term Total Objective in Monetary Term ($1000)	Five year (1972-1976) Short-term Objective in Monetary Term ($1000)	Percent of Effectiveness Measurement	Percent of Needs Met Measurements
11	18,522	8,482	42.9	45.8
41	30,260	2,241	5.7	7.4
51	287	256	25.9	89.3
52	1,129	36	3.0	3.2
53	3,292	11	0.3	0.3
63	69,813	265	8.6	0.4
64	8,288	192	0.5	2.3

Table III-2. Basin No. 2 (Arkansas-White-Red) utility number of strategy (UNS) under each evaluation criterion.

	EVALUATION CRITERION			
Strategies - Benefit Categories by Code Number*	Long-term Total Objective in Monetary Term ($1000)	Five Year (1972-1976) Short-term Objective in Monetary Term ($1000)	Percent of Effectiveness Measurement	Percent of Needs Met Measurements
11	11,336	3,758	132.6	33.2
12	56,297	7,503	32.9	13.2
17	2,095	598	25.1	28.5
31	16,816	2,508	13.3	14.9
32	8,162	1,551	15.5	19.0
34	30,051	19,476	74.9	64.8
41	101	35	58.0	34.7
51	44,501	4,434	11.1	10.0
52	2,152	943	54.1	43.8
53	5,178	96	1.5	1.9
71	68,686	1,411	2.4	2.1

Table III-3. Basin No. 3 (California) utility number of strategy (UNS) under each evaluation criterion.

Strategies - Benefit Categories by Code Number*	EVALUATION CRITERION: Long-term Total Objective in Monetary Term ($1000)	Five Year (1972-1976) Short-term Objective in Monetary Term ($1000)	Percent of Effectiveness Measurement	Percent of Needs Met Measurements
11	298,955	4,570	10.3	1.5
12	92,381	1,712	7.9	1.9
19	1,606	134	3.3	8.3
31	4,862	1,358	70.5	27.9
32	15,871	3,298	13.2	20.8
41	5,607	57	0.7	1.0
51	68,482	3,553	2.6	5.2
52	9,097	488	1.8	5.4
53	8,524	816	3.3	9.6
54	49,430	786	1.7	1.6
71	1,808	1,808	100.0	100.0

Table III-4. Basin No. 4 (Colorado) utility number of strategy (UNS) under each evaluation criterion.

	EVALUATION CRITERION			
Strategies - Benefit Categories by Code Number*	Long-term Total Objective in Monetary Term ($1000)	Five Year (1972-1976) Short-term Objective in Monetary Term ($1000)	Percent of Effectiveness Measurement	Percent of Needs Met Measurements
11	22,028	763	6.2	3.5
12	69,961	219	1.0	0.3
32	8,084	995	12.4	12.3

Table III-5. Basin No. 5 (Columbia-North Pacific) utility number of strategy (UNS) under each evaluation criterion.

Strategies - Benefit Categories by Code Number*	EVALUATION CRITERION Long-term Total Objective in Monetary Term ($1000)	Five Year (1972-1976) Short-term Objective in Monetary Term ($1000)	Percent of Effectiveness Measurement	Percent of Needs Met Measurements
11	29,432	988	7.5	3.4
12	24,920	3,445	15.8	13.8
17	2,573	10	0.6	0.4
19	3,041	299	5.6	9.8
51	105,839	396	0.3	0.4
52	22,220	250	1.2	1.1
54	5,807	145	4.8	2.5
64	25,160	1,094	0.5	4.3
71	79,915	38,742	47.3	44.5
72	18,787	11,959	55.0	63.7

Table III-6. Basin No. 6 (Great Basin) utility number of strategy (UNS) under each evaluation criterion.

	EVALUATION CRITERION			
Strategies - Benefit Categories by Code Number*	Long-term Total Objective in Monetary Term ($1000)	Five Year (1972-1976) Short-term Objective in Monetary Term ($1000)	Percent of Effectiveness Measurement	Percent of Needs Met Measurements
11	12,183	1,237	33.8	10.2
12	498	53	7.5	10.6
31	7,056	717	9.5	10.2
51	11,252	790	6.9	7.0
52	1,962	40	1.9	2.0
53	1,081	130	9.0	12.0

Table III-7. Basin No. 7 (Great Lakes) utility number of strategy (UNS) under each evaluation criterion.

