IDENTIFICATION OF ROBUST WATER RESOURCES
PLANNING STRATEGIES

by

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ABSTRACT

This thesis presents a two-objective method for water resources planning. One of the objectives is to maximize expected net benefits, and the other is to maximize robustness. In this thesis, robustness is considered a measure of the sensitivity of the projects performance to uncertain conditions. An index of robustness is developed. The index is based on the variation of net benefits from a project as consequence of the uncertainty in determining the parameters of water resources systems.

The two-objective problem is solved by obtaining the Pareto curve, which represents the set of non-inferior projects. The method uses screening models as the optimization technique.

To prove the practical viability of the method, it is applied to a case study. The case study consists in select from all possible projects to be built in a hypothetical basin, those that represent the best development alternative.

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I want to dedicate
this thesis to my
friend Aurelio.

IDENTIFICATION OF ROBUST WATER RESOURCES PLANNING STRATEGIES

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IDENTIFICATION OF ROBUST WATER RESOURCES PLANNING STRATEGIES

CHAPTER 1: INTRODUCTION

This thesis deals with water resources planning and, in particular, with a method for developing robust planning strategies. Through a literature review, I have realized that water resources planning has a different meaning for engineers than for planners. Engineers generally consider water resources planning as a series of mathematical techniques and optimization models. Engineers often group these techniques under the generic name of system analysis. For engineers new planning methods mean improvement of the mathematical techniques, perhaps at the sacrifice of decision-making needs. On the other hand, planners consider water resources institutions, objectives, decision making processes, and other social and economical issues. But planners do not usually use analytical tools to introduce their concerns into a practical analysis. This thesis should be considered as an effort for narrowing the gap between theory and practice, between engineers and planners.

The main objective in traditional water resources planning is to maximize expected net benefits. With this single criterion, the project or system of projects chosen for implementation is the one that will generate more net benefits. But most water resources planning situations are subject to some degree of uncertainty. The actual construction of the project begins years after the plan was completed. In that time interval, some variables may change from the planning forecasts. Hence, the actual net benefits from the project may differ from the predicted net benefits.

As a consequence of uncertainty, there is a distribution of possible net benefits to obtain from a project. Robustness is a measure of the dispersion of that distribution of possible net benefits. If the distribution of net benefits is widely spread, the project is considered non robust, because net benefits depend heavily on the uncertain conditions. In other words, non robust projects are those whose performance depend on the value that uncertain variables happen to take. Robust projects, on the other hand, are those which are able to maintain relatively constant net benefits under a range of conditions.

Since uncertainty is almost always present in water resources planning, robustness is a desirable characteristic of a project, because it indicates relative guarantee of net benefits from the project. Another desirable characteristic of a project is to produce as much net benefits as possible. In most water resources systems, however, the most robust project is not the one which produces the greatest net benefits. There exists a tradeoff between robustness and net benefits: those projects with the greatest robustness are those with lowest expected net benefits and vice versa.

The central topic of this thesis is to introduce a new decision making method for water resources planning. The method does not represent a mathematical advance, but the modification of existing planning practices to provide decision makers' information needs. The method evaluates the robustness and expected net benefits of the projects and ends up with a two-objective problem.

1.1.- OVERVIEW OF A MULTIOBJECTIVE METHOD FOR CONSIDERING ROBUSTNESS

The multiobjective decision-making method propose in this thesis is intended to be applied to screening models. A screening model is an optimization technique which identifies from all possible projects that could be built in the basin, the set of projects that would generate the optimal value of an objective function. The traditional solution to screening problems comes from the use of an optimization algorithm, mostly linear programming. A single optimal alternative is identified with respect to an unique objective function: maximization of benefits minus costs. The incorporation of robustness into the decision process improves traditional screening models, because it allows uncertainty to be considered and provides a two-objective (robustness and expected net benefits) tradeoff graph.

This thesis considers both robustness and expected net benefits to be important criteria for final project choice. Suppose that we are able to identify several alternative projects which have great robustness or great expected net benefits or, even better, both. These projects are called candidate alternatives. To consider candidate alternatives implies that no single optimal alternative exists. In fact, for a single optimal alternative to exist, it should have the greatest robustness and the greatest expected net benefits. Such an alternative is highly unlikely in two-objective decision problems. Therefore, we need to compare among candidate alternatives, one of which will be the final choice. Comparisons are made by using a two-objective tradeoff curve. The tradeoff curve, also called the Pareto curve, is obtained by plotting the points corresponding to the candidate alternatives. Figure 1-1 shows three points of this curve. Alternative A has the greatest expected net benefits, but the lowest robustness. Alternative C has the greatest robustness, but the lowest expected net benefits. Alternative B has neither the greatest robustness nor the greatest expected net benefits. However, if this graph were presented to a decision makers, the probable chosen alternative would be B, because it has almost as great robustness as C, and almost as great expected net benefits as A.

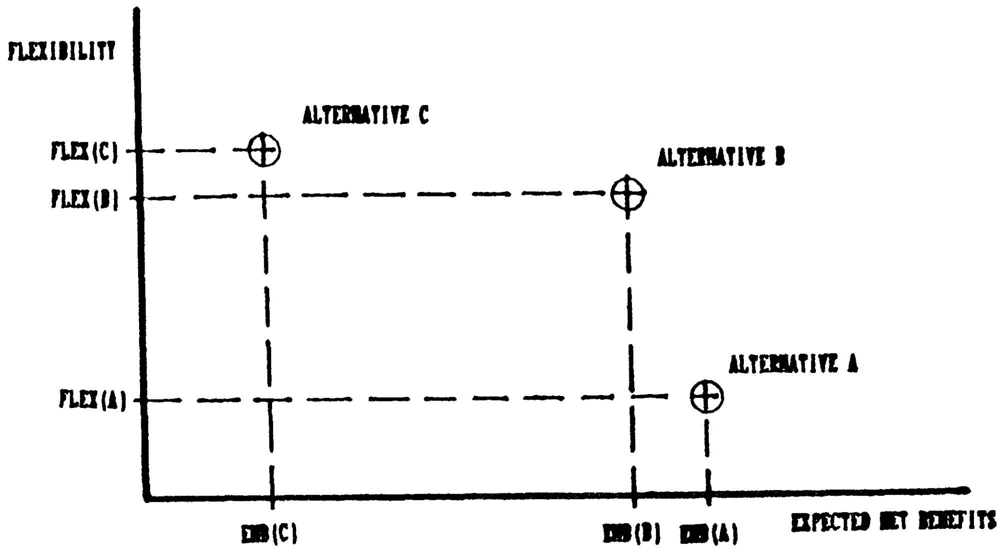

FIGURE 1-1: *Two-objective tradeoff curve for Alternatives A, B, and C*

The Pareto or tradeoff curve is the final result of the two-objective analysis. But before obtaining the Pareto curve, two values for every candidate alternative must be calculated. The first value is the expected net benefits of the given alternative. Cost-benefit techniques are widely used to calculate this value. The second value is the robustness of the given alternative. I have not found any practical formulation of robustness in the literature. Therefore, as a prior stage to obtain the Pareto curve, I had to develop a method to measure robustness in water resources projects.

Robustness may be evaluated by assessing the <u>potential</u> of the basin to produce net benefits under uncertain conditions. The potential of the basin is the expected net benefits obtained from an ideal project which is always able to exploit all hydraulic resources that the basin has. When conditions are favorable (for example, if crop prices are greater that what was forecasted) the potential of the basin is greater (i.e. more benefits can be obtained from the irrigation projects in the basin). However, if conditions are unfavorable (for example, if crop prices drop) the potential of the basin decreases. Figure 1-2 shows the potential or maximum net benefits of a basin assuming only irrigation projects and uncertainty in crop prices.

The upper curve shows the potential of the basin in the form of the distribution of expected net benefits as a function of crop price. The lower curve shows the uncertainty

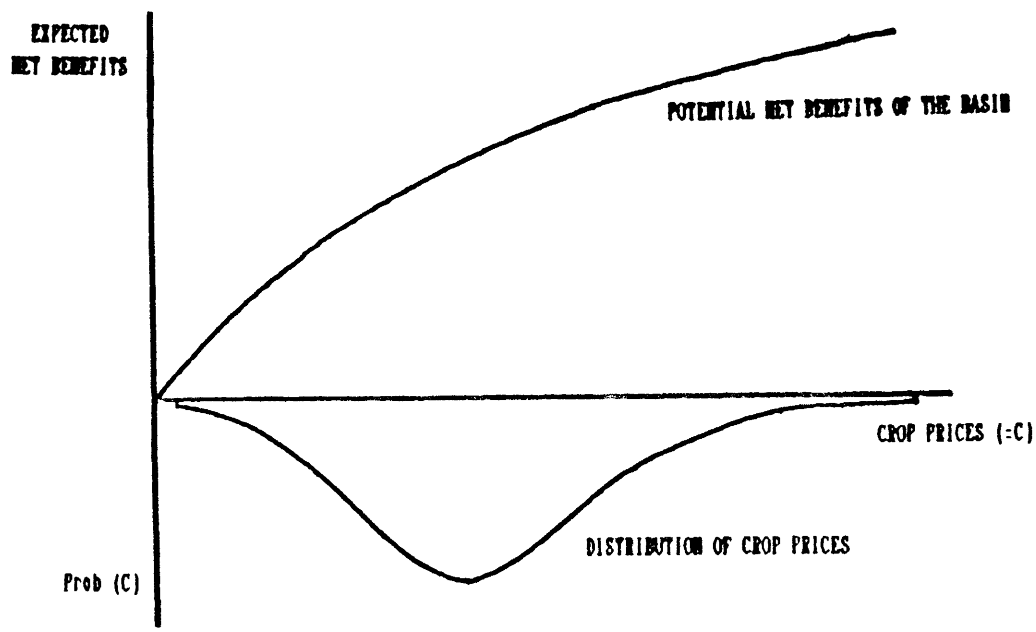

FIGURE 1-2: *Potential of a basin used for irrigation under uncertain crop prices*

in crop prices, represented by its probability distribution curve. We see that the potential of the basin increases as crop prices increases, but we also see that the probability that crop prices take these high values is small. Therefore, the probability that the basin has these high potentials is small, because it is unlikely that crop prices will be that high. In this thesis, the potential of the basin is called Ideal Net Benefits Curve, and its importance as reference curve for evaluating robustness of the alternatives is discussed below.

Robustness of a project has been defined as a measure of the variation in the distribution of possible net benefits as consequence of uncertainty. Variation of project net benefits has to be measured with respect to something. The most appropriate reference is the potential of the basin to produce net benefits. With any other reference, the measure of the variation of net benefits is misleading as a measure of robustness of projects. If we do not take the potential of the basin as reference, robust projects would be those which give the same net benefits under any condition, ignoring that certain conditions may in fact be favorable and better performance should be expected from the project. As a result, the most robust project would be to build nothing, which yields exactly the same net benefits for any conditions: zero.

The net benefits of a given alternative to be built in that basin depends also on the uncertainty of the variables.

For example, net benefits of an Alternative A depend on crop prices, as shown in Figure 1-3. When crop prices are lower than P_1, Alternative A yields negative net benefits. In other words, the agricultural costs are greater than the benefits from selling the agricultural products at price P_1.

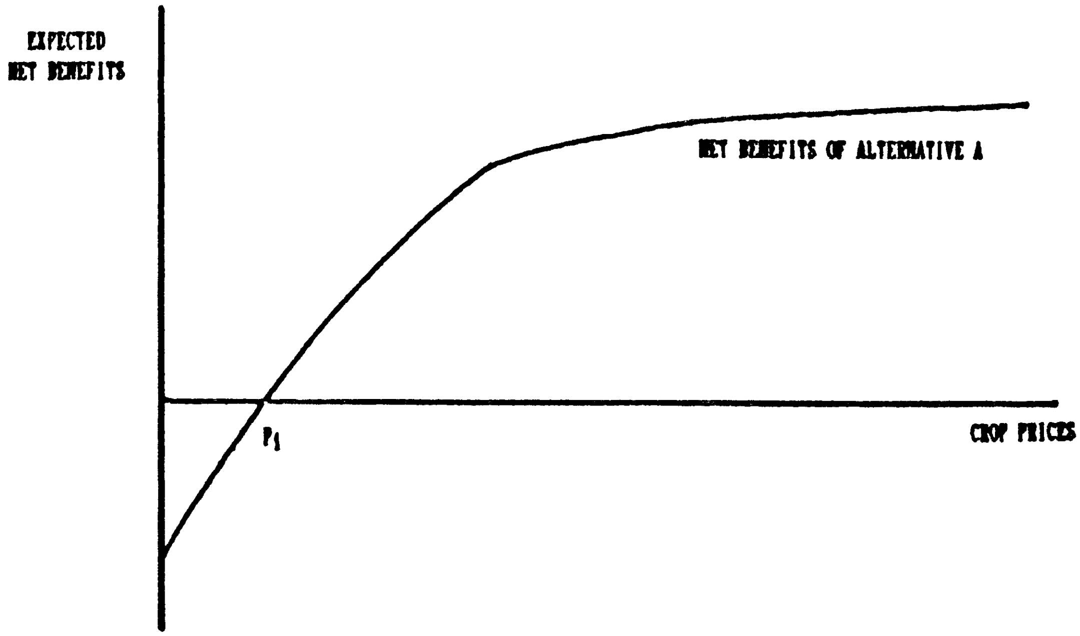

FIGURE 1-3: *Net benefits of an Alternative A under uncertain crop prices*

Comparison of Figure 1-2 (potential of the basin) and Figure 1-3 (net benefits of Alternative A) indicates how far Alternative A is from realizing the full potential of the basin. We define the difference between the two curves to be the "Delta Curve" for Alternative A (see Figure 1-4). Delta curves are important because the robustness of an alternative is directly related to the shape of its delta curve. Compare two delta curves, for Alternative A and for Alternative C

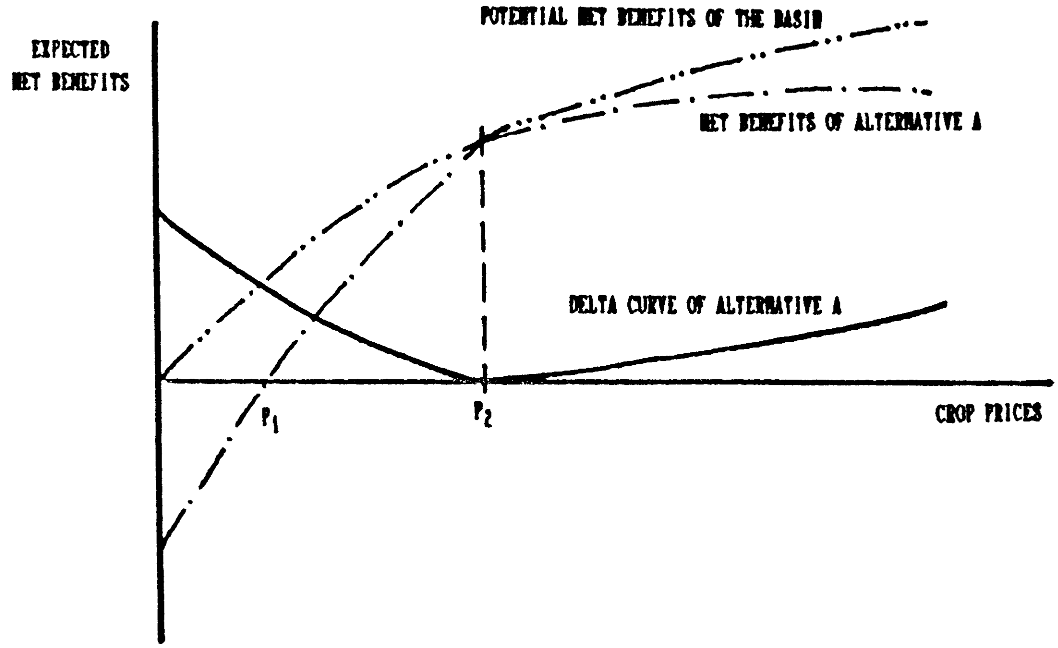

FIGURE 1-4: *Delta curve of an Alternative A*

(Figure 1-5). The curve for Alternative C is almost horizontal. This shows that the net benefits from Alternative C are relatively independent of crop price. However, the net benefits from Alternative A depend strongly on the crop prices. For crop price P_2, Alternative A achieves the full potential of the basin, but for any other crop price, Alternative A is increasingly less attractive. We may conclude that Alternatives B and C are more robust than Alternative A.

Although the assessment and study of robustness is an original contribution of this thesis, it is not a sufficient criterion for decision making. Consider two alternatives whose delta curves were shown in Figure 1-5. Alternative C is more robust than Alternative A. But Alternative A is much closer

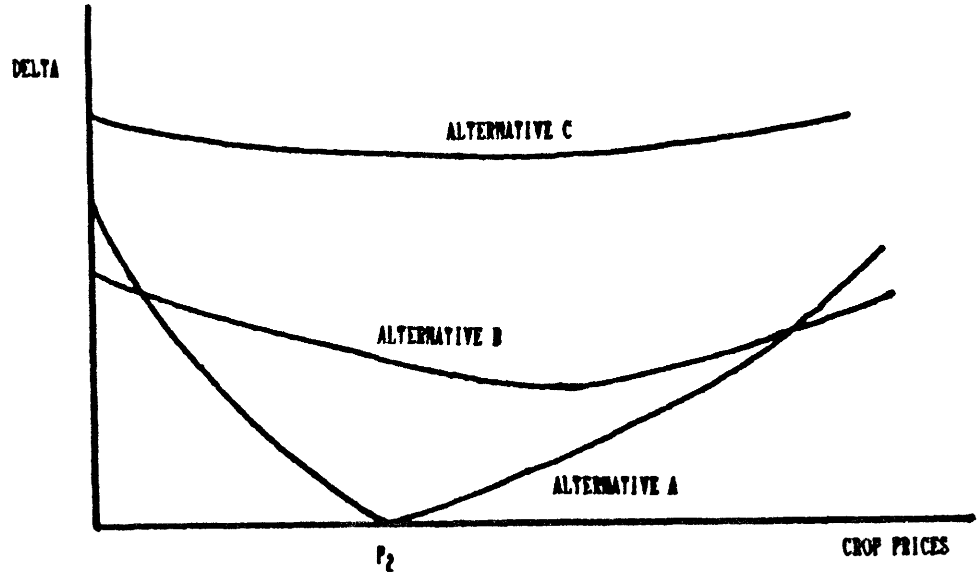

FIGURE 1-5: *Comparison of three delta curves, for Alternatives A, B, and C*

than Alternative C to reaching the potential of the basin for any crop price. In other words, although A is less robust than C, A always produces more net benefits than C. There is, therefore, the need to consider robustness along with expected net benefits as in the Pareto tradeoff curve in Figure 1-1.

1.2.- ORGANIZATION OF THE THESIS

Chapter 2 serves as an introduction to the current water resources planning methods, called system analysis techniques. The first part of the chapter reviews the existing planning techniques and discusses their current use in real planning situations. There are some institutional problems that reduce the utility of system analysis techniques. Part of the problem is that these techniques do not completely respond to decision making information needs. Four improvements to traditional system analysis techniques are analyzed in the second part of the chapter: (1) multiobjective analysis, (2) identification of nearly optimal alternatives, (3) stochastic planning, and (4) the use of performance indices.

Chapter 3 introduces the concept of robustness in water resources planning. My concern with robustness is a consequence of the presence of uncertainty in water resources variables and parameters. An index of robustness is formulated based in the distribution of projects' outcomes as consequence of uncertainty. Also in this Chapter, I describe a step-by-step method for identifying the robustness-net benefits tradeoff curve based in a screening analysis.

In Chapter 4, the general approach of Chapter 3 is used in a specific hypothetical water resources planning application. This case is concerned with deciding the most appropriate set of projects to be implemented in a basin. Possible projects are dams, irrigation areas, hydropower plants, and an intrabasin transfer. The case study is fully solved, and tables and computer outputs are accompanied in three appendixes.

Chapter 5 summarizes the importance of robustness in water resource systems, and comments on the improvements that the method represents to traditional screening models. Some limitations of the robustness method and possible improvements are also discussed.

CHAPTER 2: LITERATURE REVIEW

The design of a water resources planning system is complex enough to require the development of mathematical techniques for the analysis. Variables describing the system and their relationships can be represented through mathematical equations, forming what is called a model. Models can be used to predict the response of the system and to evaluate the benefits derived from water resource project.

Some degree of formal and objective evaluation method is always present in water resources planning. Therefore most planning use some mathematical techniques for modeling, analysis, or solution. There are given many names: operations research, management science, system engineering, etc. The most standardized name in water resources planning is system analysis. This section summarizes system analysis techniques used in water resources planning and comments on their use in actual planning situations.

Of course, not all issues of interest to the planner are reducible to mathematical form, nor are all water resource systems fully understood, or easy to identify, describe, and model. In water resources there are many other social, political, economical, and institutional factors which can only partially be introduced in formal models. Concern is found in the literature to adapt existing system analysis techniques and to devise new ones which, rather than search for optimal designs, provide help to decision makers. New methods in water resources planning, such as multiobjective analysis, identification of nearly optimal alternatives, and stochastic planning, do not end up with the optimal system but provide information on the alternatives for the decision-making process. Since the decision-making oriented approach to planning is a central issue in this thesis, these techniques will be extensively considered later in this chapter.

2.1.- CURRENT METHODS IN WATER RESOURCES PLANNING

Friedman et al. [1984] review models and techniques currently used in water related problems. Rogers [1979] and Rogers and Fiering [1986] describe a study which is similar but limited to problems which involve some optimization.

Following Rogers and Fiering [1986], there are five main groups of system analysis techniques: (1) Analytical optimization models and techniques, (2) Simulation combined with search and sampling techniques, (3) Probabilistic models and techniques, (4) Statistical techniques, and (5) Other related techniques (cost-benefit analysis, input-output analysis, and game theory). The first two are the most used system analysis techniques and the only ones that are discussed here.

2.1.1.- Optimization models and techniques.

Optimization models are a widely spread water resources planning technique [Rogers, 1979]. They are formed by decision variables, parameters, objective function, and constraints.

Decision Variables. Variables define the configuration and operation of the system which is being optimized. Their value provide the solution to the problem. For example, when trying to obtain the best reservoir size, the main variable is the volume of the reservoir.

Parameters. Parameters describe the fixed properties of the system to be modeled. Parameters are independent and their values do not vary during one particular run of the model. However parameters which are not well known, or which are likely to change during the life of the project (i.e. water prices and demands) can be frequently varied in independent runs creating sensitivity analysis.

Objective function. The objective function is a quantitative measure of the main objective of the projects. The most common objective function is the mathematical relationship of decision variables and parameters that describes the benefits minus costs from the project.

Constraints. Constraints are the relationships among parameters and variables that describe the system operation and characteristics. Normally constraints are mathematical equations in form of equalities, inequalities, integral, and differential equations. A typical example are the continuity constraints for a reservoir: the water stored at the end of a season is equal to the water that was stored at the beginning of the season, plus all the inflows received, and minus all the releases and diversions during that season.

Optimization techniques require a formal search procedure for the set of decision variables that optimize the objective function while satisfying all the constraints. When objective function and constraints can be expressed as linear algebraic equations, the set of decision variables which maximize the objective function can be found with a technique called **linear programming**. Several algorithms to solve linear programming are available in commercial software packages.