Strategies - Benefit Categories by Code Number*	EVALUATION CRITERION			
	Long-term Total Objective in Monetary Term ($1000)	Five Year (1972-1976) Short-term Objective in Monetary Term ($1000)	Percent of Effectiveness Measurement	Percent of Needs Met Measurements
11	19,838	3,512	47.8	17.7
12	1,797	9	2.4	0.5
19	859	340	12.0	39.6
31	2,301	103	7.9	4.5
34	23,403	318	4.4	1.4
41	235	146	53.6	62.3
51	129,201	4,088	3.7	3.2
52	22,378	1,503	7.7	6.7
53	39,568	204	6.2	0.5
54	2,598	2,589	53.8	99.2
61	1,140	1,131	20.3	99.2

Table III-8. Basin No. 8 (Hawaii) utility number of strategy (UNS) under each evaluation criterion.

	EVALUATION CRITERION			
Strategies - Benefit Categories by Code Number*	Long-term Total Objective in Monetary Term ($1000)	Five Year (1972-1976) Short-term Objective in Monetary Term ($1000)	Percent of Effectiveness Measurement	Percent of Needs Met Measurements
11	2,565	436	5.6	17
51	21,682	333	2.0	1.5
53	261	256	89.1	98.2
54	1,708	1,242	80.4	72.7
61	792	737	40.5	93.1

Table III-9. Basin No. 9 (Lower Mississippi) utility number of strategy (UNS) under each evaluation criterion.

Strategies - Benefit Categories by Code Number*	EVALUATION CRITERION: Long-term Total Objective in Monetary Term ($1000)	Five Year (1972-1976) Short-term Objective in Monetary Term ($1000)	Percent of Effectiveness Measurement	Percent of Needs Met Measurements
12	14,128	158	9.7	1.1
17	10,321	1,941	5.5	18.8
25	1,377	239	30.4	17.4
26	42,001	3,543	13.2	8.4
31	3,057	139	13.6	4.5
32	2,067	222	10.4	10.7
34	687	322	42.6	46.9
51	60,685	350	0.8	0.6
52	4,131	620	8.3	15.0
63	6,906	2,291	40.8	33.2
64	6,218	4,996	104.9	80.2

Table III-10. Basin No. 10 (Missouri) utility number of strategy (UNS) under each evaluation criterion.

Strategies - Benefit Categories by Code Number*	EVALUATION CRITERION Long-term Total Objective in Monetary Term ($1000)	Five Year (1972-1976) Short-term Objective in Monetary Term ($1000)	Percent of Effectiveness Measurement	Percnet of Needs Met Measurements
11	27,818	6,577	73.0	23.6
12	21,488	3,703	30.9	17.2
31	720	586	39.7	81.4
34	11,276	1,102	16.9	21.6
51	20,064	5,130	34.8	25.6
52	3,988	1,449	37.9	36.3

Table III-11. Basin No. 11 (North Atlantic) utility number of strategy (UNS) under each evaluation criterion.

Strategies - Benefit Categories by Code Number*	EVALUATION CRITERION Long-term Total Objective in Monetary Term ($1000)	Five Year (1972-1976) Short-term Objective in Monetary Term ($1000)	Percent of Effectiveness Measurement	Percent of Needs Met Measurements
11	172,732	13,817	12.3	8.2
12	127,435	2,766	2.0	2.2
19	5,441	4,707	57.3	86.5
31	11,589	6,212	38.9	53.6
34	41,212	8,804	13.1	21.4
41	3,948	2,143	38.2	54.3
51	142.270	45,334	41.6	31.9
52	1,339	1,339	4.9	8.0
53	49,116	1,207	0.8	2.5
54	30,051	6,069	14.6	20.2
61	9,223	5,431	33.1	58.9
63	9,298	6,389	4.8	68.7
71	101,777	1,955	2.1	1.9

Table III-12. Basin No. 12 (Ohio) utility number of strategy (UNS) under each evaluation criterion.

EVALUATION CRITERION

Strategies - Benefit Categories by Code Number*	Long-term Total Objective in Monetary Term ($1000)	Five Year (1972-1976) Short-term Objective in Monetary Term ($1000)	Percent of Effectiveness Measurement	Percent of Needs Met Measurements
11	60,107	7,279	8.2	12.1
12	110,067	5,160	6.3	4.7
31	14,976	12,497	58.8	83.4
34	54,432	8,335	5.6	15.3
51	225,987	15,594	4.8	6.9
52	20,961	890	1.1	4.2
53	20,666	2,504	6.9	12.1
64	128,114	54,195	27.0	42.3

Table III-13. Basin No. 13 (Puerto Rico) utility number of strategy (UNS) under each evaluation criterion.

Strategies - Benefit Categories by Code Number*	EVALUATION CRITERION			
	Long-term Total Objective in Monetary Term ($1000)	Five Year (1972-1976) Short-term Objective in Monetary Term ($1000)	Percent of Effectiveness Measurement	Percent of Needs Met Measurements
11	3,554	2,825	50.0	79.5
12	7,272	15	26.1	0.2
31	1,422	759	58.0	53.4
52	31	7	44.9	22.8
61	687	320	5.3	46.6

Table III-14. Basin No. 14 (Rio Grande) utility number of strategy (UNS) under each evaluation criterion.

	EVALUATION CRITERION			
Strategies - Benefit Categories by Code Number*	Long-term Total Objective in Monetary Term ($1000)	Five Year (1972-1976) Short-term Objective in Monetary Term ($1000)	Percent of Effectiveness Measurement	Percent of Needs Met Measurements
11	5,899	348	73.2	5.9
31	435	148	8.4	33.8
51	1,839	173	4.6	9.4
52	1,318	54	14.2	4.1

Table III-15. Basin No. 15 (Souris-Red-Rainy) utility number of strategy (UNS) under each evaluation criterion.

	EVALUATION CRITERION			
Strategies -Benefit Categories by Code Number*	Long-term Total Objective in Monetary Term ($1000)	Five-Year (1972-1976) Short-term Objective in Monetary Term ($1000)	Percent of Effectiveness Measurement	Percent of Needs Met Measurements
11	2,004	1,972	77.6	98.4
12	1,861	677	53.5	36.4
17	568	26	6.2	4.7
51	589	29	7.2	4.9
52	201	5	2.1	2.7
53	135	6	7.5	4.7

Table III-16. Basin No. 16 (South Atlantic-Gulf) utility of strategy (UNS) under each evaluation criterion.

Strategies - Benefit Categories by Code Number*	EVALUATION CRITERION			
	Long-term Total Objective in Monetary Term ($1000)	Five Year (1972-1976) Short-term Objective in Monetary Term ($1000)	Percent of Effectiveness Measurement	Percent of Needs Met Measurements
11	20,089	2,435	12.7	12.1
12	17,773	1,088	25.1	6.1
19	4,861	2,049	122.5	42.2
31	6,191	2,291	50.6	37
34	5,919	1,903	29	32
51	371,875	23,580	9.4	6.3
52	7,439	1,955	21.4	26.3
53	17,987	141	1.8	0.8
54	8,904	129	9.2	1.5
61	8,312	8,323	99.4	100.1
64	12,608	720	3.3	5.7
71	6,797	7,339	100.0	108.0

Table III-17. Basin No. 17 (Texas-Gulf) utility number of strategy (UNS) under each evaluation criterion.

	EVALUATION CRITERION			
Strategies - Benefit Categories by Code Number*	Long-term Total Objective in Monetary Term ($1000)	Five Year (1972-1976) Short-term Objective in Monetary Term ($1000)	Percent of Effectiveness Measurement	Percent of Needs Met Measurements
11	18,571	3,976	55.6	21.4
12	3,142	782	1.9	1.2
17	1,052	131	2.2	12.4
31	5,614	5,611	40.4	99.9
34	859	637	74.3	74.2
41	820	430	51.1	52.4
51	145,393	7,342	1.6	5.0
52	15,212	5,929	13.7	39
61	5,400	3,681	13.4	68.2
64	16,058	1,634	1.7	10.2

Table III-18. Basin No. 18 (Upper Mississippi) utility number of strategy (UNS) under each evaluation criterion.

	EVALUATION CRITERION			
Strategies - Benefit Categories by Code Number*	Long-term Total Objective in Monetary Term ($1000)	Five Year (1972-1976) Short-term Objective in Monetary Term ($1000)	Percent of Effectiveness Measurement	Percent of Needs Met Measurements
11	6,046	6,045	86	100
12	15,012	7,119	41.6	47.4
51	111,012	4,408	6.2	4.0
52	60,374	1,479	2.4	2.5
64	20,847	14,414	.4	69.1
67	3,100	2,847	11.9	91.8

APPENDIX IV

BUDGET ALLOCATION MODEL

APPENDIX IV

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. 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

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

subject to

$$\sum_i \sum_j X_{ij} C_{ij} \leq B \quad (2)$$

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

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

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.