When some of the variables can only take an integer value (zero or one), the optimization problem may be solved with **integer programming**. The use of integer programming provides a way to introduce more constraints into linear problems, as, for example, fixed costs for the facilities. Integer programming is also available in software packages.

Non-linear programming differs from linear programming in that the objective function and constraints may be non-linear functions of the decision variables. There is not general solution for non-linear problems, but techniques are available for special cases, such as quadratic programming (in which the constraints remain linear, but the objective function takes quadratic form).

Dynamic programming is a method to solve linear and non-linear problems which have a sequential character. Such problems can be divided in stages (i.e. years or seasons), and decisions are required at each stage. A decision taken in a given stage affects to the next stage. Although there is not general software available for dynamic programming, computational procedures are relatively simple for a limited number of stages and decisions.

2.1.2.- Simulation techniques

Simulation techniques produce information on the performance of the system under different sets of input parameters. Simulation techniques can include an objective function. In that case, for each simulation run, a value of the objective function is obtained. By performing many runs, a response surface formed by the values of the objective function can be created. Some sampling or search procedure can examine the response surface and obtain nearly optimal solutions.

2.2.- CURRENT USE OF PLANNING METHODS

Assessment on the use of system analysis planning methods in actual water resources planning situations differ among authors. Two recent surveys show very distinct results. Rogers and Fiering [1986], using in part results from Rogers [1979], conclude that agencies and major consultants only appear to use system analysis techniques in few cases. This pessimistic view differs from the conclusions of Friedman et al. [1984], using results of a study performed by the U.S. Congress Office of Technology Assessment (OTA) in 1982. Friedman et al. [1984] conclude that water agencies and organizations extensively use mathematical models to find solutions to water resources problems efficiently and effectively.

The contradictory conclusions in these studies result in part from the different meaning of system analysis techniques for the authors. Rogers and Fiering [1986] only researched optimization techniques, while OTA [1982] surveyed techniques used to solve any kind of water related problem. Despite their differences, there is a common conclusion in both studies: that the potential of system analysis and other mathematical techniques can be improved with the understanding of some institutional issues in water resources agencies which currently limit the application of the techniques. In what follows, four issues are discussed.

1. Institutional resistance to use system analysis techniques. Sophisticated mathematical models of analysis require great specialization. Rogers and Fiering [1986] in their study conclude that complex water resources models are not easily understood by many decision makers. Even senior planners and engineers, trained before system analysis techniques were used, have problem to understand the methods.

Then, those who supposedly head agencies divisions and departments, have difficulties to accept system analysis as new planning methods. In addition, the use of system analysis for non specialized people may produce wrong results. For Rogers and Fiering [1986] this may undermine even more the confidence in the new techniques.

<u>2. Lack of communication between decision makers and analysts.</u> Part of the lack of communication is a consequence of the newness and complexity of the techniques and of the difficulties of decision makers to understand them. But there is also lack of communication due to the use of optimization techniques as mathematical tools that "guarantee" the best solution for the given problem. Single best solutions do not leave any room for negotiation, and that come from techniques that in fact ignore part of the social, political, and economical environment in what decisions are taken. When analysts use system analysis as substitute for decision making judgement, decision makers are likely to perceive it as an imposition and a threat to their authority.

However, if techniques are used with the perspective of providing decision making needs for information, communication between analysts and decision makers is improved [Meyer and Miller, 1985]. Techniques are able to perform the analysis under the different optimization criteria and policies that decision makers need to evaluate their decisions. In this sense, system analysis can become very useful and accepted.

3. Institution's conditions to use system analysis.
Development of system analysis techniques within water resources agencies requires at least four main conditions: specialized personnel, computer facilities, training of support people, and availability of data. For Friedman et al. [1984], agencies and institutions do not have overall strategies for introducing system analysis in their evaluation methods. Consequently, when finally agencies decide to use system analysis, some of these four conditions could not be available and system analysis techniques do not result the efficient planning method that was expected. To complicate more this situation, no coordination exists among water planning agencies [Friedman et al., 1984], and the possibility of sharing resources and experiences among agencies is lost.

4.- Institutional situations in less developed countries.
A priory systems analysis should be more effective in less developed countries (LDC's) than in developed countries (DC's). While in DC's major water resources systems are already in place and current planning is only made on small systems, in LDC's there are still large undeveloped water resources systems to which system analysis application is more effective [Rogers, 1979]. Other advantage in LDC's is that the decision making process is simpler and easier. Simpler in the

sense that decisions are more centralized, what reduce the number of parties involved in the process. Easier because objectives are fewer (normally national or regional economical growth) and more clearly defined, what simplifies the technical analysis. Institutional problems in LDC's are similar to those on DC's, although the main problems could arise from the lack of trained personal, computational resources, and lack or non reliability of data.

Rogers [1979] reports detailed characteristics of 22 cases of application of system analysis techniques in the developing world. Most of them were successful.

2.3.- ADAPTATIONS OF SYSTEM ANALYSIS TECHNIQUES TO DECISION MAKING NEEDS

There are differences between best in the real world and optimal in the mathematical world. The mathematical solution is unlikely the best solution for the planning problem [Chang et al., 1982]. To improve system analysis the first tendency is to enter more variables, more relationships, and more complex equations. Large-scale models represent a challenge for research and devise of solution techniques. But large and complicate models may be less effective in the real world than simple models, not only because they may not represent a significant increase in the efficiency of the model, but also because they may be too complicate for other people to understand, apply, and solve.

System analysis techniques are supposed to aim decision-making information needs. The analyst should realize that what causes a project to be implemented is a decision, and not the models, and techniques. These, however, increase the chance that the decision is correct. Therefore, analysts should use system analysis to identify performances and consequences of alternative projects and be able to clearly present the information, recognizing that decision makers are normally not familiar with the technical analysis.

Four improvements to system analysis are found in the literature. These improvements are: (1) multiobjective analysis, (2) identification of nearly optimal solutions, (3) stochastic planning, and (4) definition of indices to indicate properties of the alternative designs.

2.3.1.- Multiobjective analysis

River basin problems are concerned with the allocation of water among several uses and development alternatives. Traditionally planners have used a single economic objective: maximization of national income, also called economic efficiency (benefits minus costs). However, public investment for river basin development is multiobjective. Different objectives are environmental, recreation, unemployment reduction, regional development, national self-sufficiency, etc. Solutions to water optimization problems are straight forward when a single objective is considered and the rest are ignored. The solution is not that easy when the problem has conflicting objectives. However, theoretically, single optimal solution exists. The procedure to find it consists in three steps: (1) find the possibility frontier curve (formed by the projects which represent the best possible tradeoff among the objectives); (2) find the social indifference utility curves (that show the social tradeoff among the objectives); and (3) find the tangent of the maximum possible social indifference curve with the objective possibility frontier. Figure 2-1 displays the method for the case of two objectives.

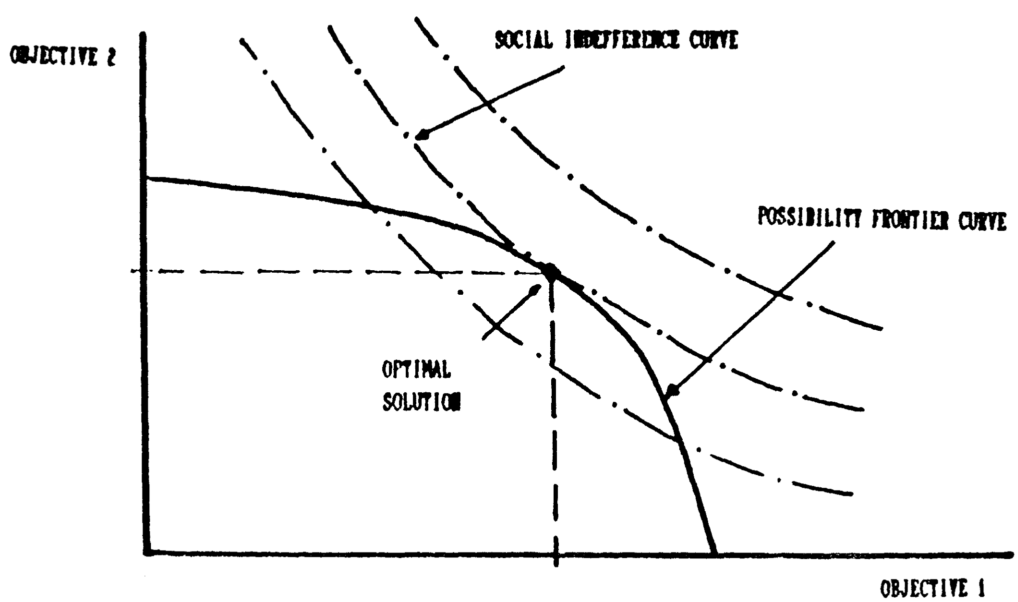

FIGURE 2-1: *Theoretical multiobjective optimal solution*

Although theoretically simple and logical, the process has almost unsolvable practical problems. First the determination of the measure of merit for each objective. How to measure the benefits from ecological preservation?: according to the number of wild animals? There are not markets for many of these objectives, and then there are not conventional measure of benefits and costs. In fact, if there was a market, it would be possible to find a way to end up with monetary measures of merit for any objective, and to convert the problem in single-objective. The multiobjective problem arises because merits for different objectives are not comparable.

Second problem is the determination of social indifference curves. They are very difficult to formulate for practical applications. Many authors do not recommend that the analysts select the curves, because of practical difficulties when quantifying preferences of the society. Without social indifference curves, the multiobjective problem do not likely have single optimal solution.

The third problem is the generation of the frontier curve. For many analysts, multiobjective analysis is just this step. Almost all efforts in multiobjective planning are centered in studying new and more effective methods for finding the frontier curve. The basic problem to solve is called vector optimization, since the objective function is a vector instead of a scalar:

objective function: $\text{Max } Z = Z\,[Z_1, Z_2, .., Z_p]$

and constraints: $Z_K = C_{Ki} \; X_i$

$$A_{ij} \; X_i - B_j \leq 0$$

$$X_i \geq 0$$

A vector cannot be directly maximized or minimized. Only a set of non-inferior solutions can be obtained. This set defines the called Pareto possibilities frontier curve, or simply frontier curve or Pareto curve. Cohon and Marks [1975] summarize the techniques developed to solve the vector optimization problem. In their study, they conclude that of the techniques available, many do not have practical application to multiobjective water resources problems. Also, for cases of more than four objectives an efficient method is yet to be developed (presently, only the called subrogate worth trade off method can be applied when great computer resources are available). For Cohon and Marks, for cases with up to four objectives, the best method is the constraint method.

The constraint method consists in the following optimization:

objective function: $\text{Max} \quad Z_m$

with the new constraint: $Z_l \geq L_l \,, \quad l = m$

and the old constraints: $Z_K = C_{Ki} \quad X_i$

$$A_{ij} \quad X_i - B_j \leq 0$$

$$X_i \geq 0$$

Then, Z_m is maximized subject to lower limits L_l in the other objectives. If this problem is solved using LP, it has the advantage that sensitivity analysis (included in most of LP packages) can rapidly obtain solutions for different values of L_l's.

There is small chance that social utility curves are available. Therefore no further choice among non-inferior alternatives could be taken, and the frontier curve is to be presented to the decision makers.

2.3.2.- Identification of nearly optimal solutions

The global optimum of a mathematical model is not the only solution of interest for the decision maker; identification of different alternatives within acceptable ranges of the objective function represent solutions to the same problem but with more possibilities for negotiation and agreement among parties involved in the decision making process. These other alternatives, very close to the optimal solution is terms of the objective function value, but which are significantly different decisions in terms of the decision variables values, are called nearly optimal solutions.

The major problem for identifying nearly optimal solutions is the lack of computer software available. Optimization algorithms are designed to reach the single optimal solution and they generate little information about nearly optimal solutions.

Harrington and Gidley [1985] suggest a simple and interesting procedure to analyze nearly optimal alternatives when using a LP package. The procedure assumes a LP problem which has a single optimal solution:

objective function: $\quad \text{Max } Z$

and constraints:

$$Z = C_i X_i$$

$$A_{ij} X_i - B_j \leq 0$$

$$X_i \geq 0$$

and the single optimal solution is: $Z = Z^*$

To generate alternative optima the software package is repeatedly applied but introducing a new constraint:

$$C_i \quad X_i \leq \alpha Z^*$$

In case that $\alpha = 1$ the global optimal solution Z^* is obtained again. For other nearly optimal alternatives, α should take any values inferior to 1. As closer is the value to 1, "more nearly optimal" the solution is. The studies made by Harrington and Gidley [1985] prove that a great number of nearly optimal solutions exists within 0.5% of the global optimal objective function value.

Other attempts have been made to generate objective functions in which the maximum value of some decision variables are randomly constrained. When these constraint are varied, new objective functions are maximized, and nearly optimal solutions are obtained.

The consideration of nearly optimal solutions has the potential not only of producing better decisions, but also of producing better understanding of the nature of the decision problem itself.

2.3.3.- Stochastic Planning

Many of the factors that define the performance of water resources systems cannot be known with certainty when the system is planned. Most of the planning is made under uncertain circumstances. The simplest approach is to take some simple probabilistic measure (mean, median, mode) for the uncertain variables, and then proceed as on a deterministic problem.

There is a second approach to deal with uncertainty that is to evaluate the consequences of uncertainty in a <u>given</u> system design. Loucks et al. [1981] review some methods under this approach. The maximum expected net benefits method considers the following problem:

$$\sum_j [NB\ (X_i \mid W_j)]\ p_j$$

where NB $(X_i \mid W_j)$ are the net benefits of the system whose given design is described by the decision variables X_i, when the uncertain parameters take the value W_j, and p_j is the probability of occurrence of W_j. The project with greater expected net benefits the chosen. In essence, this method selects, for <u>given</u> alternative projects, the one with better average performance. It can be called compromise solution.

Other of the methods indicated by Loucks et al. [1981], the max-min method, uses a most pessimistic criterion: from all the given projects, the smallest net benefits of every project are calculated, and the chosen project is the one whose smallest net benefits are the greatest. It is a way to favor alternatives which provide a minimum of benefits every year over other alternatives more profitable on the average, but that may produce very low net benefits in same conditions.

In between both methods, one overreacting to poor outcomes and other ignoring them, there is the utility theory. Its basic point is to define the utility function. From decision maker's preferences, indifference situations, and risk premiums, a continuous utility curve might be drawn (see Figure 2-2). Keeney and Raiffa [1976], the traditional decision analysis book, show how to obtain utility curves and how to include in them other attributes than money. In utility analysis, the new objective function value is utility, and the problem is to maximize it.

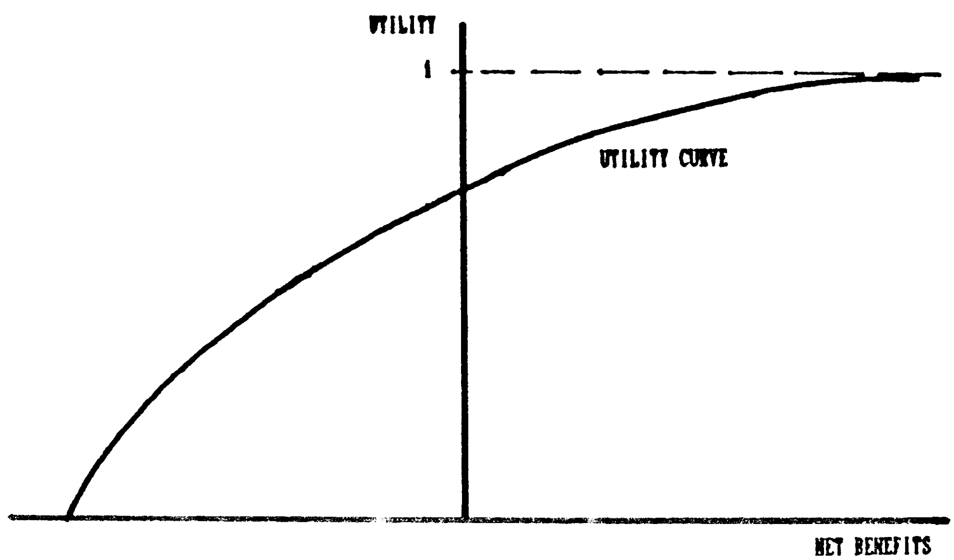

FIGURE 2-2: *Typical form of utility curves*

Utility theory has many favorable points. It represents directly social or decision maker's preferences and tradeoffs.

For example, bad outcomes are more heavily weighted than good ones. Sensitivity analysis could be applied for different utility curves, and conclusions stated for debate and participation. Difficulties in utility theory arise when quantifying preferences to assess utility curves. Different decision makers, representing social and political groups, likely have different perspectives of social values and preferences. Consensus in a utility curve might be impossible, and then the conclusions rejected for those with different utility curves.

The second approach to deal with uncertainty is to identify optimal alternatives under uncertain conditions. The main method of this approach is stochastic linear programming, suggested in part by Loucks et al. [1981]. We assume the original deterministic formulation:

$$\text{Max} \quad NB,$$

$$\text{Subject to:} \quad NB = C_i \; X_i$$

$$A_{ij} \; X_i - B_j \leq 0$$

$$X_i \geq 0$$

where C_i, A_{ij}, and B_j represent the parameters of the model. In stochastic linear programming some of these parameters are no deterministic. Assume that C_k is uncertain, and its probability distribution is represented in Figure 2-3.

There are certain steps to be taken to solve the problem. First, the continuous probability distribution function for C_k has to be approximated by a discrete distribution function, as

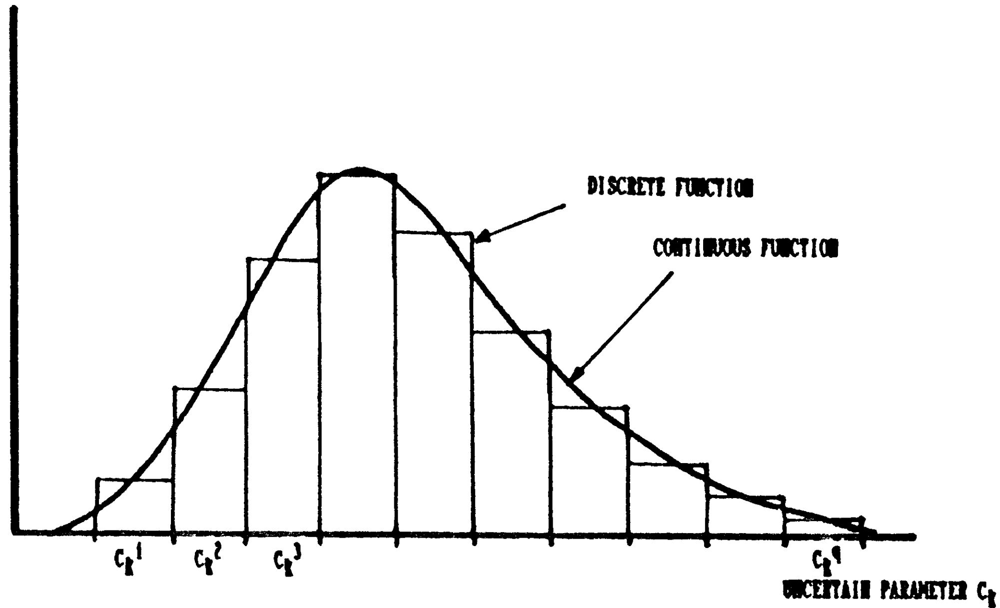

FIGURE 2-3: *Continuous and discrete probability functions for uncertain parameter C_K*

done in graph. Each interval C_K^1, C_K^2, ..., C_K^q (q is a finite number) has its correspondent probability associated $p(C_K^1)$, $p(C_K^1)$, .., $p(C_K^1)$.

In stochastic linear programming, it is important to distinguish two kind of decision variables: design decision variables and operational decision variables. Design decision variables define project sizes. Operational decision variables define operation rules of the projects once they are built. This is extensively discussed in Chapter 3.

The second step is to write the original optimization model as dependent on C_K^i, with $i = 1, 2, .., q$ (q is the number of discrete intervals of the uncertain parameter C_K). We also consider the decision variables X_j, with $j = 1, 2, .., k-1$, to be design decision variables, and the decision variables X_j, with $j = k, k+1, ..n$, to be operational decision variables. We can write:

$$NB^1 = C_1 X_1 + C_2 X_2 + .. + C_{k-1} X_{k-1} + C_k^1 X_k^1 + .. + C_n X_n^1$$

$$NB^2 = C_1 X_1 + C_2 X_2 + .. + C_{k-1} X_{k-1} + C_k^2 X_k^2 + .. + C_n X_n^2$$

$$\cdots\cdots \qquad\qquad\qquad \cdots\cdots$$

$$NB^q = C_1 X_1 + C_2 X_2 + .. + C_{k-1} X_{k-1} + C_k^q X_k^q + .. + C_n X_n^q$$

Operational decision variables take different values depending on the uncertain conditions: for any future condition, there are a set of operational decision variables that obtains the maximum possible benefit from the projects. However, design decision variables can take only a value, because the size of the project can not be adapted to the possible future conditions.

The new optimization problem is now:

$$\text{Max} \quad [NB^1 \, p(C_k^1) + NB^2 \, p(C_k^2) + .. + NB^q \, p(C_k^q)] =$$

$$= \text{Max} \sum_{m = 1, 2, ..q} NB^m \, p(C_k^m)$$

Subject to: $A_{ij} X_i^m - B_j \leq 0$

$X_i^m \geq 0$

Note that the value of the superscript m in decision variables X_i^m depends on the type of decision variable:

design decision variable: m does not have any value

operational decision variable: $m = 1, 2, ..q$.

The new problem continues being linear, but the number of constraints and variables is significantly increased. The big size of the problem is in fact the main limitation of stochastic linear programming.

As a conclusion, there are two main approaches to deal with uncertainty: (1) to forecast the consequences of uncertainty, and (2) to choose between alternatives which yield uncertain benefits. Loucks et al. [1981], when evaluating methods and models for both approaches, concludes that uncertainty models should not be used to identify single best solutions, but to eliminate clearly inferior alternatives.

2.3.4.- Indices

Indices are quantitative measures that compare performance of different alternatives under some given criteria. All the indices discussed here are consequence of uncertainty in water resources planning. Indices rank projects in regarding their performance under the following criteria:

1. Probability that the project fails
2. How bad are the consequences of the failure
3. Probability that the project will perform reasonably well under different demand conditions.

Criteria 1 and 2 are respectively measured by the reliability and vulnerability indices. For criterion 3, two indices are appropriate, although their definitions are slightly different, and so their proposed formulae: resiliency, and robustness. In what follows, the four indices are proposed and analyzed.

1.- Reliability Index

Reliability index measures probability that the project has no failure within the planning period. Hashimoto et al. [1982a] proposes the following formulation:

$$I_{rel} = \text{Prob} [X_t \in S]$$

where:

I_{rel} = Index of Reliability
X_t = Variable that describes the system's output at time t (t takes the discrete values 1, 2, ...)
S = Set of all satisfactory outputs

Reliability is opposite to risk, or what is the same, the probability of failure. In this sense, risk index is defined as $1-I_{rel}$.