Summary

The diagram shown in Fig. IV-1 indicates how the basin level model is operated. From Fig. IV-1, 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 for each benefit category in each basin 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 by 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

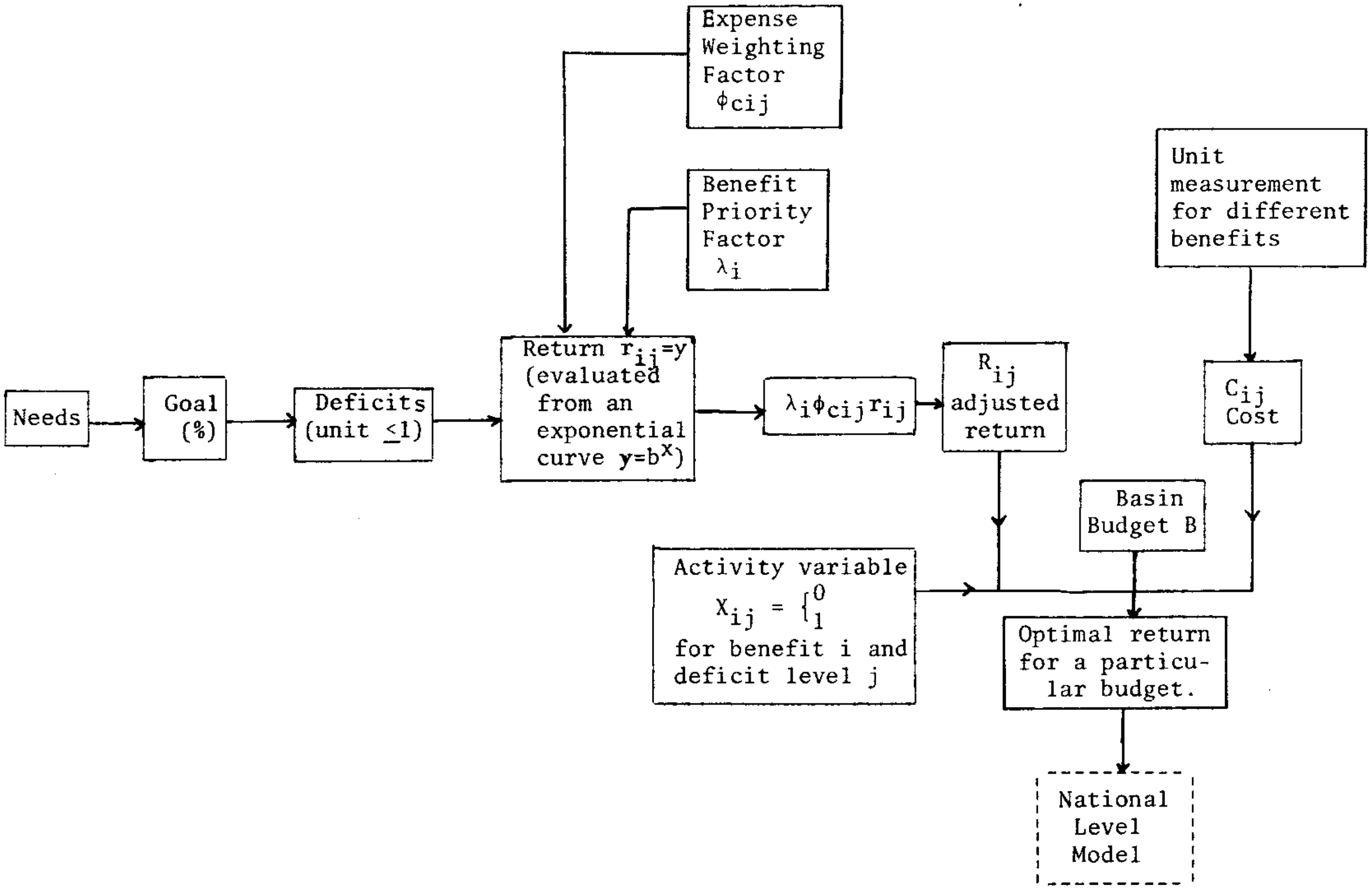

Figure IV-1. Operation of Basin Level Model

model. Solutions from the basin model will be used as inputs for the national 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 are replaced by the basins.