2.- Vulnerability Index

Vulnerability index measures the magnitude of the consequences of a failure, given that it has occurred. It does not consider the length of time until the failure, nor the number of failures, nor how long the failure lasts. Vulnerability only refers to how severe the consequences are. Hashimoto et al.[1982a] proposes the following formula:

$$I_{vul} = \Sigma\ S_j\ E_j, \qquad j \in F$$

where:

I_{vul} = Index of Vulnerability
S_j = Severity of the consequences
E_j = Probability that the consequences be with severity S_j
F = Set of unsatisfactory outputs (failures)

3.- Resiliency Index

Resilience is a term known in other sciences like ecology, materials, economy, and structures. There is not a common generalized definition for resiliency. In general, resiliency is associated to adaptation to new (no projected) situations, and to recovery from surprises and adverse situations.

In water resources there are two approaches to resiliency. First, for Hashimoto et al. [1982a], resilience describes how quickly the system will likely recover from a failure. Their mathematical formulation is based on the time of recovery. They propose the following measure of resiliency:

If T_F is the time that a system remains unsatisfactory after a failure, the index of resiliency is $1/T_F$; considering expected values, is possible to define T_F:

$$E\,[T_F] = 1 \,/\, \{Prob\,[\,X_{t+1} \in S \mid X_t \in F\,]\}$$

where:

X_{t+1} = Variable which describes the system's output at time t+1
S = Set of satisfactory outputs
X_t = Variable which describes the system's output at time t
F = Set of unsatisfactory outputs (failures)

and by definition of index of resiliency I_{res}:

$$I_{res} = Prob\,[\,X_{t+1} \in S \mid X_t \in F\,]$$

Second, for Fiering [1982a, b, c, and d] resiliency is the probability that the system will operate well enough when unlike events occur. This concept of resiliency is similar to the notion of robustness described below. According to Fiering, a system is robust to changes in certain variables when the partial derivative of the systems response is small for these variables. But, and this is Fiering's distinction between robustness and resiliency, even if the system is not robust to certain variables it may be resilient as a whole. A resilient system accommodates the surprise produced in several of its variables by changes in the remaining variables. Resiliency, therefore, should be measured as relations among total derivatives:

$$dz/dx_i = \Sigma \ (\partial z/\partial x_j) \ (\partial x_j/\partial x_i)$$

A linear combination of all the total derivatives dz/dx_i measures the resilience of a given system as a whole.

Other criteria and alternative measures of resiliency are proposed by Fiering [1982b]. In fact he proposes up to eleven different alternative indices of resiliency, based in residence time in non-failure state, and combinations of passage time between failure and non-failure states.

The method of the total derivatives proposed by Fiering [1982a] was used by Allan and Marks [1984] to measure the resiliency of agricultural systems in developing countries. They concluded that a system design can be expected to be resilient when the expected performance degradation due to "unpleasant surprises" in the planning parameters is less than the expected degradation in the planning parameters themselves.

For practical applications, highly resilient systems are considered to be those which contain many redundances of design. For these systems, proper operation rules minimize the unpleasant effects of surprises. Large systems with many connections have proved to be the most resilient.

4.- Robustness Index

For Fiering [1982a], robustness and resilience mean very much the same. However for Hashimoto et al. [1982b], robustness has other meaning. They consider robustness as a measure of the possibility and expenses of adapting a system to future conditions different from those for which the system was calculated. It is the cost of not having perfect information about the future. The index they propose is:

$$I_{rob} = \text{Prob}\ [\ C(q|D) - L(q) \leq \beta\ L\ (q)\ ],$$

where:

I_{rob} = Index of Robustness
q = Future conditions
D = A particular alternative (Project or Design)
$C(q|D)$ = Cost of accommodating the alternative D to the future demand conditions q
$L(q)$ = Minimum accommodating cost among all the alternatives
β = Level of robustness

Under the "demand conditions" term used by Hashimoto et al. [1982a], there are grouped the set of future conditions which affect the project (demand, costs, prices, ...) and which are uncertain and likely to vary.

This thesis uses a different concept of robustness, already introduced in Chapter 1. Robustness of a project is a measure of the dispersion of possible net benefits from the project as consequence of uncertainty in some parameters. According to this criterion, an index of robustness is developed in Chapter 3.

CHAPTER 3: A METHOD FOR INCORPORATING ROBUSTNESS IN PLANNING DECISIONS

This chapter describes a method to identify robust water resources planning strategies. The method is a multiobjective analysis of the water resources system. One of the objectives is to maximize robustness and the other is to maximize expected net benefits. The reason for analyzing robustness is the presence of uncertain conditions in the basin. Robustness is a measure of how sensitive the project is to uncertain parameters. A project is called robust when its performance is relatively constant under different conditions. In this thesis, robustness is considered a desirable property of a project. The measure of project robustness, as indicated in Chapter 1, is based on the distribution of net benefits from the project under uncertain conditions.

In multiobjective analysis, no single best project exists. Therefore the outcome of this method is to define several non-inferior development alternatives for the water resources system. The method begins by displaying all possible projects to be built in the basin. From these, after the method is applied, the projects or combinations of projects with greater robustness and expected net benefits are identified. One of them will be the final development choice.

3.1.- DESCRIPTION OF THE METHOD

Previously to applying the method itself, we must write the screening model for the basin. The screening model is an optimization technique that selects among all possible projects that could be built in the basin those which provide the greatest value of the objective function (normally the objective function is to maximize net benefits from the basin). In particular, a screening model is a group of mathematical relationships that represent the water system, including all possible projects to be built and all possible uses for the water. Projects are defined by their decision variables. To solve the screening model consists in obtaining the optimal value of every decision variable, that define the most profitable set of projects to build. The model contains two main elements: objective function and constraints. Both, objective function and constraints, are mathematical expressions of parameters and decision variables.

The objective function is a quantitative measure of the main policy criterion: maximize economic efficiency, minimize unemployment, etc. If, for example, the criterion is to maximize economic efficiency, the objective function could be the mathematical expression of benefits minus costs. Benefits and costs are considered for a typical year, that is assumed to be repeated during the water system lifetime.

Constraints are mathematical expressions which show the physical conditions (water continuity, maximum sizes, etc.), institutional conditions (water priorities, operation rules, etc.), and social-economical conditions (demands for water, prices and costs, etc.) of the basin or water resources system.

The mathematical representation of a screening model looks like:

(for the typical year)

- objective function (1 equation):

  Maximize: $F (X_1, X_2, .. , X_m)$
  for $\{X_j\}$

- constraints (i equations):

  $Gi (X_1, X_2, .. , X_m)$

where X_j are the decision variables.

Once the screening problem is formulated, an optimization technique may be used to obtain the optimum values of the decision variables X_j, which normally are project sizes and operating rules. These optimal values of the decision variables define the most profitable projects to be built (irrigation areas, hydropower plants, etc.), their sizes, and their optimal operation rules.

The most used screening models are linear screening models. Linear screening models can be solved using linear programming (LP), that is the most available optimization technique. The mathematical representation of a linear screening model is: (for the typical year)

- objective function (1 equation):

$$\text{Maximize: } F(X_1, X_2, \ldots, X_m) = F(X) = C_j X_j$$
for $\{X_j\}$

- constraints (i equations):

$$G_i(X_1, X_2, \ldots, X_m) = A_{ij} X_j - B_i \leq 0$$

where:

X_j are the decision variables, and C_j, A_{ij}, B_i are input parameters (some of them may be uncertain)

3.1.1.- Step 1: Derive the ideal net benefits curve

Decision Variables

Decision variables define project design and operating rules. There are two types of decision variables in the screening model: design decision variables and operational decision variables. Design decision variables define the sizes of the projects to be built. Area of irrigation, volume of reservoir, and capacity of hydropower plant are typical examples of design decision variables. Operational decision variables define the operation rules of the projects once they are built. Releases from reservoirs and water diverted for irrigation are examples of operational decision variables. Design decision variables are of primary interest in our analysis, since they define what projects are to be built and what projects are not to be built. Also, for those projects to be built, design decision variables indicate their sizes.

The values of the design decision variables are not known a priori. In fact, when we search for candidate alternatives in Step 2, what we actually do is to find the set of design decision variables which define the candidate development alternative. In general, design decision variables form a vector X, such that:

$$X = \{X_1, X_2, \ldots, X_m\}$$

where m is the number of design decision variables, and where X_1 may represent volume of reservoir, X_2 irrigation area, and so on.

<u>Uncertain Parameters</u>

The reason why predicted and actual performance of the project may differ is the uncertainty in some parameters. In the particular case of linear screening models, uncertain parameters are a subset of the input parameters C_j, A_{ij}, and B_i. We group this subset formed by the uncertain parameters in a vector Θ:

$$\Theta = \{\Theta_1, \Theta_2, \ldots, \Theta_n\}$$

where n is the number of uncertain parameters existing in the basin, and where Θ_1 may represent discount rate, Θ_2 price of agricultural products, and so on.

We need to have the probability distribution of every uncertain parameter. The most common models of probability distributions used in engineering and risk analysis (for example: gaussian, lognormal, Gumbel, or log Pearson) are continuous distributions. For present purposes, these must be divided into a finite number of discrete intervals with their associated probabilities as shown in Figure 2-3 in Chapter 2.

If we assume that, for example, the parameter "discount rate" is uncertain, and it is approached with a gaussian distribution, Figure 3-1 shows the division of the continuous distribution in discrete intervals.

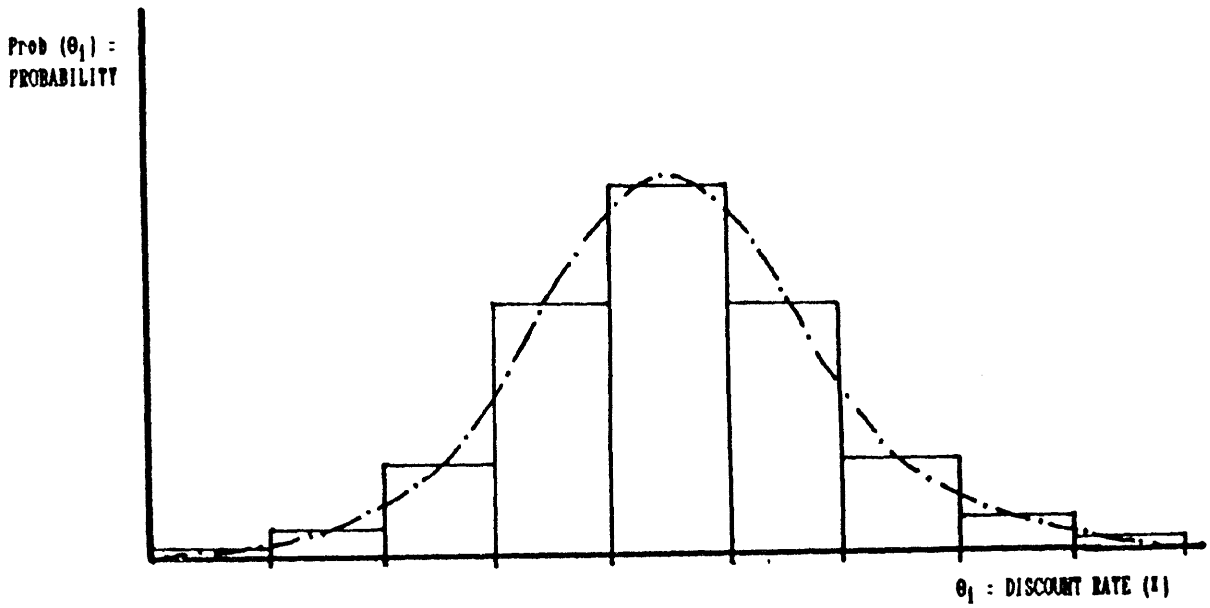

FIGURE 3-1: *Discrete probability functions for the uncertain parameter Θ_i = discount rate.*

In general, after dividing in discrete intervals, the continuous uncertain parameter vector Θ_i is converted to:

$$\Theta = \Theta_i{}^j$$

where:

$$i = 1, 2, .., n$$
$$j = 1, 2, .., M_i$$

where M_i is the number of intervals of the uncertain parameter i. We also obtain the corresponding discrete probability of each interval:

$p(\Theta_i{}^j)$

To compute this probability we have to assume that the uncertain parameters are independent; in other words, no correlation exists among them. This assumption is obvious in some cases (for example, no correlation exists between irrigation water demands and discount rate), although in other cases some correlation may be present (for example, between irrigation water demands and agricultural prices).

<u>Ideal net benefits curve</u>

The ideal net benefits curve is formed by the potential net benefits of the basin under uncertain conditions. The ideal net benefits curve is the reference to calculate robustness, as shown in Chapter 1. To obtain one point of this curve, we pick up a particular element $\Theta_i{}^j$ of the uncertain parameters vector Θ, and, using the screening model, we obtain the maximum net benefits that the basin may yield under the conditions defined by $\Theta_i{}^j$. We also obtain the optimal set of design decision variables for the conditions $\Theta_i{}^j$. The projects defined by that optimal set of design decision variables exploit the full potential of the basin for that situation $\Theta_i{}^j$.

For the element $\Theta_i{}^j$ of the uncertain parameters vector Θ, let $X^*(\Theta_i{}^j)$ represent the optimal set of design decision variables obtained from the screening model. And let
$NB\ [X^*(\Theta_i{}^j)]$ represent the net benefits obtainable from the

projects defined by the design decision variables $X^*(\Theta_i{}^j)$. The value NB $[X^*(\Theta_i{}^j)]$ represents the potential of the basin for the situation $\Theta_i{}^j$, and, consequently, represents a point of the ideal net benefits curve. When the same process is repeated for all the other elements of the uncertain parameter vector Θ, the ideal net benefits curve is fully defined.

Therefore, the mathematical representation of the ideal net benefits curve is:

$$NB\ [X^*(\Theta^{jk..l})],$$

for: $i = 1, 2, .., n$
$j = 1, 2, .., M_i$

It is important to note that the ideal net benefits curve does not correspond to a single project. The ideal net benefits curve indicates, for every element $\Theta_i{}^j$ of the uncertain parameters vector, the maximum possible net benefits that we may expect. Finally, also note that, associated with every element $\Theta_i{}^j$, there is an optimum set of decision variables $X^*(\Theta_i{}^j)$ that defines the projects to be built. This will be useful in the next steps.

A typical form of the ideal net benefits curve of a basin under uncertain discount rate is shown in Figure 3-2. In this example, the final curve never takes negative values. It is zero when the discount rate equals the internal rate of return of the system. At that point, benefits from the project are equal to the project costs, and there are no net benefits. For discount rates higher than the internal rate of return, the costs of building any project are greater than the benefits

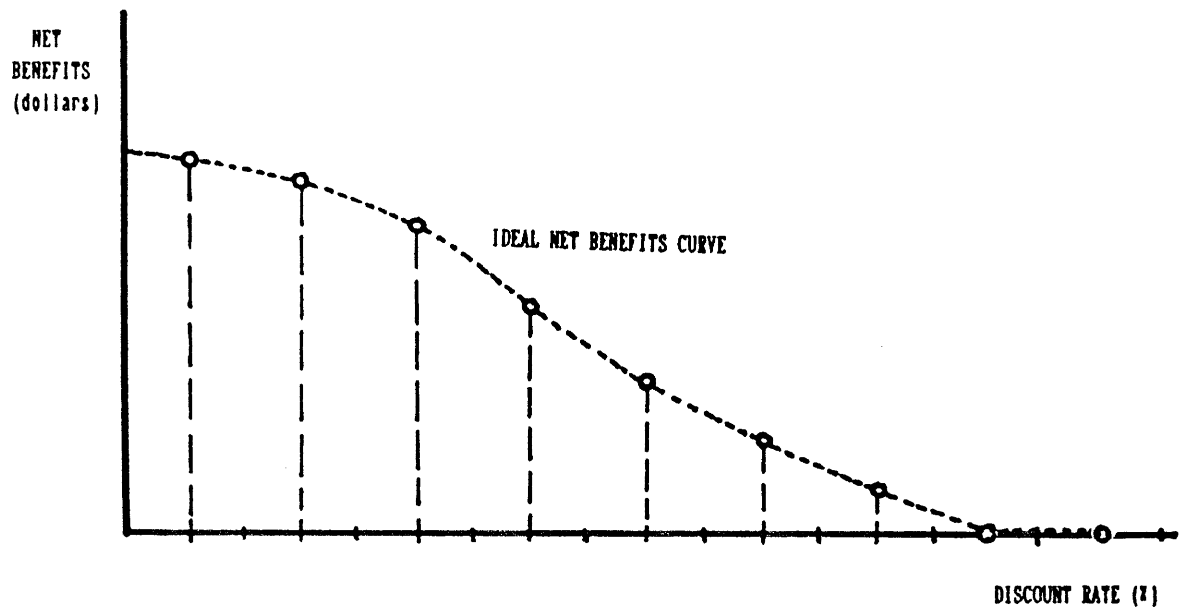

FIGURE 3-2: *Typical ideal net benefits curve for a basin under uncertain discount rate.*

obtained. Consequently the optimal project to build is none, which yields zero benefits and zero costs. Then the ideal net benefits curve remains zero for discount rates higher than the internal rate of return of the system.

3.1.2.- Step 2: Select candidate alternatives

We should identify alternatives that have high expected net benefits or that have high robustness or, even better, that have both. Alternatives are defined by their design decision variables. Selection of alternatives means selection of design decision variables.

There is no formal procedure for identifying candidate alternatives. However, from Step 1, while obtaining the ideal net benefits curve, we developed enough information on the projects to suggest the use of some very effective informal procedures. In fact, in Step 1 it was necessary to perform M_1 M_2 M_n independent optimization runs, which gave equal number of optimal sets of decision variables $X^*(\Theta_i{}^j)$, one for each element $\Theta_i{}^j$. From the analysis of these optimal sets, using the procedures proposed below, we can obtain candidate alternatives.

Several procedures for the analysis of the optimal sets of decision variables $X^*(\Theta_i{}^j)$ are suggested here. The first procedure is to calculate the probability distribution of the values of the design decision variables. This is a very simple procedure that produces great insight into the system's design. Consider the set of design decision variables: $X = \{X_1, X_2, .. , X_m\}$, and in particular one of them, the design decision variable X_u (that may, for example, represent the volume of a reservoir). When the problem was optimized for the uncertain parameters element $\Theta_i{}^j$, the value of X_u was $X_u{}^*(\Theta_i{}^j)$, with probability of $p(\Theta_i{}^j)$. Since we performed M_1 M_2 M_n optimization runs, we have M_1 M_2 M_n different values of $X_u{}^*(\Theta_i{}^j)$, one for each combination of i and j. The distribution for the values of X_u is therefore:

$$X_u{}^*(\Theta_i{}^j) \quad \text{with probability} \quad p(\Theta_i{}^j)$$

for: $\quad i = 1, 2, .., n$
$\quad\quad j = 1, 2, .., M_i$

Therefore we have a discrete probability distribution of the values of the design decision variable X_u. The analysis of that probability distribution helps to identify the most likely values for the design decision variable X_u. If the optimization algorithm used to solve the screening model in Step 1 is LP, the probability distribution tends to be highly concentrated around two or three values. This is because LP searches for the vertices of the n-dimension polygon formed by the constraints, vertices which reduce to a few the otherwise infinite possible values of the design decision variable X_u.

The second procedure is a graphical representation, like shown in Figure 3-3 for an hypothetical example of the probability distribution of $X_u^*(\Theta_i^j)$. Using the graph, it is easier to visualize the most probable values of the decision variable X_u. These values seem clustered in three groups.

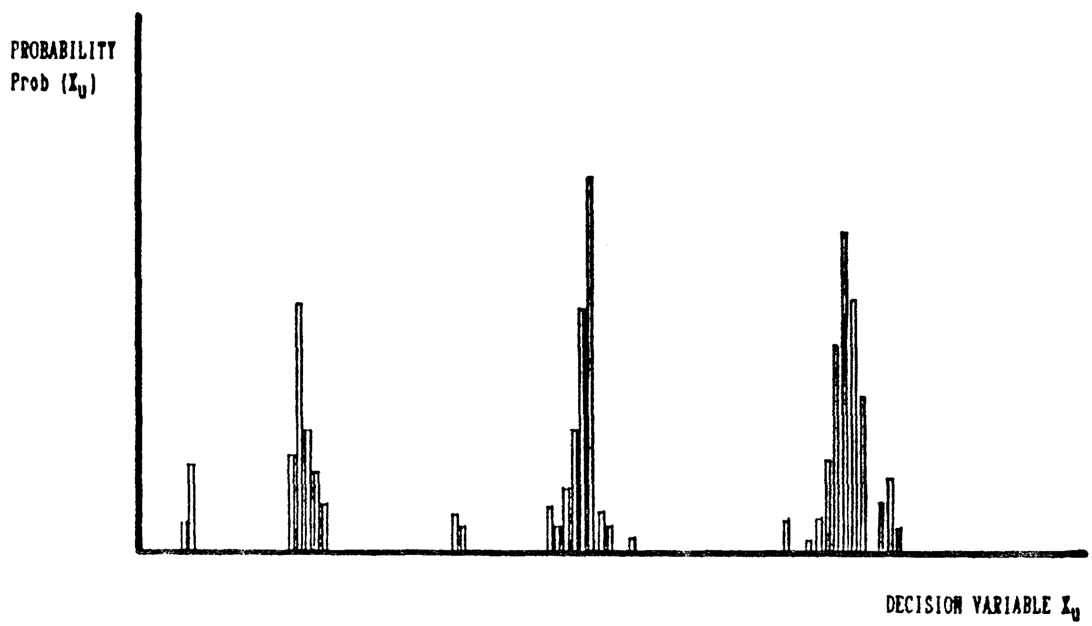

FIGURE 3-3: *Typical bar graph representation of an hypothetical probability distribution of values of a design decision variable X_u, obtained from the M1 M2 Mn optimization runs performed in Step 1*

Taking the average value of each group, we could identify the three more likely values of X_u.

The purpose of this procedure is to identify alternatives that we expect to be both robust and profitable. These candidate alternatives are constructed by combining the most likely values of the design decision variables. With the graphs we may identify the likely values of every decision variable, but before examining all possible combinations among the more likely values of the decision variables, a third procedure is suggested.

The third procedure is to create a table of compatibilities and incompatibilities among design decision variables. A characteristic of optimization problems in water resources systems that are formed by several projects is that those projects that use resources more effectively are built before than other projects. It is when the effective projects do not have more production capacity and there are some resources still left that the other projects are built. Therefore, less profitable projects are built only after more profitable projects are built. However more profitable projects do not require the existence of other projects. These relationships among projects can be identified by inspection of the decision variables vectors resulting from the M_1 M_2 M_n different optimization runs performed in Step 1. Three kinds of relationships among projects are suggested; for a given project: (1) projects that are always built when that particular project is built (more profitable projects that the given one); (2) projects that are never built when that particular project is built (incompatible projects with the given one); and (3) projects that do not have any relationship with that particular project. These tables are not difficult to construct, especially for small water resources systems, and they are very helpful in developing candidate alternatives, because they reduce the number of possible combinations among the more likely values of the design decision variables.

3.1.3.- Step 3: Assess the performance of the alternatives

From Step 2, we have a reduced but promising group of alternatives. Step 3 assesses the performance of every alternative in this group. In this thesis, two characteristics define the performance of an alternative: (1) the expected value of net benefits, and (2) the robustness index. To calculate them, it is necessary to use an intermediate step: the curve of net benefits of every alternative.

Curve of net benefits

For a given candidate alternative, its curve of net benefits indicates the net benefits obtained under uncertain conditions. We assume Alternative A defined by the decision variables:

X^A_k with $k = 1, 2, ..m.$

This Alternative A, under the particular element Θ_i^j of the uncertain parameters vector Θ, yields some net benefits (or, if negative, net costs). Mathematically these net benefits are represented by:

$$NB\ [X^A \mid \Theta_i^j]$$

that reads:

net benefits of the alternative defined by the decision variables X^A given Θ_i^j.

To calculate $NB\ [X^A \mid \Theta_i^j]$ we use an optimization technique (like LP), that could be the same technique used before to calculate the ideal net benefits curve. The use of an optimization technique is required, because the process to calculate $NB\ [X^A \mid \Theta_i^j]$ involves optimization of operational decision variables for Alternative A (while the design decision variables of Alternative A are held constant) in order to procure the maximum possible net benefits.

The full net benefits curve for Alternative A is obtained when net benefits of Alternative A are computed for every element Θ_i^j. In other words, when the uncertain parameters take the value indicated by Θ_i^j, the performance curve of Alternative A indicates the net benefits that Alternative A will yield.

Figure 3-4 shows the curve of net benefits of an hypothetical alternative under uncertain discount rate. The internal rate of return of the alternative is for what the net benefits curve is zero. For discount rates higher than the

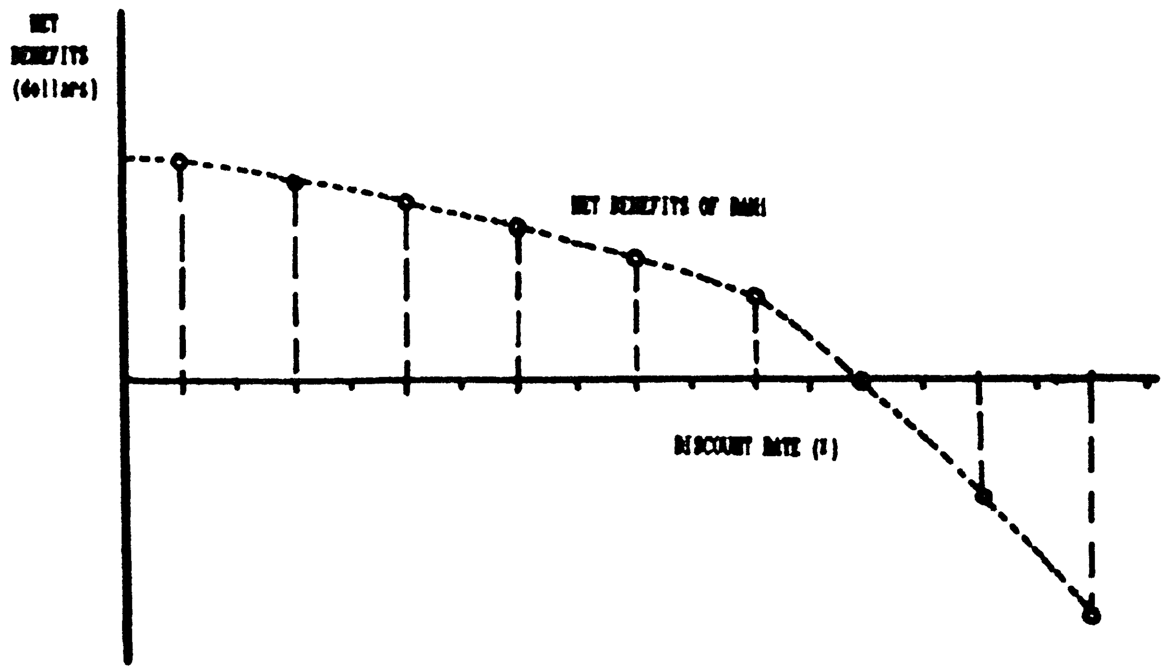

FIGURE 3-4: *Net benefits curve of an hypothetical alternative under uncertain discount rate*

internal rate of return, the net benefits curve takes negative values, because benefits from the alternative are smaller than the costs of building it.

The two measures of performance of candidate alternatives that are of concern in our study (expected value of net benefits and robustness) are based on the net benefits curves.

<u>Expected Value of Net Benefits of an Alternative</u>

For a given candidate alternative, the expected value of net benefits can be calculated by adding net benefits for each uncertain situation $\Theta_i{}^j$, weighted by the respective probabilities of $\Theta_i{}^j$. The net benefits are given by the net benefits curve just calculated. The probabilities have also been calculated before: $p(\Theta_i{}^j)$. Therefore, for Alternative A, the expected value of net benefits is given by:

$$E\ [NB\ (A)] = \Sigma\ NB\ [X^A \mid \Theta_i{}^j]\ p(\Theta_i{}^j)$$
$$i = 1, 2, .., n$$
$$j = 1, 2, .., M_i$$

E [NB (A)] is evidently a scalar value.

The same process has to be done for the rest of candidate alternatives.

Index of robustness

For a given candidate alternative, robustness is related to the possible variation in net benefits which result from uncertainty. This variation measured with respect to the potential of the basin, as shown in Chapter 1. And the potential of the basin is represented by the ideal net benefits curve calculated in Step 1. On the other hand, for the given alternative, net benefits under uncertainty are represented by its net benefits curve, already calculated at the beginning of Step 3. The difference between the ideal net benefits curve and the net benefits curve shows how far the given alternative is from reaching the potential of the basin. We call that difference the "Delta Curve" of the given alternative. Delta curves are important because robustness may be related to their shape as proved below.

The mathematical representation of the delta curve of Alternative A is :

$$\delta\ [X^{A} \mid \Theta_i^{\ J}] = NB\ [X^{*}(\Theta_i^{\ J})] - NB\ [X^{A} \mid \Theta_i^{\ J}]$$

Figure 3-5 shows the delta curve of the hypothetical alternative shown in Figure 3-4, obtained by subtracting Figure 3-4 (net benefits curve of the hypothetical alternative) from Figure 3-2 (the assumed ideal net benefits curve of the basin).

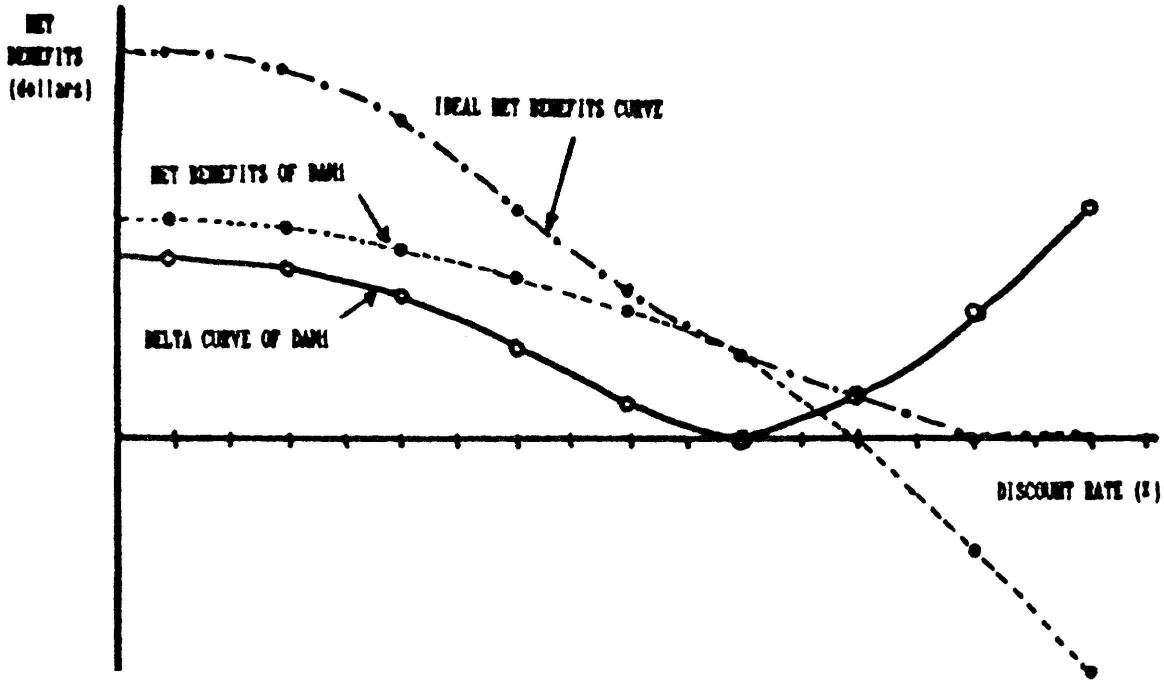

FIGURE 3-5: *Delta Curve of an hypothetical alternative, by subtracting the net benefits curve (Figure 3-4) from the ideal net benefits curve of the basin (Figure 3-2)*

It is interesting to note two characteristics in Figure 3-5. First, the ideal net benefits curve is not exceeded in any point by the net benefits curve of the alternative. Second, these two curves meet in a point. Therefore, at that corresponding discount rate, the delta curve is zero.

The delta curve is the basis for our study of robustness.

Its measure of differences from the optimum can be used to evaluate the variations in the performance of alternatives. Consider the two delta curves depicted in Figure 3-6. The curve for Alternative A indicates sensitive performance of this alternative under the uncertain variable Θ_i. When Θ_i is Θ_i^1, Alternative A is the best alternative to be built. But when Θ_i takes other values, there are big losses of potential net benefits, which indicates sensitive performance depending on Θ_i. On the other hand, Alternative B is never the best alternative for any value of Θ_i (its delta curve is never zero), but losses of potential net benefits are almost constant even for very different values of Θ_i, like Θ_i^2 and Θ_i^3. This indicates insensitive performance of Alternative B

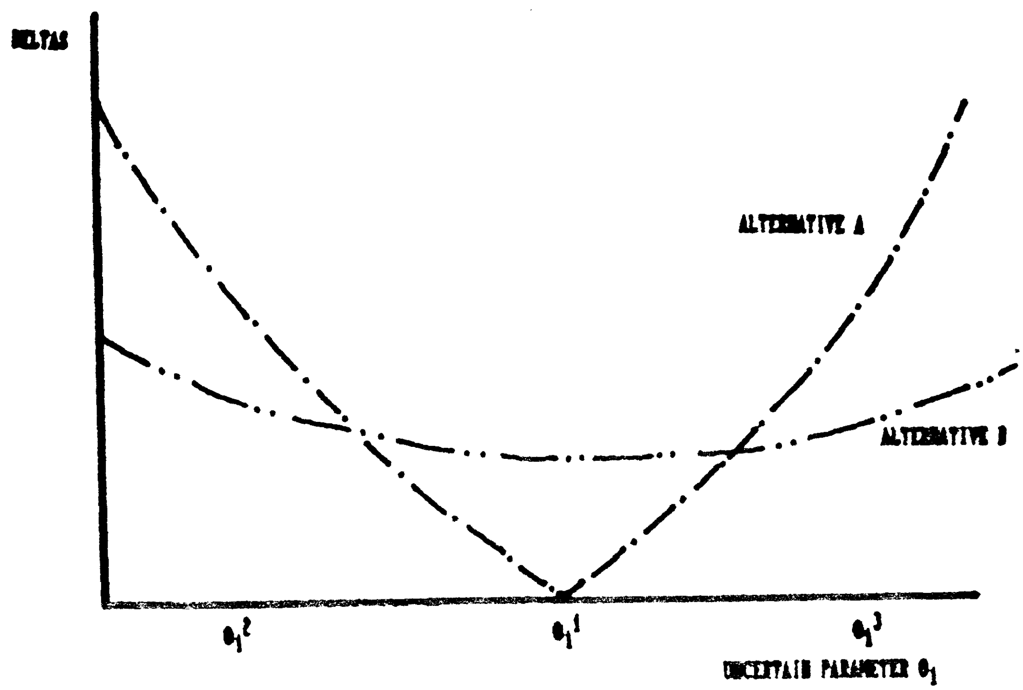

FIGURE 3-6: *Robustness related to the shape of the delta curve. Comparison between Alternative A, a non robust alternative, and Alternative B, a robust alternative.*

under the uncertain variable Θ_i. Alternative B is more robust than alternative A with respect to the uncertain parameter Θ_i.

As said before, robustness of an alternative is related to the shape of its delta curve. The question now is how to measure this robustness associated with the shape of the delta curves. We could measure this with the radius of curvature: the higher were the curvature, the higher would be the robustness. However this process is complex and can not be applied to all the cases, because delta curves may be piecewise linear, and then the radius of curvature can not be calculated. A simpler procedure is to calculate the coefficient of variation (CV) of the values that form the delta curve. If the alternative has great robustness, the delta curve is very horizontal (which means low dispersion in the distribution of net benefits with respect to the potential of the basin), and the coefficient of variation is very low. Similarly, if the alternative has low robustness, the delta curve is very tilted (which means high dispersion in the distribution of net benefits with respect to the potential of the basin), and the coefficient of variation is very high. A brief summary is:

High CV <---------> Low Robustness

Low CV <---------> High Robustness

The CV of the values of the delta curve is called the robustness index of the alternative. After this step, the performance of every candidate alternative is defined with two values: an expected value of net benefits and a robustness index.

3.1.4.- Step 4: Compare among alternatives

The performance of the candidate alternatives was evaluated in Step 3. Two performance measures are associated with every alternative: expected net benefits and robustness. The objective of the present step is collect these values for all candidate alternatives and to present this information in an easily understandable form that facilitate comparison and selection among alternatives.

We have a two-objective decision problem where expected net benefits and robustness both matter in alternative comparisons and final choice. Thus, we could only say that a candidate alternative is superior to another when both expected net benefits and robustness are greater. If only robustness is superior but not expected net benefits, we do not have an objective argument to prefer one alternative to another. The case is similar when only expected net benefits are superior but not robustness.

To easily visualize robustness and expected net benefits for all the projects, we consider a graph where expected net benefits are in the horizontal axis and robustness is in the vertical. Each alternative is represented as a point in the graph. Figure 3-7 shows the typical form of these graphs. These curves, called Pareto curves or Pareto frontier, are common in two-objective evaluation methods.

The vertical axis represents robustness. In order for robustness to increase as we move up in the axis, we represent robustness by N - CV (where N is a "large" fixed number, like 4 or 5). If instead of representing N - CV, we represent directly CV, robustness increases as we go down in the vertical axis. This creates an unconventional, although valid, representation of this kind of curves.

The Pareto frontier is formed by candidate alternatives which are not inferior to others. An Alternative B is inferior to an Alternative A, when B has smaller both expected net benefits and robustness than A. Alternative B could be omitted from the final evaluation and does not enter in the Pareto frontier.

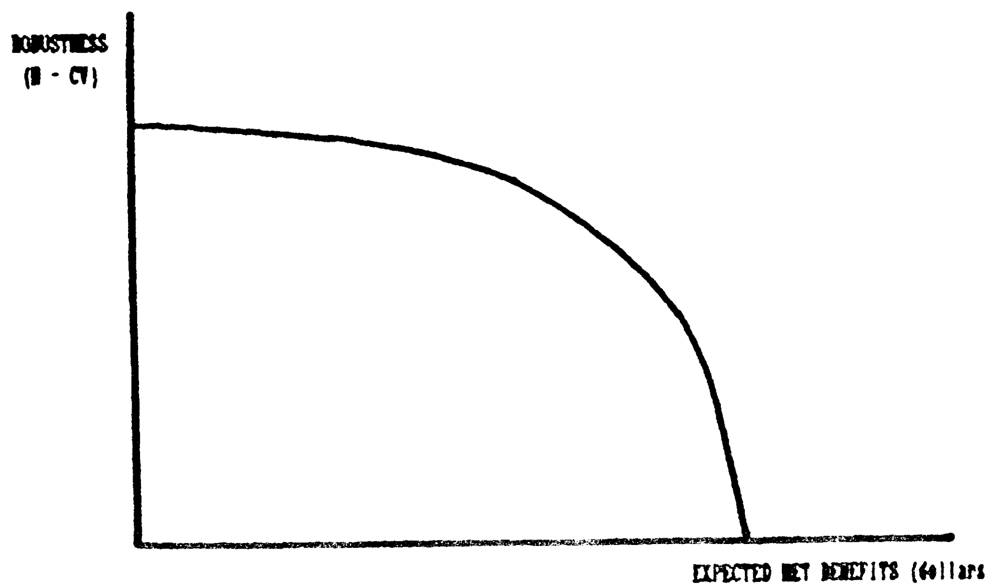

FIGURE 3-7: *Typical form of the Pareto frontier curves*

Elimination of inferior alternatives, can be done from direct inspection of the Pareto curve: those alternatives which fall inside of the frontier curve are inferior and should be eliminated. Minimum expected net benefits and robustness may also be required. Development of minimum requirements for expected net benefits is a political decision. From the analysts' point of view, alternatives which yield expected net benefits greater than zero are viable. However, other minimum requirements (greater or smaller than zero) may be politically imposed. To decide minimum requirements for robustness is harder. An index of robustness equal to 1 indicates that the CV of the delta curve is 1. In other words, the standard deviation of the delta values is equal to the mean value. In some cases, CV=1 can be considered an acceptable value. However, if CV=2, the standard deviation is twice the value of the mean. This indicates great dispersion in the values of the delta curve, and consequently very low robustness. CV=2 is almost always an unacceptable value.

Figure 3-8 illustrate this concepts for an hypothetical case, with minimum required net benefits of NB_1 and minimum required robustness of CV_1

3.1.5.- Final remarks

The two-objective analysis of the water system ends at this stage. The outcome is not one single best alternative,

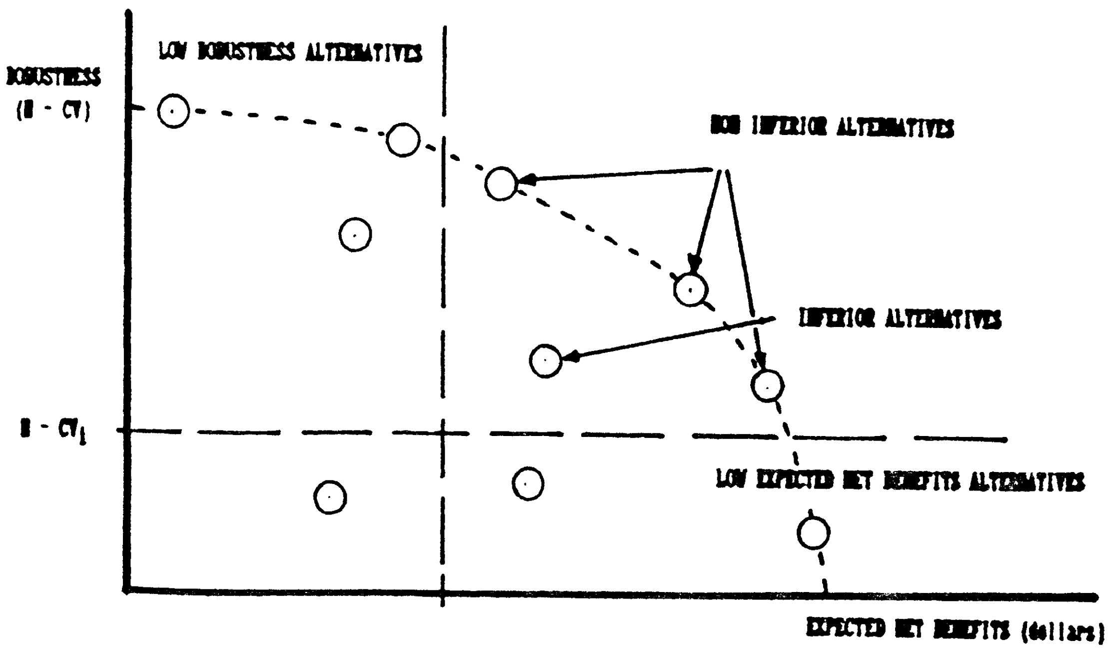

FIGURE 3-8: *Derivation of the Pareto frontier curve*

although it could be if the non-inferior set only includes formed for one alternative. There not always exists such an optimum alternative If it exists, it should have the greatest robustness and expected net benefits at the same time. But normally there is a trade-off between robustness and net benefits: to choose a more robust alternative it may be necessary to give up some net benefits, and vice versa. The lack of a final global best alternative could be regarded as a limitation of the method. But I think that it is an advantage, because the purpose of the method is to help the decision making process, revealing a limited number of candidate alternatives with enough data for comparison and decision.

The method applies to general and complex water resources systems. The method does not have more limitations than the imposed by the optimization technique used to solve the screening models of Step 1.

A practical summary of the method is indicated below.

Objective:

To identify a limited set of non-inferior alternatives in a two-objective analysis (robustness and expected net benefits), and display the information in a Pareto graph.

Procedure:

STEP 1. Derive the ideal net benefits curve

The ideal net benefits curve serves as reference for evaluating the performance of the candidate alternatives. It is derived as follows:

a.) Formulate the screening model for the basin

b.) Perform M_1 M_2 M_n optimization runs by using the screening model, one for every vector $\Theta_1{}^j$

c.) Obtain the ideal net benefits curve: NB $[X^*(\Theta_1{}^j)]$

d.) Obtain an optimal set of decision variables: $X^*(\Theta_1{}^j)$

STEP 2. Select candidate alternatives

The candidate alternatives will later define the Pareto curve, and one of them will be chosen for implementation.

a.) Calculate probability distributions of the M_1 M_2 M_n values of each design decision variables, obtained from the optimization runs of Step 1

b.) Depict bar graphs of these distributions, and identify the two or three most likely values of every design decision variables

c.) Construct a compatibility - incompatibility table

d.) Generate candidate alternatives by combining the most likely values of the design decision variables while satisfying the compatibility table

STEP 3. Assess the performance of the candidate alternatives

a.) Formulate a model for every alternative

b.) For each candidate alternative, perform M_1 M_2 M_n optimization runs in order to optimize operation rules and calculate the maximum possible net benefits

c.) Obtain the net benefits curves: NB $[X^A \mid \Theta_i^j]$

d.) Calculate E [NB] values for each candidate alternative:

$$E\ [NB\ (A)] = \Sigma\ NB\ [X^A \mid \Theta_i^j]\ p(\Theta_i^j)]$$

e.) Obtain the delta curves

$$\delta\ [X^A \mid \Theta_i^j] = NB\ [X^*(\Theta_i^j)] - NB\ [X^A \mid \Theta_i^j]$$

f.) Calculate CV (δ) values. These measure the robustness of each candidate alternative

STEP 4. Compare among alternatives

a.) Plot an Expected Net Benefits versus N - CV (δ) graph

b.) Eliminate inferior alternatives

c.) Set minimum requirements for expected net benefits and robustness

d.) Present the Pareto non-inferior set of alternatives

CHAPTER 4: CASE STUDY

The purpose of this chapter is to demonstrate the practical viability and usefulness of the method described in Chapter 4. This case study does not correspond to a real basin. However, most of the coefficients and parameters correspond to the Rio Colorado basin in Argentina, exposed in Major and Lenton [1979]. The size of the case study is large enough to show the general applicability of the method, but also small enough to easily illustrate each step of the method.

The optimization algorithm used to solve the screening models and to optimize operation rules of the candidate alternatives is linear programming (LP). Therefore, the first simplification of the case study is that the objective function and constraints of the screening model have to be expressed as linear equations. This simplification is not a limitation of the method, but imposed by the LP optimization technique. Most of the real world planning situations use linear programming as the optimization technique [Rogers, 1979]. Hence, approximation of relationships and constraints by linear equations is a common practice.