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, Eq. (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, Eq. (3) indicates one return must be chosen for each basin; and constraint three, Eq. (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, Eq. (1), will assume that returns from each basin are the optimal minimum.

Summary

Compared to the basin level model, the national level model is relatively simple. Figure IV-2 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

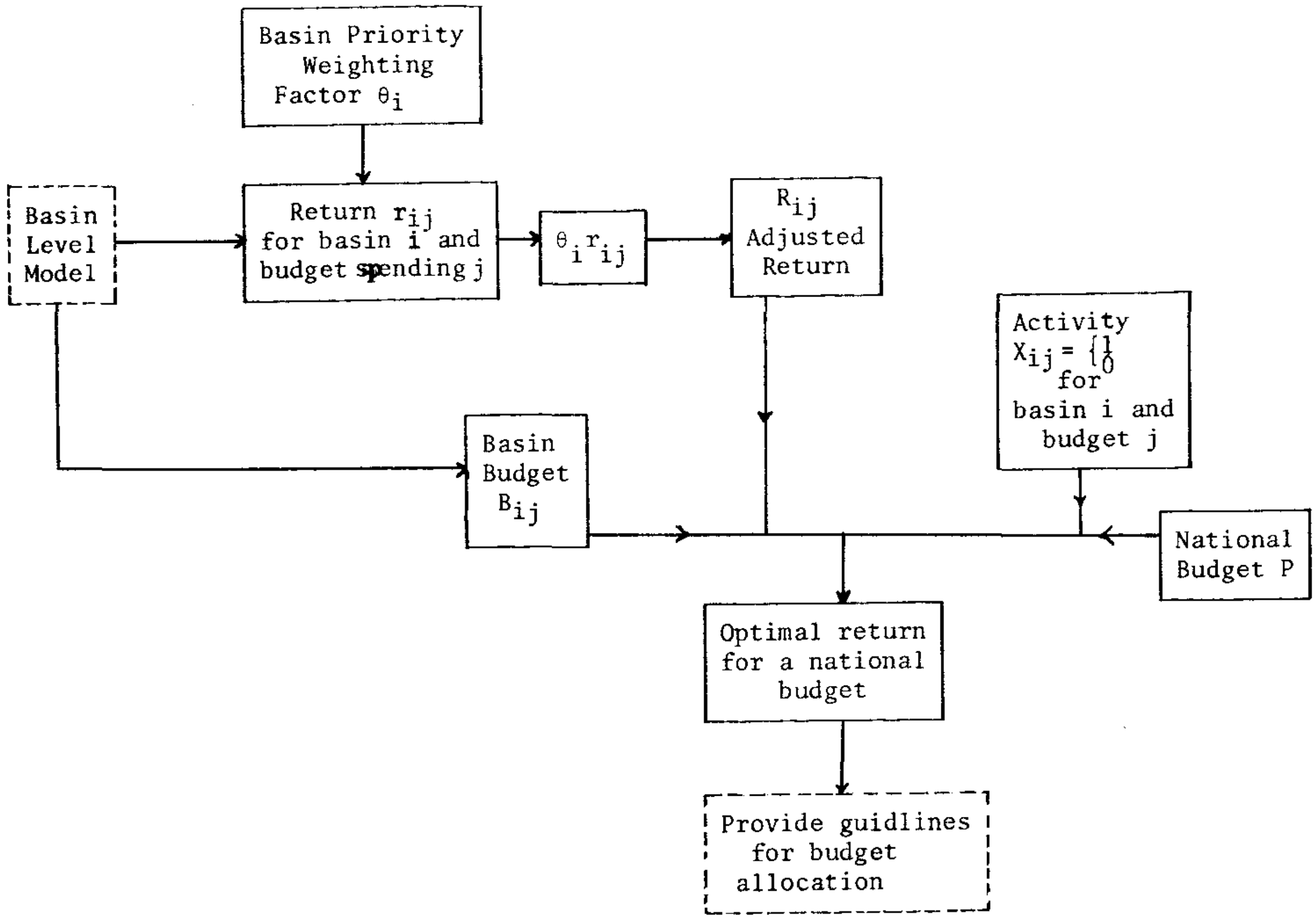

Figure IV-2. Operation of National Level Model of minimum returns associated with a corresponding basin budget. This can be used to show how a certain national budget can be distributed among different basins more effectively with all of the basins being considered simultaneously (i.e., all of the basins are more closely interrelated).