The computer used to run the LP package was a personal computer IBM AT. Computer time was extensive because, although the method does not requires very sophisticated computer facilities, it requires many independent optimization runs: 243 runs for the screening model, and 243 runs to optimize operating rules of each candidate alternative (14 candidate alternatives times 243 runs for each, results in 2402 runs). Each run for the screening model took about 14 minutes; each run to optimize operating rules of the candidate alternatives took about 2 minutes. Therefore the total computer time was about 231 hours.

4.1.- DESCRIPTION OF THE CASE STUDY

The object of this case study is to decide what hydraulic projects are to be built in a hypothetical river basin. We assume that the development of the basin is an important part of a regional development plan, and we are interested in getting as much benefit as possible from the river. But, since there are several uncertain variables that affect the amount of benefit to be obtained from the basin, we are also concerned with obtaining a robust development strategy which is insensitive to the existing uncertainty. Our task is to identify the non-inferior set of projects that represents the trade-off curve between robustness and expected net benefits.

The scheme of the basin is shown in Figure 4-1. There are four possible dams, three possible irrigation areas, two possible hydropower plants, and a possible transfer. Any of

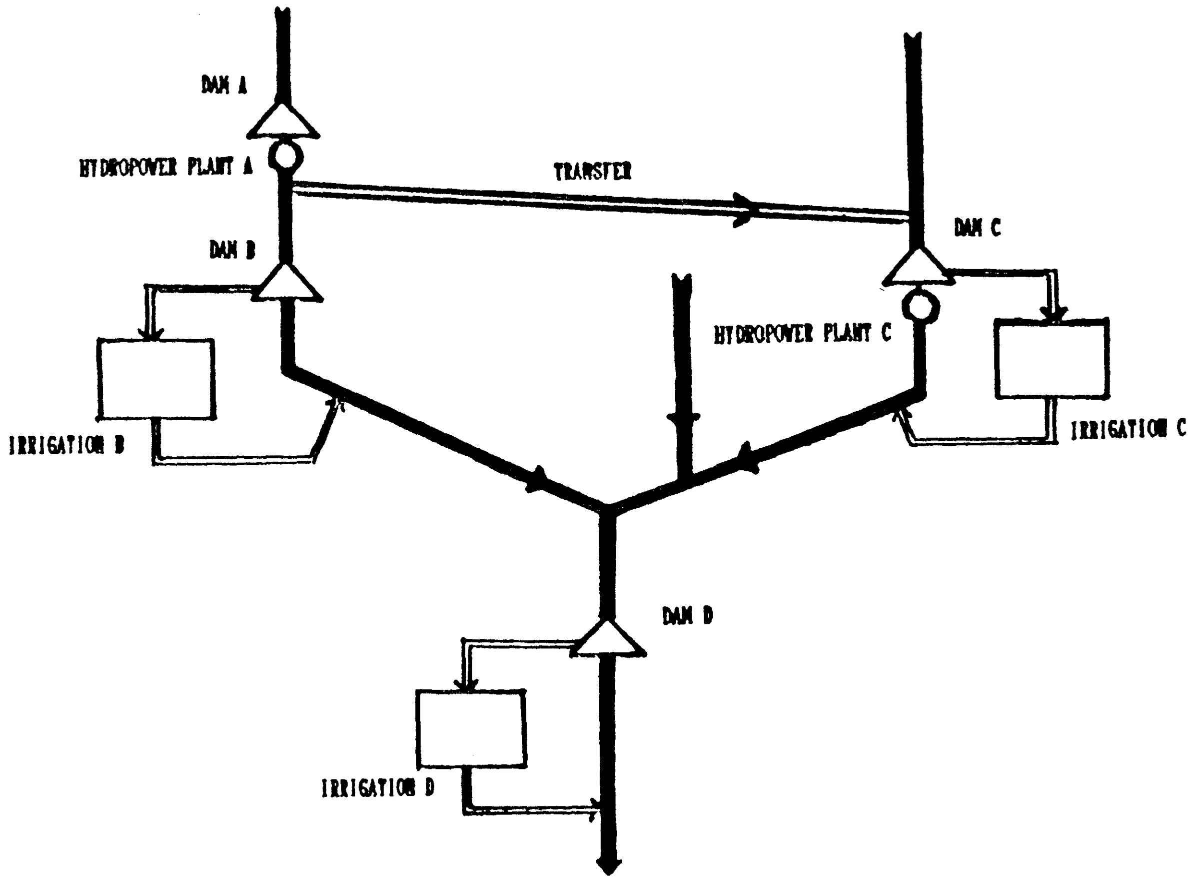

FIGURE 4-1: *Scheme of the basin*

these projects could be built in the basin. Most of the data for these projects has been taken from the characteristics of real projects in the Rio Colorado in Argentina, as described in Chapters 9 and 10 of Major and Lenton [1979].

Before formulating a screening model for the basin, we have to define the typical year. The screening model considers that benefits and costs for this typical year are repeated throughout the project lifetime. River inflows are assumed at the heads of the three upstream tributaries of the main river. Inflows enter in the model as average inflows for each season of the typical year. There are no tributary inflows nor outflows in the river course. A downstream minimum flow requirement exists to provide water to downstream users and for ecological reasons. The minimum downstream flow is 40 % of the total river upstream inflows. Figure 4-2 shows the total yearly inflows of the river in its upstream branches.

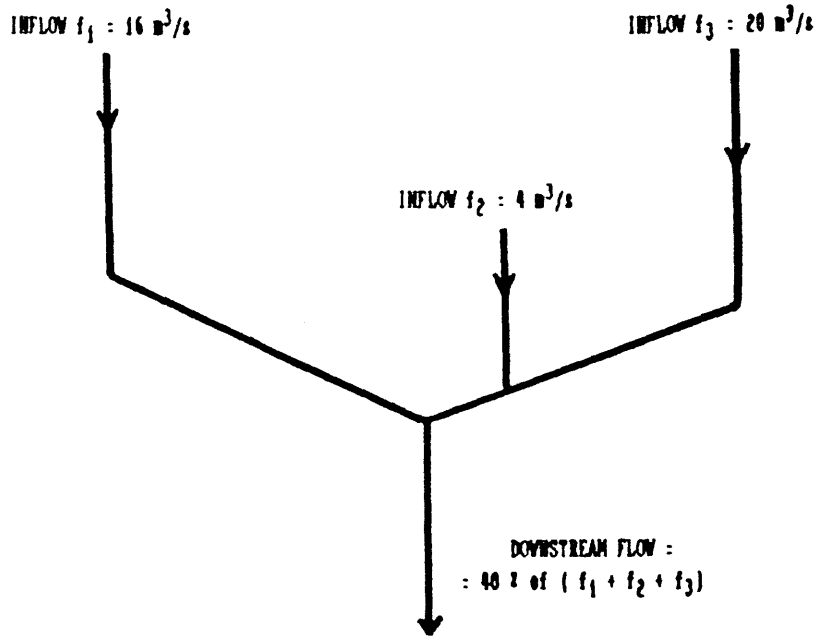

FIGURE 4-2: *Total river inflows for the typical year*

The typical year has three seasons. The three seasons are Season I, from January to April (medium flow season); Season II, from May to August (low flow season); and Season III, from September to December (high flow season). Figure 4-3 shows the seasonal distribution of yearly inflows. The demands for water for irrigation are medium in Season I, maximum in Season II, and zero in Season III, as shown in Figure 4-4.

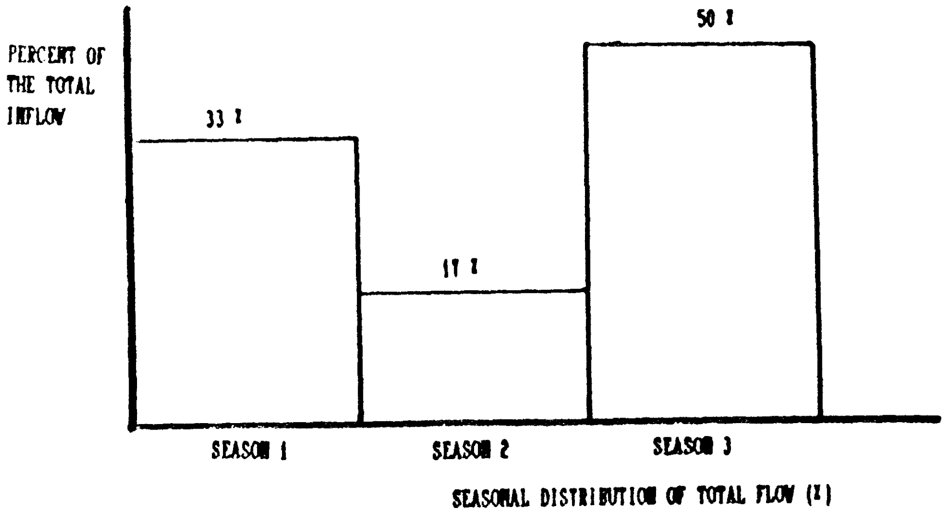

FIGURE 4-3: *Seasonal distribution of total river inflows for the typical year*

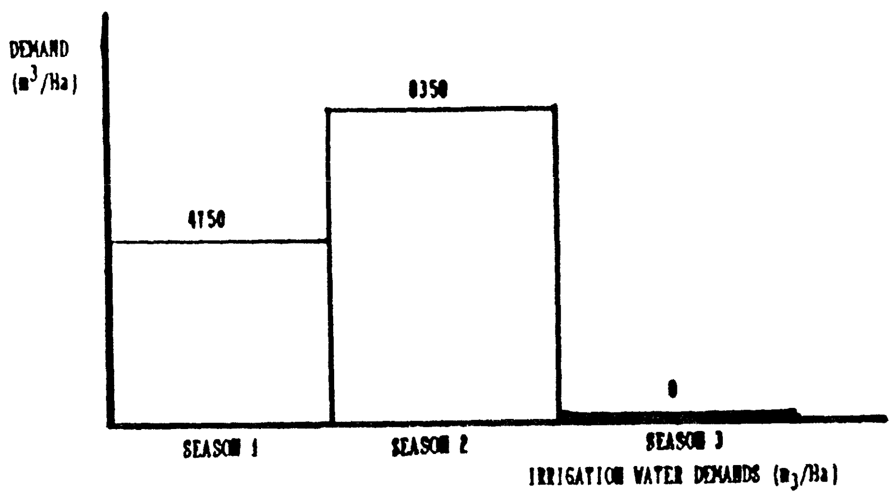

FIGURE 4-4: *Water demands for irrigation in the typical year*

For simplicity, the two hydropower plants are assumed to have fixed heads. Otherwise, we would obtain a non-linear term in the screening model (power is proportional to the product of head and flow), and to linearize it would be very time consuming. In this case study, hydropower plants can be built without requiring the construction of their associated dam, since the dam is not needed to create head. However, irrigation areas do require the construction of their associated dam. The dam could serve only to divert water to the irrigation area without storing any water, or could also serve for regulation and interseasonal storage.

This case study considers that irrigation areas return non-consumed water to the river. No groundwater inflows or losses to groundwater are included. The water not consumed by crops returns to the river in three stages: some water returns immediately in the same season (before 4 months); some water returns in the next season (between 4 and 8 months later); and the rest of water returns in two seasons (between 8 and 12 month later). After two seasons, all non-consumed water has already returned to the river. Figure 4-5 shows the seasonal return of non-consumed water. In this figure, the top graph refers to the return of non-consumed water during irrigation in Season I, and the bottom graph is for non-consumed water during irrigation in Season II. No graph exits for Season III because there is no irrigation in Season III.

The transfer connects the left upstream branch of the river with the right upstream branch. The transfer acts in only one direction: from the left branch to right branch. Water is assumed to move by gravity, without needing elevation pumps nor operation costs.

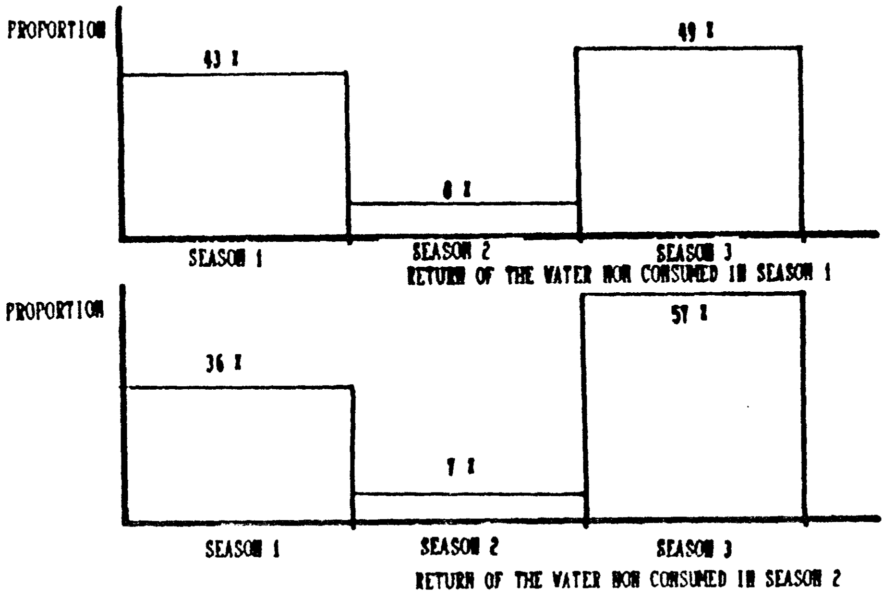

FIGURE 4-5: *Return of the irrigation water non-consumed by crops*

4.2.- SCREENING MODEL

The screening model is formed by mathematical equations that describe the physical and economic relationships existing in the basin. These are identified for a typical year that is assumed to be repeated during the project lifetime. In the particular case of this case study, the screening model is an mixed linear-integer programming model with 34 decision variables (10 project sizes and 24 operational variables) and 10 integer variables (whose value is 0 or 1). Decision variables, objective function, and constraints are discussed below. Appendix A contains the screening model formulation and the summary of variables. The framework for this screening model is taken from Chapter 5 of Major and Lenton [1979].

4.2.1.- DECISION VARIABLES

There are two types of decision variables in this screening model. The first type is "design" decision variables. Design decision variables are the size of the projects of the water resources system. There are 10 design decision variables, one for each project:

V_A : Volume of Reservoir A (Hm^3)
V_B : Volume of Reservoir B (Hm^3)
V_C : Volume of Reservoir C (Hm^3)
V_D : Volume of Reservoir D (Hm^3)
A_B : Area of Irrigation B (Ha)
A_C : Area of Irrigation C (Ha)
A_D : Area of Irrigation D (Ha)
C_A : Capacity of hydropower Plant A (MW)
C_C : Capacity of hydropower Plant C (MW)
T : Size of the Transfer (m^3/s)

The second type is "operational" decision variables. Releases from reservoirs, water diverted to irrigation areas, and water diverted to the transfer are the operational decision variables. There are 24 operation decision variables, 12 corresponding to the releases from the reservoirs (four dams times three seasons), 9 corresponding to the water diverted for irrigation (three irrigation areas times three seasons), and 3 corresponding to the water diverted to the transfer. There are not any operational decision variable for the hydropower plants. If the dam associated with the plant is built, the operation of the plant is given by the releases from the reservoirs. If the dam is not built, the plant operation depends directly on the flow in the river. The operational decision variables are:

$R_{A,t}$: Releases from Reservoir A (t = season 1, 2, or 3)

$R_{B,t}$: Releases from Reservoir B (t = season 1, 2, or 3)
$R_{C,t}$: Releases from Reservoir C (t = season 1, 2, or 3)
$R_{D,t}$: Releases from Reservoir D (t = season 1, 2, or 3)
$I_{B,t}$: Water diverted to Irrigation B (t = season 1, 2, or 3)
$I_{C,t}$: Water diverted to Irrigation B (t = season 1, 2, or 3)
$I_{D,t}$: Water diverted to Irrigation B (t = season 1, 2, or 3)
T_t : Water diverted to the Transfer (t = season 1, 2, or 3)

In this case study, we are only concerned about the design decision variables. Design decision variables indicate what projects are to be built and what projects are not to be built. Also, for those projects to be built, design decision variables indicate their optimal sizes.

4.2.2.- OBJECTIVE FUNCTION

The objective function is a measure of economic efficiency, or in other words, of benefits minus costs for the typical year. Benefits come from the agricultural products evaluated at their selling prices, and from the produced electricity evaluated at its market price. The general mathematical equation for benefits is:

$$B = \sum_{\substack{s = B, C, D \\ t = 1, 2}} [\Theta_1 \; L_{s,t}] + \sum_{\substack{s = A, C \\ t = 1, 2, 3}} [\Theta_2 \; P_{s,t}]$$

where:

B : Annual benefits ($)
Θ_1 : Price of agricultural products ($/Ha)
$L_{s,t}$: Land irrigated at Irrigation s in season t (Ha)
Θ_2 : Price of electricity ($/MWh)
$P_{s,t}$: Power produced at Plant s in season t (MWh)

The coefficients Θ_1 (crop prices) and Θ_2 (electricity prices) are considered uncertain. Instead of a fixed value, we assume a probability distribution of their possible values

(Figure 4-6 and Figure 4-7). Section 4.2.4. briefly explain the reasons to consider Θ_1 and Θ_2 as uncertain parameters.

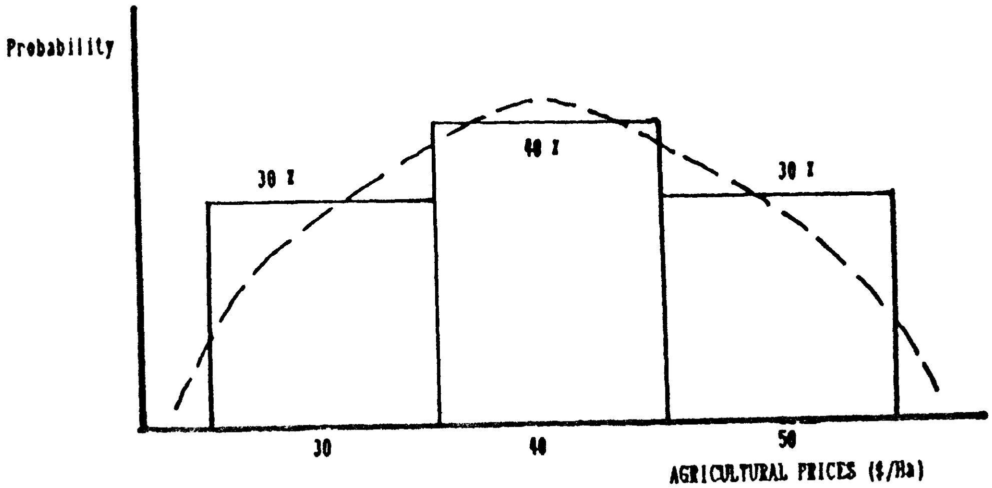

FIGURE 4-6: *Assumed probability distribution of Θ_1: crop prices*

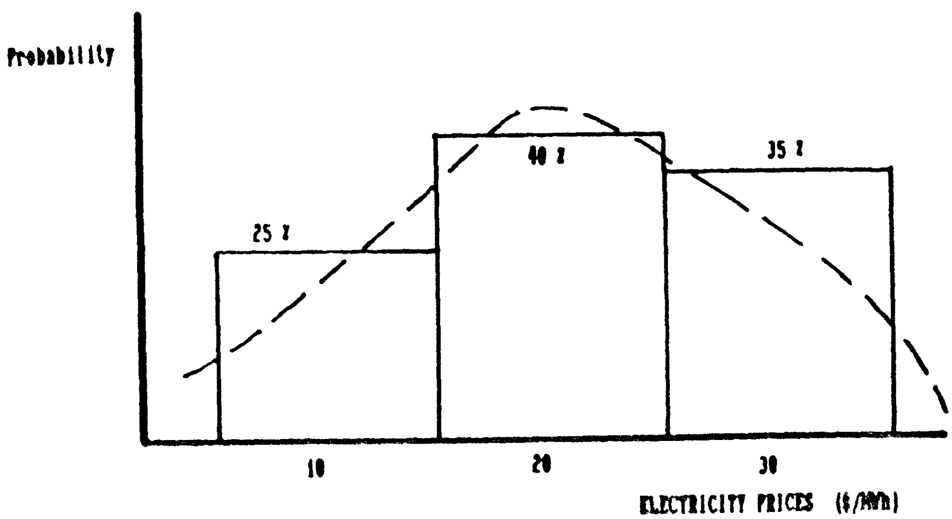

FIGURE 4-7: *Assumed probability distribution of Θ_2: electricity prices*

Costs are only incurred from construction of the projects, because no operating costs are considered. The costs for the typical year result from the amortization of construction costs over the project lifetime with a given discount rate Θ_3%. The formula is:

$$C = CC\ [(1 + \Theta_3)^n\ \Theta_3]\ /\ [(1 + \Theta_3)^n - 1]$$

where:

- C : Annual costs ($)
- CC : Total construction costs ($)
- Θ_3 : Discount rate (%)
- n : Projects lifetime (years)

For example, if the discount rate is Θ_3 = 10% and the projects lifetime is 50 years, the costs for the typical year are 0.101 times the total construction costs.

The coefficient Θ_3 (discount rate) is considered uncertain. Figure 4-8 shows its probability distribution, and Section 4.2.4. briefly justifies the uncertainty in Θ_3.

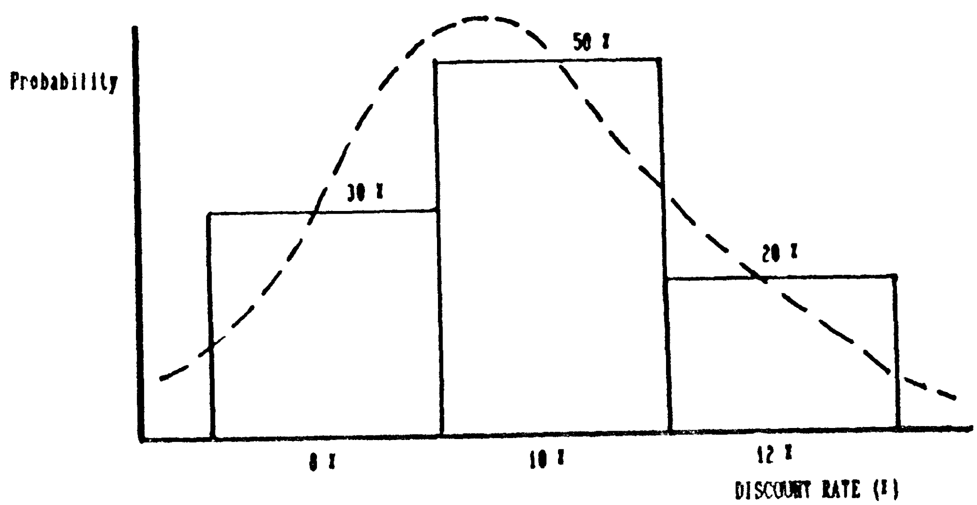

FIGURE 4-8: *Assumed probability distribution of Θ_3: discount rate*

The costs of construction of any project have two terms: a fixed cost term independent on the project size, and a variable cost term dependent on the size of the project. For example, the cost of construction of a dam has fixed costs (fixed machinery, personnel, offices, etc.) and variable costs that depend on how big the dam is (volume of excavation, volume of concrete, amount of labor, etc.). Appendix B includes four graphs that indicate the construction costs for every facility. Figure A-1 shows construction costs for the dams, Figure A-2 for the irrigation areas, Figure A-3 for the hydropower plants, and Figure A-4 for the transfer. Table 4-1 summarizes the numerical coefficients.

TABLE 4-1: *Fixed and variable costs for the possible projects to be built in the basin*

PROJECT	FIXED (10^6 \$)	VARIABLE	
Dam A	FV_A: 1.50	α_A: 0.0044	(10^6 \$/Hm^3)
Dam B	FV_B: 1.50	α_B: 0.0176	(10^6 \$/Hm^3)
Dam C	FV_C: 3.00	α_C: 0.0056	(10^6 \$/Hm^3)
Dam D	FV_D: 2.00	α_D: 0.0104	(10^6 \$/Hm^3)
Irrigation B	FA_B: 0.25	β_B: 0.000082	(10^6 \$/Ha)
Irrigation C	FA_C: 0.50	β_C: 0.000247	(10^6 \$/Ha)
Irrigation D	FA_D: 1.00	β_D: 0.000536	(10^6 \$/Ha)
Plant A	FC_A: 1.00	τ_A: 0.050	(10^6 \$/MW)
Plant C	FC_C: 1.50	τ_C: 0.077	(10^6 \$/MW)
Transfer	FT : 1.50	μ : 0.140	(10^6 \$/(m^3/s))

The general mathematical equation for construction costs (CC) is:

$$CC = \Theta_4 \left[\sum_{s=A,B,C,D} (V_s \alpha_s + FV_s YV_s) + \sum_{s=B,C,D} (A_s \beta_s + FA_s YA_s) + \right.$$

$$\left. + \sum_{s=A,C} (C_s \tau_s + FC_s YC_s) + (T \mu + FT\ YT) \right]$$

where:

Θ_4 : General increase or decrease in construction costs (%)

V_s : Volume of Reservoir s (s = A, B, C, D) (Hm^3)
α_s : Variable costs of Reservoir s ($/$Hm^3$)
FV_s : Fixed costs of Reservoir s ($)
YV_s : Integer variable for Reservoir s:
If Reservoir s is built: $YV_s = 1$
If Reservoir s is not built: $YV_s = 0$
A_s : Area of Irrigation s (s = B, C, D) (Ha)
β_s : Variable costs of Irrigation s ($/Ha)
FA_s : Fixed costs of Irrigation s ($)
YA_s : Integer variable for Irrigation s:
If Irrigation s is built: $YA_s = 1$
If Irrigation s is not built: $YA_s = 0$
C_s : Capacity of hydropower Plant s (s = A, C) (MW)
τ_s : Variable costs of Plant s ($/MW)
FC_s : Fixed costs of Plant s ($)
YC_s : Integer variable for Plant s:
If Plant s is built: $YC_s = 1$
If Plant s is not built: $YC_s = 0$
T : Size of the Transfer (m^3/s)
μ : Variable costs of Transfer [$/($m^3/s$)]
FT : Fixed costs of Transfer ($)
YT : Integer variable for Transfer:
If Transfer is built: $YT_s = 1$
If Transfer is not built: $YT_s = 0$

The variable and fixed costs coefficients α_s, FV_s, β_s, FA_s, τ_s, FC_s, μ, and FT are found in Table 4-1. The coefficient Θ_4 (general increase or decrease in construction costs) is considered uncertain. Figure 4-9 shows its assumed probability distribution, and Section 4.2.4. discusses it.

After defining benefits and costs, the objective function can be expressed as:

$$\max_{\{\text{decision variables}\}} \quad B - C$$

where B are the benefits for a typical year and C are the costs for a typical year.

4.2.3.- CONSTRAINTS

The screening model of this case study includes seven

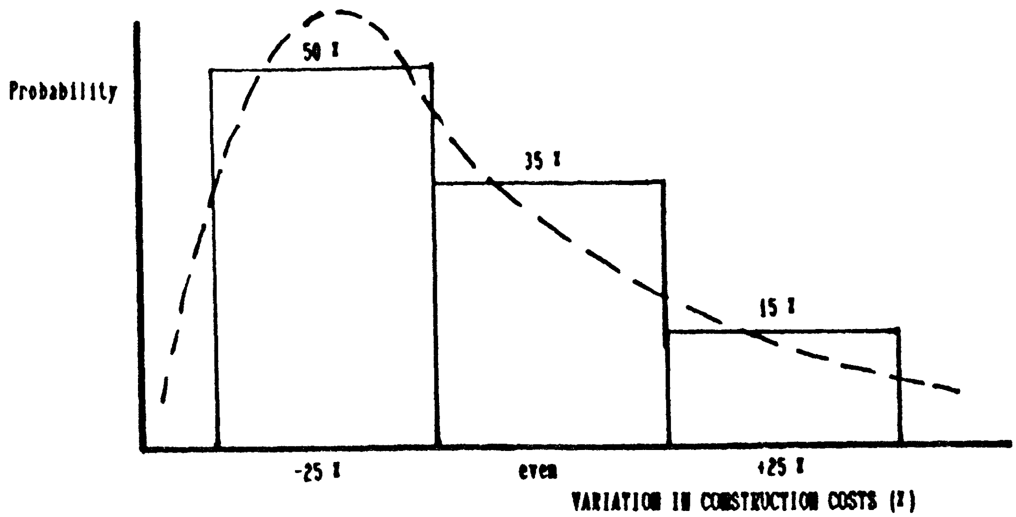

FIGURE 4-9: *Assumed probability distribution of Θ_4: general increase or decrease in construction costs*

sets of constraints. Instead of repeating Major and Lenton [1979], Chapter 5, this section briefly discusses the special characteristics of the constraints for this case study, and refers to Major and Lenton [1979] for details.

(1) Continuity constraints. Continuity constraints insure conservation of mass in the reservoirs: all water that enters in a reservoir must be stored in it, released, diverted, or lost through evaporation of subsurface leakage. There are three equations for every dam, one per season. There are also equations for continuity between dams. Three additional equations are necessary to indicate the minimum downstream requirements. The explicit mathematical notation is:

- for Dam A:

$$S_{A,t+1} = S_{A,t} - R_{At} + f_{1t} - e_{At} S_{A,t}$$

where:

$S_{A,t}$: Storage in Reservoir A in season t (t = 1, 2, 3)
R_{At} : Releases from Reservoir A in season t
f_{1t} : Inflows of the left branch of the river in season t
e_{At} : evaporation coefficient of Reservoir A in season t

- continuity between Dam A and Dam B:

$$I_{Bt} = R_{At} - TR_t$$

where:

I_{Bt} : Inflows in Reservoir B in season t
TR_t : Flow of the Transfer in season t

- for Dam B:

$$S_{B,t+1} = S_{B,t} + I_{Bt} - R_{Bt} - D_{Bt} - e_{Bt} S_{B,t}$$

where:

$S_{B,t}$: Storage in Reservoir B in season t (t = 1, 2, 3)
R_{Bt} : Releases from Reservoir B in season t
D_{Bt} : Water diverted to Irrigation B in season t
e_{Bt} : evaporation coefficient of Reservoir B in season t

- for Dam C:

$$S_{C,t+1} = S_{C,t} + f_{3t} + TR_t - R_{Ct} - D_{Ct} - e_{Ct} S_{C,t}$$

where:

$S_{C,t}$: Storage in Reservoir C in season t (t = 1, 2, 3)
f_{3t} : Inflows of the right branch of the river in season t
R_{Ct} : Releases from Reservoir C in season t
D_{Ct} : Water diverted to Irrigation C in season t
e_{Ct} : evaporation coefficient of Reservoir C in season t

- continuity between dams B and C and Dam D:

$$I_{Dt} = R_{Bt} + R_{Ct} + f_{2t} + RI_{Bt} + RI_{Ct}$$

where:

I_{Dt} : Inflows in Reservoir D in season t
f_{2t} : Inflows of the center branch of the river in season t
RI_{Bt} : Water that return to the river in season t from Irrigation B
RI_{Ct} : Water that return to the river in season t from

Irrigation C

- for Dam D:

$$S_{D,t+1} = S_{D,t} + I_{Dt} - R_{Dt} - D_{Dt} - e_{Dt} S_{D,t}$$

where:

$S_{D,t}$: Storage in Reservoir D in season t ($t = 1, 2, 3$)
R_{Dt} : Releases from Reservoir D in season t
D_{Dt} : Water diverted to Irrigation D in season t
e_{Dt} : evaporation coefficient of Reservoir D in season t

- for downstream requirements (40 % of all river inflows):

$$R_{Dt} + RI_{Dt} \geq 0.4\,(f_{1t} + f_{2t} + f_{3t})$$

where:

RI_{Dt} : Water that return to the river in season t from Irrigation D

The values of the inflow parameters f_{1t}, f_{2t}, and f_{3t} ($t = 1, 2, 3$) can be calculated from Figure 4-2 and Figure 4-3. The values of the evaporation coefficients e_{At}, e_{Bt}, e_{Ct}, and e_{Dt} ($t = 1, 2, 3$) are indicated in Table 4-2.

<u>(2) Reservoir maximum storage.</u> The storage of the reservoir in any season can not exceed the volume of the reservoir. There are three equations per dam. The explicit mathematic formulation is:

$$S_{A,t} \leq V_A$$
$$S_{B,t} \leq V_B$$
$$S_{C,t} \leq V_C$$
$$S_{D,t} \leq V_D$$

where V_A, V_B, V_C, V_D are the design decision variables that represent the volume of the reservoirs (see Section 4.2.1. above)

(3) Water requirements for irrigation. These constraints show the relationships between water divested for irrigation and

TABLE 4-2: *Parameters needed for the screening model*

Project lifetime: n — 50 years

Evaporation from the reservoirs: e_{st}

	SEASON 1	SEASON 2	SEASON 3
DAM A	1%	3%	1%
DAM B	2%	5%	1%
DAM C	5%	9%	3%
DAM D	7%	10%	3%

Irrigation channel losses: ϵ_s

IRRIGATION B	4%
IRRIGATION C	6%
IRRIGATION D	10%

Consumptive use of water in irrigation: ϕ

65% of the irrigation water is consumed

Coefficients of hydropower plants

Head of Plant A:	100 m
Head of Plant C:	50 m
Efficiency:	0.65
Load factor:	0.86
Factor of utilization:	0.68

the land irrigated. Water losses in the irrigation channels are also considered. There are six equations, two for each irrigation area. Six more equations indicate that the irrigated surfaces in each period can not exceed the irrigation project areas. The mathematical formulation is:

- water requirements for irrigation

$$(1 - \epsilon_B)\, D_{Bt} = \theta_5\, \Gamma_t\, L_{Bt}$$

$$(1 - \epsilon_C)\ D_{Ct} = \Theta_5\ \Gamma_t\ L_{Ct}$$
$$(1 - \epsilon_D)\ D_{Dt} = \Theta_5\ \Gamma_t\ L_{Dt}$$

where:

- ϵ_B : water losses in Irrigation B channels
- ϵ_C : water losses in Irrigation C channels
- ϵ_D : water losses in Irrigation D channels
- Θ_5 : general increase or decrease in irrigation water demands
- Γ_t : irrigation water demands in season t (t = 1, 2)
- L_{Bt} : land irrigated in Irrigation B in season t
- L_{Ct} : land irrigated in Irrigation C in season t
- L_{Dt} : land irrigated in Irrigation D in season t

– maximum irrigation per season:

$$L_{Bt} \leq A_B$$
$$L_{Ct} \leq A_C$$
$$L_{Dt} \leq A_D$$

where A_B, A_C, A_D are the design decision variables that represent the surface or the irrigation areas (see Section 4.2.1. above)

The values of the parameters ϵ_B, ϵ_C, ϵ_D are indicated in Table 4-2. The values of the parameters Γ_t (t = 1, 2, 3) are indicated in Figure 4-4. The parameter Θ_5 (general increase or decrease in irrigation water demands) is considered uncertain. Figure 4-10 shows its assumed probability distribution, that is discussed in Section 4.2.4.

(4) Irrigation water return. This constraint relates water diverted for irrigation with the return to the main river of the non consumed water. The mathematical formulation is:

$$RI_{Bt} = \Omega_{It}\ [(1 - \Phi)(1 - \epsilon_B)\ D_{Bt} + \epsilon_B\ D_{Bt}]$$
$$RI_{Ct} = \Omega_{It}\ [(1 - \Phi)(1 - \epsilon_C)\ D_{Ct} + \epsilon_C\ D_{Ct}]$$
$$RI_{Dt} = \Omega_{It}\ [(1 - \Phi)(1 - \epsilon_D)\ D_{Dt} + \epsilon_D\ D_{Dt}]$$

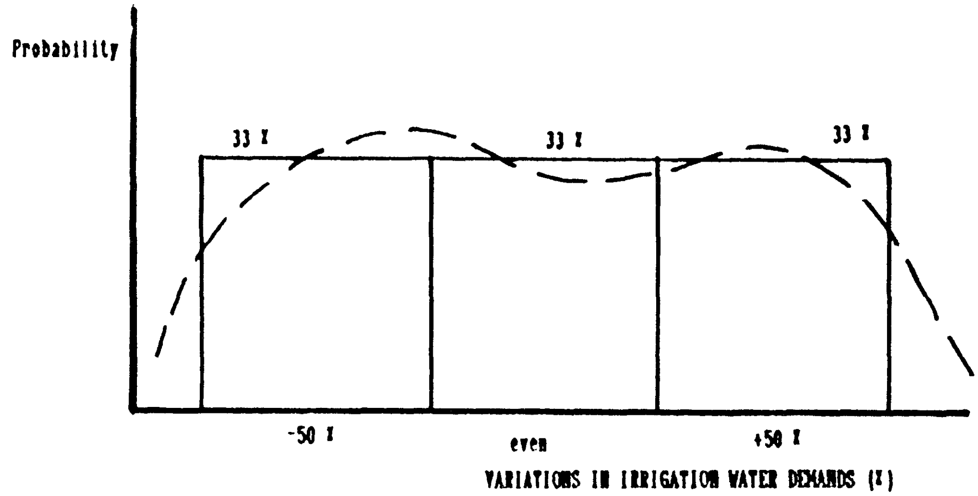

FIGURE 4-10: *Assumed probability distribution of θ_5: general increase or decrease in irrigation water demands*

where:

Ω_{it} : water non consumed in season i ($i = 1, 2$) that return to the river in season t ($t = 1, 2, 3$)

ϕ : water consumed by crops

The values of the parameters Ω_{it} can be calculated from Figure 4-5. The value of the parameter ϕ is indicated in Table 4-2.

(5) Hydropower constraints. The first set of constraints relates flow with electricity production. There is one equation for each season for each plant. The second set indicates that the electricity production in each season can not exceed the capacity of the plants. The mathematical representation is:

- electricity production:

$$P_{At} = (2.73\ 10^{-6})\ R_{At}\ H_A\ s_A\ k_t$$
$$P_{Ct} = (2.73\ 10^{-6})\ R_{Ct}\ H_C\ s_C\ k_t$$

where:

$P_{A,t}$: power produced at Plant A in season t (t = 1, 2, 3)
$P_{C,t}$: power produced at Plant C in season t
H_A : head of Plant A
H_C : head of Plant C
s_A : efficiency of Plant A
s_C : efficiency of Plant C
K_t : number of seconds in season t

- maximum electricity per season:

$$P_{At} \leq h_t \, lf \, u \, C_A$$
$$P_{Bt} \leq h_t \, lf \, u \, C_C$$

where:

h_t : number of hours in season t (t = 1, 2, 3)
lf : load factor
u : factor of utilization

and C_A and C_C are the design decision variables that represent the capacity of the hydropower plants (see Section 4.2.1. above)

The values of the parameters H_A, H_C, s_A, s_C, lf, and u are indicated in Table 4-2.

(6) Transfer size. These constraints limit the amount of water transferred in each season to the capacity of the transfer. In a general mathematical form:

$$TR_t \leq T$$

where:

TR_t : Flow of the Transfer in season t (t = 1, 2, 3)

and T is the design decision variable that represent the size of the Transfer (see Section 4.2.1. above)

(7) Conditionality and maximum sizes. Conditionality constraints indicate that to build an irrigation area the corresponding dam has also to be built. The maximum size

constraints ensure that if a project is built the fixed costs are included. There are ten of these equations, one for each project. The mathematical representation is:

- irrigation-dam conditionality:

$$A_B - AMAX_B \; YV_B \leq 0$$
$$A_C - AMAX_C \; YV_C \leq 0$$
$$A_D - AMAX_D \; YV_D \leq 0$$

- maximum size constraints:

$$V_A - VMAX_A \; YV_A \leq 0$$
$$V_B - VMAX_B \; YV_B \leq 0$$
$$V_C - VMAX_C \; YV_C \leq 0$$
$$V_D - VMAX_D \; YV_D \leq 0$$
$$A_B - AMAX_B \; YA_B \leq 0$$
$$A_C - AMAX_C \; YA_C \leq 0$$
$$A_D - AMAX_D \; YA_D \leq 0$$
$$C_A - CMAX_A \; YC_A \leq 0$$
$$C_C - CMAX_C \; YC_C \leq 0$$
$$T - TMAX \; YT \leq 0$$

The coefficients $VMAX_A$, $VMAX_B$, $VMAX_C$, $VMAX_D$, $AMAX_B$, $AMAX_C$, $AMAX_D$, $CMAX_A$, $CMAX_C$, and TMAX represent maximum sizes for the projects. These values can be obtained from Figures B-1 through Figure B-4.

4.2.4.- UNCERTAIN PARAMETERS

In this case study we consider the existence of five uncertain parameters: (1) crop prices, (2) electricity prices, (3) discount rate, (4) construction costs, and (5) irrigation water demands. Irrigation water demands affect the irrigation constraints. The other four uncertain parameters affect the objective function. This section briefly discusses the reasons for the uncertainty in these parameters.

Crop prices and electricity prices affect the benefits from the projects. Market fluctuations are very common for agricultural products depending on climatological conditions, crop productions, and international imports and exports. Crop prices are uncertain and affected for complex factors. Figure 4-6 shows the estimated distribution of crop prices. Electricity prices are more stable than crop prices and normally tend to rise. In rural areas, electricity may be subsidized when used as energy for pumping and irrigation as an incentive for agricultural development. This makes electricity cost an uncertain variable difficult to estimate (Figure 4-7).

The meaning and importance of the discount rate has been stressed in other parts of this thesis. We could assume that discount rate is the interest rate of the money borrowed for construction, money that has to returned yearly during 50 years. Therefore, the objective function is strongly affected for this variable. Figure 4-8 shows the assumed distribution of discount rates for the case study.

Construction costs have also a direct effect on the objective function. We have assumed that the only costs are those of construction. Therefore, if there is an increase in construction costs, all projects are more expensive and net benefits are reduced. Projects costs are a very uncertain factor in real situations. Most of the elements that define the construction costs of a project (labor costs, row materials, fuel, etc) are subject to uncertainty. The assumed probability distribution for construction costs is shown in figure 4-9.

Irrigation water demands are subject to great uncertainty. First, unexpected water losses could happen in irrigation channels and installations. This will require a greater amount of water to satisfy the irrigation requirements. Second, irrigation requirements are not perfectly defined. Physical conditions of soil and plants may differ from the initial forecasts. Third, different crops may be planted with different water requirements. All these factors create a great uncertainty in the amount of water demanded for irrigation, as can be seen in Figure 4-10.

4.3.- APPLICATION OF THE METHOD TO THE CASE STUDY

We have supposed here that the development of the river is an important aspect of the development of a rural area. People of that area want, of course, to obtain as much net benefit as they can. But they are equally concerned with the effect of uncertainty. They want robust projects that "guarantee" that even if uncertain conditions happen to be bad, they can still expect satisfactory performance from the projects. Our job as analysts is to decide, from all the projects indicated in Figure 4-1, what projects should be built and what projects should not be built. Also for the projects to be built, we have to decide their sizes. These projects have to provide acceptable net benefits and also the robustness that people want.

The method described in Chapter 4 is suited to solve this case. The method identifies a few candidate alternatives and evaluates their robustness and expected net benefits. After that, in a decision making process among the parties involved in the basin, each candidate alternative may be compared with the others. The comparison process consists in deciding how much robustness are people willing to give up to obtain more expected net benefits. The subsequent decision making process is beyond the scope of the method. What follows describes how the case study is solved using the method. The description is based in the step by step process indicated in Chapter 4.

4.3.1.- Step 1: Derive the ideal net benefits curve

There are five uncertain parameters in this case study. Therefore, the vector Θ is formed by five elements:

$$\Theta = \{\Theta_1, \Theta_2, \Theta_3, \Theta_4, \Theta_5\}$$

where:

Θ_1 = agricultural products prices (\$/Ha)
Θ_2 = electricity prices (\$/MWh)
Θ_3 = discount rate (%)
Θ_4 = construction costs (% increase)
Θ_5 = irrigation water demands (% increase)

Figures 4-6 through 4-10 showed the probability distribution of the uncertain parameters. To use these curves in the method, we have to divide them in discrete intervals. We divide each probability curve in three intervals. Table 4-3 summarizes the values of the intervals and their probabilities for every uncertain parameter.

TABLE 4-3: *Intervals in which the continuous probability distribution of the uncertain parameters have been divided*

VARIABLE	1st INTERVAL Value	Prob.	2nd INTERVAL Value	Prob.	3rd INTERVAL Value	Prob.	UNITS
Discount Rate	8%	30%	10%	50%	12%	20%	%
Constr. Costs	-25%	50%	even	35%	+25%	15%	% Increase
Irrig. Demands	-50%	33%	even	33%	+50%	33%	% Increase
Agric. Prices	30	30%	40	40%	50	30%	$/Ha
Electr. Prices	10	25%	20	40%	30	35%	$/MWh

Now, for example, the uncertain parameter Θ_3, discount rate, has three values associated: $\Theta_3{}^1 = 8\%$, $\Theta_3{}^2 = 10\%$, and $\Theta_3{}^3 = 12\%$. The same can be said for the other uncertain parameters. The vector Θ is therefore formed by: $3 \cdot 3 \cdot 3 \cdot 3 \cdot 3 = 243$ elements. To clarify the meaning of the uncertain parameters vector Θ, consider one of its elements, for example the element $[\Theta_1{}^1, \Theta_2{}^2, \Theta_3{}^2, \Theta_4{}^1, \Theta_5{}^3]$. This element indicates uncertain conditions defined by (according to Table 4-3):

Θ_1 = agricultural products prices = 30 $/Ha
Θ_2 = electricity prices = 20 $/MWh
Θ_3 = discount rate = 10%
Θ_4 = construction costs = 25% decrease
Θ_5 = irrigation water demands = 50% increase

From table 4-3 we can also obtain the probability of the element $[\Theta_1{}^1, \Theta_2{}^2, \Theta_3{}^2, \Theta_4{}^1, \Theta_5{}^3]$. We assume independence between the uncertain parameters, what in this case seems a very reasonable assumption. The probability of $[\Theta_1{}^1, \Theta_2{}^2, \Theta_3{}^2, \Theta_4{}^1, \Theta_5{}^3]$ is:

$p\ [\Theta_1{}^1, \Theta_2{}^2, \Theta_3{}^2, \Theta_4{}^1, \Theta_5{}^3] = p(\Theta_1{}^1)\ p(\Theta_2{}^2)\ p(\Theta_3{}^2)\ p(\Theta_4{}^1)\ p(\Theta_5{}^3) =$

$= 0.50 \quad 0.50 \quad 0.33 \quad 0.30 \quad 0.40 = 0.010 = 1.000\ \%$

After doing this for each one of the 243 elements of the uncertain parameters vector, we have defined all the uncertain situations with their probability of occurrence. Table B-1 in Appendix B shows the probability of occurrence of each uncertain element.