Conclusion

Figure IV-3 shows how the whole model operates. First, in the basin level model the projected needs for each basin according to benefit categories are converted into deficits 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.

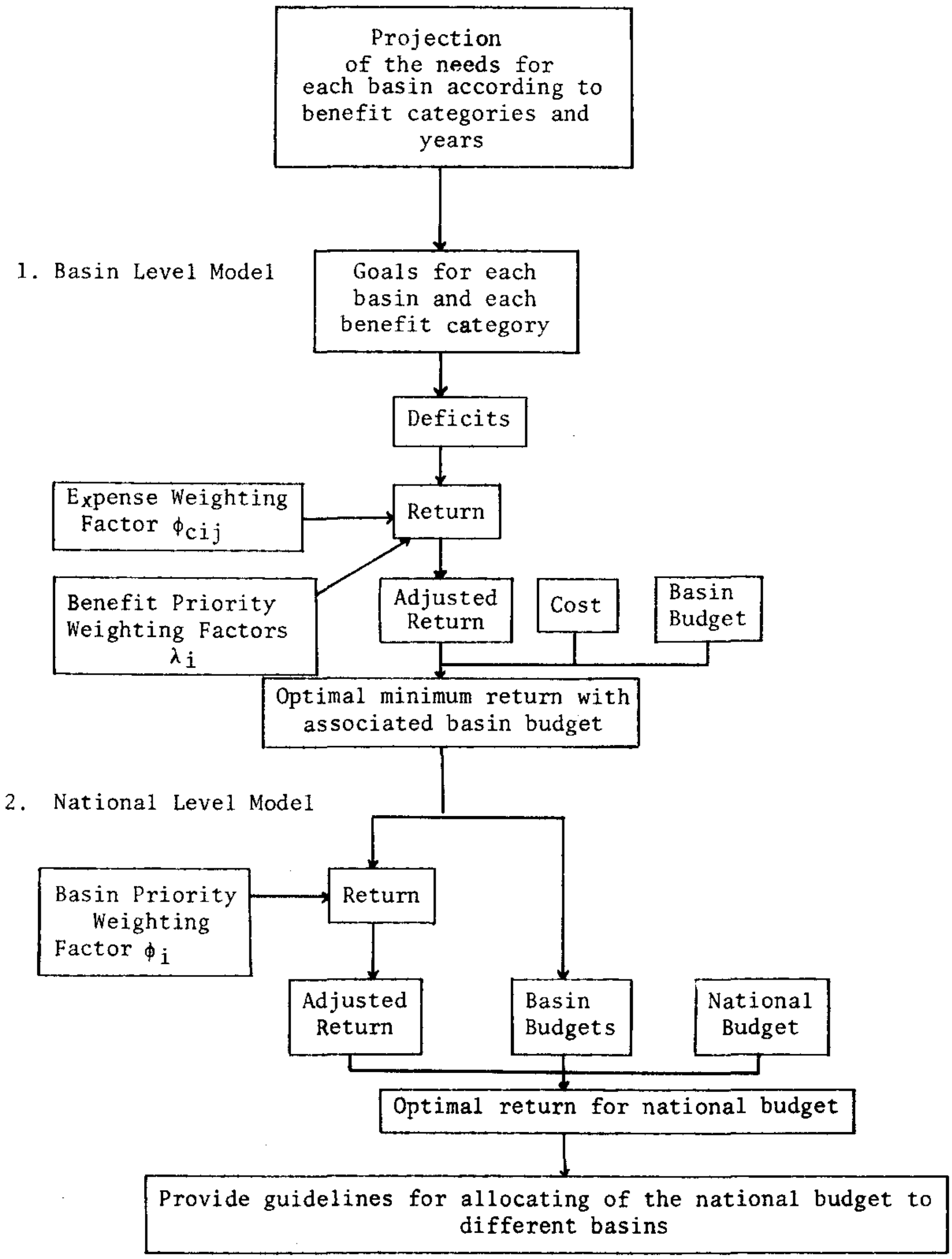

Figure IV-3. Operation of the budget allocation model.