<u>Ideal net benefits curve</u>

We have defined 243 possible future situations with their correspondent possibilities of occurrence. The ideal net benefits curve indicates the maximum net benefits that can be obtained from the basin for each one of the 243 possible future situations. To calculate one point of the ideal net benefits curve we utilize the LP package to solve the screening model. For example, in the screening model for $[\Theta_1{}^1, \Theta_2{}^2, \Theta_3{}^2, \Theta_4{}^1, \Theta_5{}^3]$, agricultural products prices are 30 $/Ha, electricity prices are 20 $/MWh, discount rate is 10%, construction costs are multiplied by 0.75, and irrigation water demands are multiplied by 1.50. The computer gives us the maximum net benefits that could be obtained for this situation, and also the optimal sizes of the projects to build. The same process has to be done for the other 242 possible future situations. In total, 243 optimization runs of the screening model have to be performed.

The ideal net benefits curve can not be graphically represented, because it is defined in a 5-dimensions space. Table 4-4 shows the numerical values of the ideal net benefits curve for the case study. We can see that for $[\Theta_1{}^1, \Theta_2{}^2, \Theta_3{}^2, \Theta_4{}^1, \Theta_5{}^3]$, the ideal net benefits curve indicates net benefits of 1.03 million $.

Optimal sets of design decision variables

In this case study there are ten design decision variables. Then, the vector X is formed by:

$X = \{X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, X_9, X_{10}\}$

where:

X_1 = Volume of Reservoir A (Hm^3)
X_2 = Volume of Reservoir B (Hm^3)
X_3 = Volume of Reservoir C (Hm^3)
X_4 = Volume of Reservoir D (Hm^3)
X_5 = Area of Irrigation B (Ha)
X_6 = Area of Irrigation C (Ha)
X_7 = Area of Irrigation D (Ha)
X_8 = Capacity of Plant A (MWh)
X_9 = capacity of Plant C (MW)
X_{10} = Size of the Transfer (m^3/s)

From the 243 optimization runs performed to obtain the ideal net benefits curve, we also obtained 243 optimal sets of decision variables. We generically represented them by:

$X^*[\Theta]$

To illustrate the meaning of $X^*[\Theta]$, lets consider the particular value $X^*[\Theta_1{}^1, \Theta_2{}^2, \Theta_3{}^2, \Theta_4{}^1, \Theta_5{}^3]$. This represents the optimal set of decision variables obtained from the optimization run performed for $[\Theta_1{}^1, \Theta_2{}^2, \Theta_3{}^2, \Theta_4{}^1, \Theta_5{}^3]$. In particular for decision variable X_1 (volume of Reservoir A), we obtained the optimal value: $X_1{}^*[\Theta_1{}^1, \Theta_2{}^2, \Theta_3{}^2, \Theta_4{}^1, \Theta_5{}^3]$ =

TABLE 4-4: *Ideal net benefits curve (million $)*

DISCOUNT RATE: 8 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	3.67	4.01	4.49	1.50	1.80	2.26	0.80	1.14	1.63
COSTS=	Agr.Pr.=40	5.19	5.51	5.99	2.20	2.52	3.00	1.27	1.57	2.01
-25 %	Agr.Pr.=50	6.71	7.01	7.50	2.91	3.26	3.75	1.73	2.03	2.51
CONSTR.	Agr.Pr.=30	3.30	3.60	4.02	1.20	1.50	1.80	0.50	0.98	1.47
COSTS=	Agr.Pr.=40	4.79	5.09	5.51	1.90	2.20	2.53	0.97	1.27	1.69
even	Agr.Pr.=50	6.31	6.61	7.00	2.60	2.90	3.27	1.43	1.73	2.03
CONSTR.	Agr.Pr.=30	3.00	3.30	3.60	0.90	1.20	1.64	0.34	0.82	1.30
COSTS=	Agr.Pr.=40	4.40	4.70	5.03	1.60	1.90	2.20	0.67	1.04	1.53
+25 %	Agr.Pr.=50	5.92	6.21	6.52	2.30	2.60	2.90	1.13	1.43	1.75

DISCOUNT RATE: 10 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	3.39	3.69	4.16	1.29	1.59	1.92	0.59	1.03	1.51
COSTS=	Agr.Pr.=40	4.91	5.20	5.64	1.99	2.29	2.67	1.05	1.35	1.74
-25 %	Agr.Pr.=50	6.43	6.72	7.15	2.69	2.99	3.41	1.52	1.82	2.17
CONSTR.	Agr.Pr.=30	3.02	3.32	3.62	0.92	1.22	1.64	0.35	0.83	1.26
COSTS=	Agr.Pr.=40	4.42	4.72	5.06	1.62	1.92	2.21	0.68	1.05	1.53
even	Agr.Pr.=50	5.94	6.23	6.54	2.32	2.62	2.91	1.15	1.45	1.76
CONSTR.	Agr.Pr.=30	2.65	2.95	3.24	0.55	0.96	1.44	0.20	0.63	1.11
COSTS=	Agr.Pr.=40	4.05	4.35	4.65	1.25	1.55	1.84	0.42	0.85	1.33
+25 %	Agr.Pr.=50	5.45	5.75	6.05	1.95	2.25	2.54	0.78	1.08	1.55

DISCOUNT RATE: 12 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Fr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	3.18	3.48	3.82	1.08	1.38	1.73	0.43	0.92	1.40
COSTS=	Agr.Pr.=40	4.63	4.93	5.31	1.78	2.08	2.38	0.85	1.14	1.62
-25 %	Agr.Pr.=50	6.15	6.45	6.81	2.48	2.78	3.08	1.31	1.61	1.91
CONSTR.	Agr.Pr.=30	2.74	3.04	3.34	0.64	1.01	1.49	0.24	0.68	1.16
COSTS=	Agr.Pr.=40	4.14	4.44	4.74	1.34	1.64	1.94	0.46	0.90	1.38
even	Agr.Pr.=50	5.57	5.86	6.16	2.04	2.34	2.64	0.87	1.17	1.60
CONSTR.	Agr.Pr.=30	2.30	2.60	2.90	0.39	0.77	1.26	0.08	0.47	0.95
COSTS=	Agr.Pr.=40	3.70	4.00	4.30	0.90	1.20	1.59	0.28	0.66	1.14
+25 %	Agr.Pr.=50	5.10	5.40	5.70	1.60	1.90	2.20	0.50	0.88	1.37

0 Hm^3. Besides this optimal value of X_1 for $[\Theta_1{}^1, \Theta_2{}^2, \Theta_3{}^2, \Theta_4{}^1, \Theta_5{}^3]$, there are other 242 optimal values of X_1, corresponding to the other 242 possible future situations. Table B-2 in Appendix B shows the 243 optimal values of X_1.

The same could be said for the other nine design decision variables. There are 243 optimal values for each one. Tables B-3 through B-11 show the optimal values for design decision variables X_2 through X_{10}. These tables are the basis for next step.

4.3.2.- Step 2: Select candidate alternatives

We have 243 values for each design decision variable. When we consider one decision variable, for example X_1, we can get the probability distribution of these values. For X_1, looking at table B-2, there are only two different values: 84 Hm^3 and 0 Hm^3. In table B-1 we have the probability of each optimal value to occur. With this, we have all the data we need to calculate the probability distribution of the values of X_1. And the same can be said for the other nine design decision variables. Table 4-5 shows the probability distributions of the values of the ten design decision variables.

The probability distributions indicated in Table 4-5 can also be plotted. Figures B-1 through B-10 show the bar graphs representation of the probability distributions. These graphs provide a quick means for identifying the most likely values

TABLE 4-5: *Probability distribution of the values of the design decision variables*

VOLUME DAM A

Hm3	PROB. %
0	88.50%
84	11.50%
	100.00%

CAPACITY PLANT A

MW	PROB. %
0	0.00%
9	100.00%
	100.00%

TRANSFER SIZE

m3/s	PROB. %
0	99.28%
8	0.72%
	100.00%

VOLUME DAM B

Hm3	PROB. %
0	12.41%
84	87.59%
	100.00%

AREA IRRIGATION B

Ha	PROB. %
0	0.91%
16550	83.71%
16750	11.50%
27880	3.88%
	100.00%

VOLUME DAM C

Hm3	PROB. %
0	40.58%
105	59.42%
	100.00%

AREA IRRIGATION C

Ha	PROB. %
0	40.58%
18470	48.76%
19660	10.66%
	100.00%

CAPACITY PLANT A

MW	PROB. %
0	61.14%
6	38.14%
10	0.72%
	100.00%

VOLUME DAM D

Hm3	PROB. %
0	68.75%
21	10.66%
122	3.50%
123	17.10%
	100.00%

AREA IRRIGATION D

Ha	PROB. %
0	68.75%
1550	1.43%
1650	8.85%
1720	0.38%
20670	14.44%
20770	2.65%
20840	3.50%
	100.00%

of the design decision variables. Consider for example Figure B-7, for the design decision variable X_7 = area of irrigation D. The values of X_7 are clustered in three groups: (1) 0 Ha, (2) around 1600 Ha, and (3) around 20700 Ha. The first cluster is formed exclusively by the value of 0 Ha. The second cluster is formed by values of 1550, 1650, and 1720 Ha. The third cluster is formed by values of 20670, 20770, and 20840 Ha. The reference value of the first cluster is obviously zero. For the second cluster, the representative value can be obtained by obtaining the weighted average of the three values included in the cluster (weighted by the probability of each value). The weighted average is 1640 Ha. Then, in this cluster, instead of considering three very close values, we only consider the representative value 1640 as the reference value for the cluster. It can be analogously done for the third cluster obtaining 20710 Ha as the reference value.

The clustering procedure serves to identify the two or three more likely reference values (with their respective probabilities) for each design decision variable. Table 4-6 shows the reference values of the decision variables after the clustering procedure. A size of zero means that the project is not built. Table 4-7 summarizes the projects that are more likely to be built, their sizes, and their probability.

Analyzing Tables B-2 through B-11, we can infer some relationships among projects. Consider, for example, Dam A. It is easy to see, by comparing Table B-2 with Table B-3, that

TABLE 4-6: *Probability distribution of the reference values of the design decision variables after clustering*

VOLUME DAM A

Hm3	PROB. %
0	88.50%
84	11.50%
	100.00%

CAPACITY PLANT A

MW	PROB. %
0	0.00%
9	100.00%
	100.00%

TRANSFER SIZE

m3/s	PROB. %
0	99.28%
8	0.72%
	100.00%

VOLUME DAM B

Hm3	PROB. %
0	12.41%
84	87.59%

AREA IRRIGATION B

Ha	PROB. %
0	0.91%
16570	95.21%
27880	3.88%
	100.00%

VOLUME DAM C

Hm3	PROB. %
0	40.58%
105	59.42%
	100.00%

AREA IRRIGATION C

Ha	PROB. %
0	40.58%
18680	59.42%
	100.00%

CAPACITY PLANT A

MW	PROB. %
0	61.14%
6	38.14%
10	0.72%
	100.00%

VOLUME DAM D

Hm3	PROB. %
0	68.75%
21	10.66%
123	20.60%
	100.00%

AREA IRRIGATION D

Ha	PROB. %
0	68.75%
1640	10.66%
20710	20.60%
	100.00%

TABLE 4-7: *Projects more likely to be built*

PROBABILITY	PROJECT	SIZE
100.00 %	Plant A	9 MW
95.21 %	Irrigation B	16570 Ha
87.59 %	Dam B	84 Hm^3
59.42 %	Irrigation C	18680 Ha
59.42 %	Dam C	105 Hm^3
38.14 %	Plant C	6 MW
20.60 %	Irrigation D	20710 Ha
20.60 %	Dam D	123 Hm^3
11.50 %	Dam A	84 Hm^3
10.66 %	Irrigation D	1640 Ha
10.66 %	Dam D	21 Hm^3
3.88 %	Irrigation B	27880 Ha
0.72 %	Plant C	10 MW
0.72 %	Transfer	8 m^3/s

when Dam A is built (size different that zero), Dam B is never built. Also when Dam B is built, Dam A is never built. Therefore, we can then say that Dam B is an incompatible project with Dam A: they are mutually exclusive. Comparing Table B-2 for Dam A with the rest of the tables, we see that when Dam A is built, four other facilities are always built: Dam D, Irrigation B, Irrigation D, and Plant A. This means that these four facilities are more profitable than Dam A, because these facilities have to be already built before building Dam A. Study now the relationship between Dam A and Irrigation C. We see from their respective Tables (B-2 and B-7) that sometimes Dam A is built and Irrigation C is also built. Other times Dam A is built and Irrigation C is not built. We can conclude that there is no unique relation between Dam A and Irrigation C: no one is more or less profitable than the other.

Repeating the same comparison process made with Dam A for all the other design decision variables, we obtain Table 4-8, called the Compatibilities table. For any given project, this table shows the more profitable projects, the incompatible projects, and the non related projects. The same information can be graphically represented in "hierarchical" form (Figure 4-11). Top projects are more profitable than bottom ones. When we decide to build a project, those projects that are above it have to be also built. There are projects (for example, Irrigation D and Dam D) that have to be built together or not built at all: Irrigation D can not be built without building Dam D, and Dam D can not be built without also building Irrigation D.

To create candidate alternatives for development of the basin, we combine the possible projects (dams, irrigation areas, plants, and transfer). Many combinations can be made with these projects that will result in different planning strategies. But, when we impose the constraint that the combinations among projects have to respect the compatibility table (Table 4-8) or the hierarchical graph (Figure 4-11), the number of possible combinations is very reduced. In fact, only 14 possible combinations are allowed in this case study.

Once we have decided what projects are part of a candidate alternative, we must decide their sizes. We already have the reference sizes for the projects. It is reasonable to

TABLE 4-8: *Compatibilities table*

Initial facility:	Additional facilities that are ALWAYS built:	Facilities that are NEVER built:	Facilities that MAY or MAY NOT be built
DAM A	PLANT A IRRIG B DAM D IRRIG D	TRF DAM B	DAM C IRRIG C PLANT C
DAM B	PLANT A IRRIG B	DAM A TRF	DAM C IRRIG C PLANT C DAM D IRRIG D
DAM C	PLANT A IRRIG B IRRIG C	TRF PLANT C	DAM A DAM B DAM D IRRIG D
DAM D	PLANT A IRRIG B IRRIG D	TRF	DAM A DAM B DAM C IRRIG C PLANT C
IRRIG B	PLANT A	TRF	DAM A DAM B DAM C IRRIG C PLANT C DAM D IRRIG D
IRRIG C	PLANT A IRRIG B DAM C	TRF PLANT C	DAM A DAM B DAM D IRRIG D
IRRIG D	PLANT A IRRIG B DAM D	TRF	DAM A DAM B DAM C IRRIG C PLANT C
PLANT A			DAM A TRF DAM B IRRIG B DAM C IRRIG C PLANT C DAM D IRRIG D
PLANT C	PLANT A	DAM C IRRIG C	DAM A TRF DAM B IRRIGB DAM D IRRIG D
TRF	PLANT A PLANT C	DAM A DAM B IRRIG B DAM C IRRIG C DAM D IRRIG D	

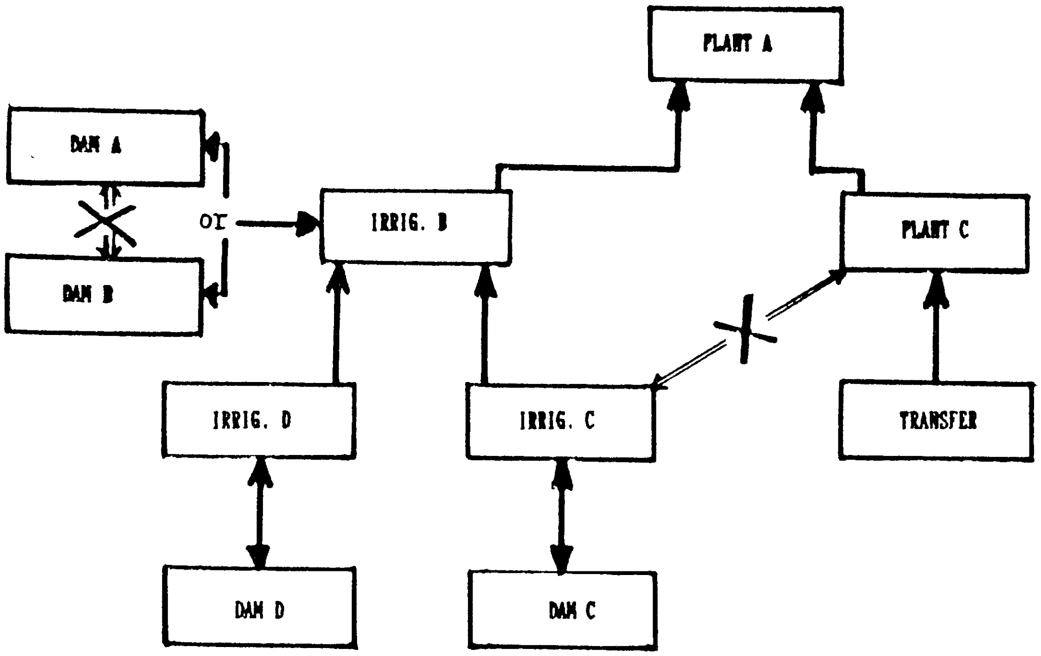

FIGURE 4-11: *Hierarchical representation of relationships among projects*

think that the sizes of the projects included in the candidate alternative are the reference sizes of the projects. For each project, the most likely reference size is the one with greatest probability. In some cases two or even three most reference sizes with similar probabilities can be identified for a single project. In this case study, however, each project has a main reference size that stands clearly. Secondary reference sizes have probabilities of at least half of the probability of the main reference size. Table 4-9 summarizes the reference size for every project.

Now we have identified 14 possible combinations of projects, and for each project we have identified its

TABLE 4-9: *Reference sizes for the projects*

PROJECT	SIZE	PROBABILITY
Dam A	84 Hm^3	11.50 %
Dam B	84 Hm^3	87.59 %
Dam C	105 Hm^3	59.42 %
Dam D	123 Hm^3	20.60 %
Irrigation B	16570 Ha	95.21 %
Irrigation C	18680 Ha	59.42 %
Irrigation D	20710 Ha	20.60 %
Plant A	9 MW	100.00 %
Plant C	6 MW	38.14 %
Transfer	8 m^3/s	0.72 %

reference size. Therefore we have identified 14 candidate alternatives, that are described in Table 4-10. These alternatives are candidate because are formed by combinations of projects that satisfy the Compatibility table, and each project has its reference size.

4.3.3.- Step 3: Assess the performance of the alternatives

From the former step we have 14 candidate alternatives. In this step we have to asses the performance of every one of them under the uncertain conditions existing in the basin.

Curves of net benefits

Uncertain conditions are approximated by defining 243 possible future situations. To assess the performance of a candidate alternative under uncertain conditions we have to independently evaluate the performance of the alternative under each one of the 243 possible future situations.

Lets study the performance of Alternative A. We consider

TABLE 4-10: *Candidate alternatives*

ALTERNATIVE A:

Plant A:	9 MW

ALTERNATIVE B:

Plant A:	9 MW
Irrigation B:	16,570 Ha
Dam B:	84 Hm3

ALTERNATIVE C:

Plant A:	9 MW
Plant C:	6 MW

ALTERNATIVE D:

Plant A:	9 MW
Irrigation B:	16,570 Ha
Dam A:	84 Hm3

ALTERNATIVE E:

Plant A:	9 MW
Irrigation B:	16,570 Ha
Dam B:	84 Hm3
Plant C:	6 MW

ALTERNATIVE F:

Plant A:	9 MW
Irrigation B:	16,570 Ha
Dam B:	84 Hm3
Irrigation C:	18,680 Ha
Dam C:	105 Hm3

ALTERNATIVE G:

Plant A:	9 MW
Irrigation B:	16,570 Ha
Dam B:	84 Hm3
Irrigation D:	20,710 Ha
Dam D:	123 Hm3

ALTERNATIVE H:

Plant A:	9 MW
Irrigation B:	16,570 Ha
Dam B:	84 Hm3
Irrigation C:	18,680 Ha
Dam C:	105 Hm3
Irrigation D:	20,710 Ha
Dam D:	123 Hm3

ALTERNATIVE I:

Plant A:	9 MW
Irrigation B:	16,570 Ha
Dam A:	84 Hm3
Plant C:	6 MW

ALTERNATIVE J:

Plant A:	9 MW
Irrigation B:	16,570 Ha
Dam A:	84 Hm3
Irrigation C:	18,680 Ha
Dam C:	105 Hm3

ALTERNATIVE K:

Plant A:	9 MW
Irrigation B:	16,570 Ha
Dam A:	84 Hm3
Irrigation D:	20,710 Ha
Dam D:	123 Hm3

ALTERNATIVE L:

Plant A:	9 MW
Irrigation B:	16,570 Ha
Dam A:	84 Hm3
Irrigation C:	18,680 Ha
Dam C:	105 Hm3
Irrigation D:	20,710 Ha
Dam D:	123 Hm3

ALTERNATIVE M:

Plant A:	9 MW
Irrigation B:	16,570 Ha
Dam B:	84 Hm3
Plant C:	6 MW
Irrigation D:	20,710 Ha
Dam D:	123 Hm3

ALTERNATIVE N:

Plant A:	9 MW
Irrigation B:	16,570 Ha
Dam A:	84 Hm3
Plant C:	6 MW
Irrigation D:	20,710 Ha
Dam D:	123 Hm3

the future situation defined by $[\Theta_1^1, \Theta_2^2, \Theta_3^2, \Theta_4^1, \Theta_5^3]$. To calculate the maximum net benefits that Alternative A would produce if the situation defined by $[\Theta_1^1, \Theta_2^2, \Theta_3^2, \Theta_4^1, \Theta_5^3]$ does come, we optimize operating rules for Alternative A under the conditions $[\Theta_1^1, \Theta_2^2, \Theta_3^2, \Theta_4^1, \Theta_5^3]$. We use the LP package, and we obtain the optimal releases and irrigation policies that yield maximum net benefits for Alternative A. We are not really concern about the operating rules, but only about the value of maximum net benefits of Alternative A under conditions $[\Theta_1^1, \Theta_2^2, \Theta_3^2, \Theta_4^1, \Theta_5^3]$.

To evaluate the performance of Alternative A for all the possible future situations, we must run the LP program a total of 243 times, to optimize operating rules for each possible future situation Θ_i^j. Table C-1 in Appendix C indicates the maximum net benefits resulting from the 243 optimization runs for Alternative A. The same process has to be repeated for Alternatives B through M. Tables C-2 to C-14 show their respective maximum net benefits under uncertain situations. These Tables C-1 to C-14 are called curves of net benefits of the candidate Alternatives A to N.

In total, it was necessary to perform $14 \cdot 243 = 3402$ optimization runs to calculate the curves of net benefits for the 14 candidate alternatives.

Expected value of net benefits for the alternatives

The expected value of net benefits for a candidate alternative is directly calculated from its curve of net benefits. The expected value of net benefits is only the weighted average of the values of the curve of net benefits. The weights are the probabilities of the uncertain conditions given in Table B-1. The values of expected net benefits for every candidate alternative are given in Table 4-11.

Indices of robustness for the alternatives

The index of robustness for a given candidate alternative is also calculated from its curve of net benefits. But it is also required the ideal net benefits curve (Table 4-4). The first stage is to calculate the difference between the curve of net benefits of the candidate alternative and the ideal net benefits curve. The difference is the called delta curve of the alternative. The delta curve indicates how far the candidate alternative is from reaching the potential of the basin. The second stage is to calculate the expected value and the standard deviation of the values of the delta curve. To calculate both we need again to use the probabilities of the uncertain conditions in Table B-1. The last stage is to compute the coefficient of variation of the values of the delta curve. The coefficient of variation is just the standard deviation divided by the expected value (note that the expected value of delta always has to be greater than zero). As shown in Chapter 4, the Index of Robustness of an alternative is equal to the coefficient of variation of the values of its delta curve. Table 4-11 summarizes the indices of robustness of the candidate alternatives.

TABLE 4-11: *Expected net benefits and index of robustness of each candidate alternative*

ALTERNATIVE	EXPECTED NET BENEFITS	INDEX OF ROBUSTNESS	N - CV (N=2)
Ideal NB Curve	2.818	0.000	2.000
Alternative A	0.496	0.769	1.231
Alternative B	1.698	0.858	1.142
Alternative C	0.710	0.846	1.154
Alternative D	1.657	0.825	1.175
Alternative E	1.913	1.057	0.943
Alternative F	2.718	1.343	0.657
Alternative G	2.331	0.455	1.545
Alternative H	1.722	0.374	1.626
Alternative I	1.871	1.008	0.992
Alternative J	2.693	1.079	0.921
Alternative K	2.292	0.437	1.563
Alternative L	1.706	0.381	1.619
Alternative M	2.545	0.972	1.028
Alternative N	2.507	0.872	1.128

4.3.4.- Step 4: Compare among alternatives

Once we have the expected value of net benefits and the index of robustness for every alternative, we have to organize this information in a clear form. The best method is to use a graph where expected value of net benefits is in the horizontal axis and robustness is in the vertical. As indicated in Chapter 4, robustness should be represented by N - CV, where N is a "large" number. In this case, N is equal to 2. Figure 4-12 shows the Pareto two-objective graph for our case study. Each alternative is represented as a point in this graph.

The non-inferior set is formed by Alternatives H, K, G,

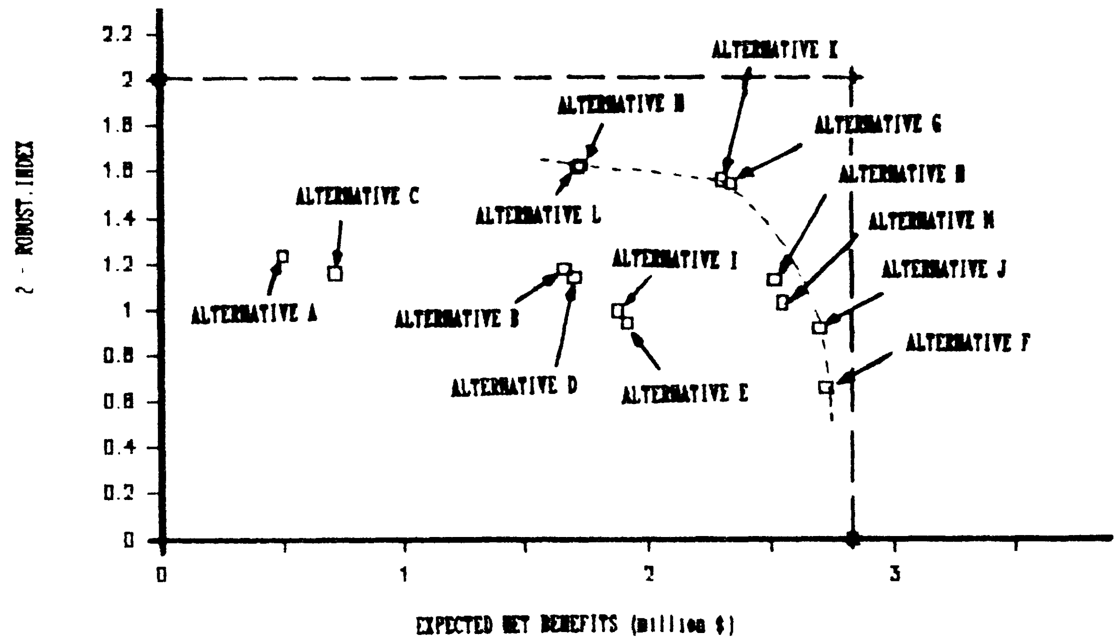

FIGURE 4-12: *Pareto two-objective graph for the candidate alternatives of the case study*

N, M, J, and F. The maximum robustness is provided by Alternative H, and the maximum expected net benefits is provided by Alternative F. With respect to these extreme values, we can calculate the percent of losses in robustness and expected net benefits of the other alternatives (Table 4-12).

Alternatives K and G seem to be in the "compromise" zone. These alternatives have relatively high expected net benefits (only about 15% less expected net benefits than F), and they are relatively robust (only about 20% less robustness than H). Any other of the non-inferior alternatives (H, M, N, J, or F) has significant decrease in either robustness or expected net benefits. The final choice of an alternative to implement is outside of the scope of this thesis, because it depends on

TABLE 4-12: *Decrease in expected net benefits and in index of robustness of the non-inferior alternatives with respect to the maximum values*

NON-INFERIOR ALTERNATIVE	DECREASE IN EXPECTED NET BENEFITS	DECREASE IN INDEX OF ROBUSTNESS
Alternative H	36.64%	---
Alternative K	15.67%	16.87%
Alternative G	14.26%	21.75%
Alternative N	7.77%	133.50%
Alternative M	6.36%	160.29%
Alternative J	0.93%	188.92%
Alternative F	---	259.58%

agreement among the parties involved in the decision-making process. However, as conclusion of the case study, the alternatives that have more possibility of being chosen are Alternatives K and G.

<u>4.3.5.- Conclusions about expected net benefits and robustness</u>

From the analysis of the Pareto curve in Figure 4-12, we may obtain some conclusions about the relationship between the characteristics of the alternatives and their expected net benefits and robustness.

First, we study the expected value of net benefits. Table 4-7 shows the most likely project to be built. The alternatives which contain the most likely projects to be built (those with probability of more than 50% in Table 4-7) are the alternatives which have the greater net benefits. Therefore, Alternative F, which contains the most profitable projects (Plant A, Irrigation B with its associated Dam B, and

Irrigation C with its associated Dam C), is the alternative with the greatest expected net benefits. Other alternatives formed by less profitable projects have smaller expected net benefits. For example, Alternative G is formed by the same projects than Alternative F, but substituting Irrigation C by Irrigation D. Since Irrigation D has a lower probability of being built than Irrigation C, Alternative G has smaller expected net benefits than Alternative F. An interesting exception to this rule happens when substituting Plant C by Irrigation D. Irrigation D is less likely to be built than Plant C (see Table 4-7). Therefore, alternatives containing Plant C are supposed to have greater expected net benefits than the same alternatives containing Irrigation D. However the contrary happens, as can be seen by comparing Alternative E with Alternative G, or Alternative I with Alternative K. The special circumstances of Irrigation D, that are discussed at the end of the chapter, may be the reason for this exception.

Second, we study robustness. We should expect that those alternatives formed by more interrelated projects are the most robust, because they have more possibilities of varying operation rules to mitigate the effect of unfavorable conditions in some projects. In fact, the two alternatives formed by more projects (Alternatives H and L, each one formed by seven projects) are the most robust. But, except in this case, there is no consistent relationship between the number of projects included in an alternative and its robustness. For example, Alternative A, formed only by one project, is more robust than Alternatives N and M, each formed by six projects.

There are, however, two consistent relationships between the composition of the alternatives and robustness. The first relationship refers to the alternatives which replace Dam B by Dam A. From the hierarchical graph (Figure 4-11), we see that Dam A and Dam B are incompatible projects and can not be present in the same alternative. We found that an alternative is more robust (although having less expected net benefits) with Dam A than with Dam B. This is the case of Alternatives D, I, N, J, and K over Alternatives B, E, M, F and G respectively. Dam A is less likely to be built than Dam B (see Table 4-7). This explains that alternatives containing Dam A have smaller expected net benefits than alternatives containing Dam B. The greater robustness of alternatives which include Dam A instead of Dam B may be explained by looking at the configuration of the system (see Figure 4-1). Dam A is upstream of Dam B. Dam B can only be used for regulation of the water of Irrigation B. However, Dam A, in addition of being used for regulation of Irrigation B, can also be used for regulation of Plant A and for regulation of the Transfer. This possibility of using Dam A for several uses of the water confers greater robustness to the alternatives.

There is a second consistent relationship between the composition of the alternatives and robustness: alternatives that include Irrigation D (with its associated Dam D) are more robust than the same alternative without Irrigation D. For example, Alternative B is less robust than Alternative G, Alternative D than Alternative K, Alternative F than Alternative H, etc. Curiously, Irrigation D is not a likely project to be built (see Table 4-7). The possible explanation of the increase in robustness when including Irrigation D in an alternative is that Irrigation D is the last chance of using the extra water (that is the water in excess over the downstream requirements) that otherwise will be lost downstream. Extra water is always present in this section of the river because the return flows from Irrigations B and C and the flow of the middle tributary. Then, although Irrigation D does not make a very efficient use of the water (and this is the reason why some alternatives with Irrigation D have smaller expected net benefits than without Irrigation D), the existence of extra water provides the possibility of using Irrigation D under any condition.

The conclusion of this section is that, while there is a clear relationship between the configuration of the alternatives and their expected net benefits, no such clear relationship exits with respect to their robustness. The characteristics of the individual projects (as Dam A and Irrigation D) seem to be more important than the configuration of the system as a whole.

CHAPTER 5: CONCLUSION

This chapter is divided in two parts. The first part summarizes the planning method described in this thesis. The second part discusses the characteristics of the method within the general framework of water resources planning.

Summary of the method

This thesis presented a two-objective method for water resources planning. One of the objectives is to maximize expected net benefits (the traditional water resources objective) and the other objective is to maximize robustness. The reason for considering robustness is the existence of uncertain parameters in the process of planning water systems. In deterministic problems, the concept of robustness does not have any meaning.

The consideration of robustness is original in this thesis. Robustness is a measure of the sensitivity of the performance of a project to uncertain conditions. Insensitive performance correspond to robust projects, that are able to maintain a reliable performance, independently of the value that the uncertain parameters happen to take.

In Chapter 2, I reviewed some indices to measure robustness and resiliency of water systems. The indices exposed by Hashimoto [1982a, and b] and Fiering [1982a, b, c, and d] do not correspond to the concept of robustness indicated in this thesis. Therefore, to quantify robustness and to use it in the two-objective analysis, I developed a new robustness index. This index of robustness of a project is related to the distribution of possible net benefits as consequence of uncertainty. Because of uncertainty, we can not predict a single value of net benefits from a project, but we may be able to obtain the possible distribution of net benefits as a function of the uncertain parameters. If this distribution is very disperse, it indicates non-robust performance of the project: there is a wide range of project performance depending on variation on the input parameters. On the other hand, small dispersion of the values of the distribution indicates robust performance, because the performance of the project is similar even under different conditions.

The process to obtain the indices of robustness of the planning alternatives is part of the general method proposed in this thesis to solve the two-objective problem. The method requires the use of screening models as optimization technique. The method begins by displaying all possible facilities that could be built in the basin. Then, after performing the four steps described in Chapter 3, the result of the method is a set of non-inferior development strategies for the basin, presented in a Pareto form graph. In Chapter 4, to prove the practical viability of the method, it was applied to an hypothetical case study.

One of the main advantages of the method is that, in the process of finding the Pareto curve, the method produces interesting information on the basin as a whole and on the individual projects. For example, the method evaluates the potential of the basin to produce net benefits, represented by the ideal net benefits curve. This shows the maximum net benefits the basin would ideally yield for each uncertain future condition. These net benefits can never be exceeded for any candidate alternative. The goal of the candidate alternatives is to be as close as possible to the ideal net benefits curve. The method also provides information on the individual projects. The most and least profitable projects are identified. Also compatible and incompatible combinations of projects are detected. In summary, after the method is applied, we can have a good insight on the potential of the basin and projects.

Characteristics of the method within the water resource planning framework

The purpose of any planning method is to provide information to decision makers. Different planning methods are characterized by the amount of relevant information provided and by the time and expenses in generating the information. This section discusses the improvements to the planning process that the method described in this thesis will bring about, particularly in dealing with uncertainty and multiobjective analysis.

Uncertainty. Traditional water resources optimization models only provide one solution that maximizes the objective measure. There is nothing wrong with this procedure, if we were certain that the model represents the real situation of the basin. However, water resources systems are subject of great uncertainty. There is uncertainty in our estimation of the physical and economical conditions of the basin, and there is also uncertainty due to the randomness of the hydrological process itself. There are some methods that may, in theory, deal with uncertainty and still obtain an unique optimal solution (stochastic linear programming, described by Loucks et al., 1981). But the practical utility of these methods is very limited since they require extraordinary computer facilities.

The method developed in this thesis is specially suited to deal with the uncertainty issue. The method accomplishes this task by performing many independent optimization runs. Any available algorithm to solve deterministic optimization problems can be used (screening models, in particular). The method does not requires sophisticated computer equipment; in fact the case study in Chapter 4 was fully solved using an IBM XT personal computer.

Another advantage of the method is that there is no limitation to the level of uncertainty we can consider. If we want to include more or other uncertain parameters in the analysis, the method can still be applied. Of course, the number of optimization runs is increased, and more computer time is necessary. The limitation to the study of uncertainty is not given by the method itself, but by our ability and knowledge to represent the actual relationships between the variables modeling the existing conditions in the basin in a mathematical form .

The method not only serves for planning under uncertainty, but also it quantifies the effect of uncertainty in the projects. We are concerned about uncertainty, because when uncertainty is present, we can not surely predict the future performance of the projects. This thesis calls robustness the measure of the sensitivity of projects to uncertainty.

The method further advances the research in the area of uncertainty in water resources planning.

Multiobjective analysis. Economic criterion is the most utilized evaluation criterion to evaluate the merits of the projects. To use this criterion alone is correct when all the outcomes of the projects can be quantified in monetary terms. However, the project may have other non-economic effects (for example, pollution) that could interest decision makers. The practical problem of considering non-economic effects is how to measure them. Methods are found in the literature to quantify ecological, recreational and other effects. Some of these methods are general, and some are just for specific cases.

The method of this thesis is part of the multiobjective techniques. As said before, this thesis studies robustness and net benefits as part of a two-objective problem. We consider that neither robustness nor net benefits are criteria to be used alone. Robustness is an important element to be considered in the decision making process for decision making because it indicates reliability in the project performance under future conditions. In rural areas or in developing countries, the issue of robustness of water resources projects may be critical. These projects may be implemented to provide a mean of subsistence to the people of underdeveloped regions. In those cases, to implement a reliable project that always produces some net benefits is preferable than to implement a project that may produce much more net benefits, but may also produce nothing.

The method solves the two-objective problem by finding a Pareto curve or, in other words, the non-inferior set of projects. The Pareto curve is the result of the method, and it is to be given to the decision makers. The advantage of the Pareto curve is that the information about the alternative projects is easily visualized and understood. There are two reasons why the decision-making process is much improved with the Pareto curve. First, when decision making involves a collective process of negotiation, the Pareto curve increases the probability of agreement and of finding compromise solutions. This is not the case in the traditional single objective water resource planning techniques that present to the decision makers only one optimal alternative that is guaranteed to be the best solution. This does not provide much room for negotiation. However, in two-objective methods like the one of this thesis, the concept of best alternative does not exist. A decision-making process is necessary to define the tradeoffs among objectives, in this case robustness and net benefits.

Secondly, the method also improves the communication between analysts and decision makers. For example, if a decision-making group strongly supports a particular project, the analyst may evaluate the performance of the project and locate it in the Pareto graph. The project can now be objectively compared with other candidate projects, and in the case of being inferior, it should be disregarded in favor of a non-inferior project.

APPENDIX A

FORMULATION OF THE SCREENING MODEL

```
MAX BENEFITS - DISCOST
ST
!
! Alter parameters
DISCOST - 0.0817 COST = 0
COST - 0.75 CONSTRUC = 0
IRRIGAT - 0.5 IRRAREA = 0
IRRBEN - 0.03 IRRAREA = 0
ELECBEN - 0.1 POWER = 0
!
! Benefits and costs
BENEFITS - IRRBEN - ELECBEN = 0
CONSTRUC - DAMCOST - IRRCOST - ELECCOST - TRFCOST = 0
DAMCOST - 1.5 YDAMA - 1.5 YDAMB - 3 YDAMC - 2 YDAMD - 0.44
VOLDAMA - 1.76 VOLDAMB - 0.56 VOLDAMC - 1.04 VOLDAMD = 0
IRRCOST - 0.25 YIRRB - 0.5 YIRRC - YIRRD - 0.082 AREAB - 0.247
AREAC - 0.536 AREAD = 0
ELECCOST - YPLANTA - 1.5 YPLANTC - 5 CAPACA - 7.7 CAPACC = 0
TRFCOST - 1.5 YTRF - 0.14 TRFSIZE = 0
! Continuity
9.513 SA2 - 9.418 SA1 + RELA1 = 5.28
9.513 SA3 - 9.228 SA2 + RELA2 = 2.72
9.513 SA1 - 9.418 SA3 + RELA3 = 8
9.513 SB2 - 9.323 SB1 + RELB1 + IRRB1 - RELA1 + TRF1 = 0
9.513 SB3 - 9.037 SB2 + RELB2 + IRRB2 - RELA2 + TRF2 = 0
9.513 SB1 - 9.418 SB3 + RELB3 - RELA3 + TRF3 = 0
9.513 SC2 - 9.037 SC1 + RELC1 + IRRC1 - TRF1 = 6.6
9.513 SC3 - 8.657 SC2 + RELC2 + IRRC2 - TRF2 = 3.4
9.513 SC1 - 9.228 SC3 + RELC3 - TRF3 = 10
9.513 SD2 - 8.847 SD1 + RELD1 + IRRD1 - RELB1 - RELC1 - IRRTB1 -
IRRTC1 = 1.32
9.513 SD3 - 8.562 SD2 + RELD2 + IRRD2 - RELB2 - RELC2 - IRRTB2 -
IRRTC2 = 0.68
9.513 SD1 - 9.228 SD3 + RELD3 - RELB3 - RELC3 - IRRTB3 - IRRTC3 =
2
RELD1 + IRRTD1 >= 5.28
RELD2 + IRRTD2 >= 2.72
RELD3 + IRRTD3 >= 8
! Reservoir volumes
SA1 - VOLDAMA <= 0
SA2 - VOLDAMA <= 0
SA3 - VOLDAMA <= 0
SB1 - VOLDAMB <= 0
SB2 - VOLDAMB <= 0
SB3 - VOLDAMB <= 0
SC1 - VOLDAMC <= 0
SC2 - VOLDAMC <= 0
SC3 - VOLDAMC <= 0
SD1 - VOLDAMD <= 0
SD2 - VOLDAMD <= 0
SD3 - VOLDAMD <= 0
! Irrigation losses and water requirements for irrigation
```

```
2.125 IRRB1 - LANDB1 = 0
2.125 IRRB2 - LANDB2 = 0
2.08 IRRC1 - LANDC1 = 0
2.08 IRRC2 - LANDC2 = 0
1.992 IRRD1 - LANDD1 = 0
1.992 IRRD2 - LANDD2 = 0
IRRIGAT - LANDB1 - LANDB2 - LANDC1 - LANDC2 - LANDD1 - LANDD2 = 0
LANDB1 - AREAB <= 0
LANDB2 - AREAB <= 0
LANDC1 - AREAC <= 0
LANDC2 - AREAC <= 0
LANDD1 - AREAD <= 0
LANDD2 - AREAD <= 0
! Irrigation return flow
IRRTB1 - 0.162 IRRB1 - 0.135 IRRB2 = 0
IRRTB2 - 0.030 IRRB1 - 0.026 IRRB2 = 0
IRRTB3 - 0.184 IRRB1 - 0.214 IRRB2 = 0
IRRTC1 - 0.167 IRRC1 - 0.140 IRRC2 = 0
IRRTC2 - 0.031 IRRC1 - 0.027 IRRC2 = 0
IRRTC3 - 0.191 IRRC1 - 0.222 IRRC2 = 0
IRRTD1 - 0.178 IRRD1 - 0.149 IRRD2 = 0
IRRTD2 - 0.033 IRRD1 - 0.029 IRRD2 = 0
IRRTD3 - 0.203 IRRD1 - 0.237 IRRD2 = 0
! Hydropower constraints
5.361 POWERA1 - RELA1 <= 0
5.361 POWERA2 - RELA2 <= 0
5.361 POWERA3 - RELA3 <= 0
10.722 POWERC1 - RELC1 <= 0
10.722 POWERC2 - RELC2 <= 0
10.722 POWERC3 - RELC3 <= 0
0.059 POWERA1 - CAPACA <= 0
0.059 POWERA2 - CAPACA <= 0
0.059 POWERA3 - CAPACA <= 0
0.059 POWERC1 - CAPACC <= 0
0.059 POWERC2 - CAPACC <= 0
0.059 POWERC3 - CAPACC <= 0
POWER - POWERA1 - POWERA2 - POWERA3 - POWERC1 - POWERC2 - POWERC3
= 0
! Transfers size
TRF1 - TRFSIZE <= 0
TRF2 - TRFSIZE <= 0
TRF3 - TRFSIZE <= 0
! Conditionality and maximum sizes
AREAB - 50 YDAMB <= 0
AREAC - 75 YDAMC <= 0
AREAD - 90 YDAMD <= 0
VOLDAMA - 3 YDAMA <= 0
VOLDAMB - 7 YDAMB <= 0
VOLDAMC - 10 YDAMC <= 0
VOLDAMD - 30 YDAMD <= 0
AREAB - 50 YIRRB <= 0
AREAC - 75 YIRRC <= 0
```

```
AREAD - 90 YIRRD <= 0
CAPACA - YPLANTA <= 0
CAPACC - 3 YPLANTC <= 0
TRFSIZE - 30 YTRF <= 0
END
INTEGER YDAMA
INTEGER YDAMB
INTEGER YDAMC
INTEGER YDAMD
INTEGER YIRRB
INTEGER YIRRC
INTEGER YIRRD
INTEGER YPLANTA
INTEGER YPLANTC
INTEGER YTRF
```

SUMMARY OF VARIABLES AND PARAMETERS OF THE SCREENING MODEL

Design decision variables

V_A : Volume of Reservoir A (Hm^3)
V_B : Volume of Reservoir B (Hm^3)
V_C : Volume of Reservoir C (Hm^3)
V_D : Volume of Reservoir D (Hm^3)
A_B : Area of Irrigation B (Ha)
A_C : Area of Irrigation C (Ha)
A_D : Area of Irrigation D (Ha)
C_A : Capacity of hydropower Plant A (MW)
C_C : Capacity of hydropower Plant C (MW)
T : Size of the Transfer (m^3/s)

Operational decision variables

$R_{A,t}$: Releases from Reservoir A (t = season 1, 2, or 3)
$R_{B,t}$: Releases from Reservoir B (t = season 1, 2, or 3)
$R_{C,t}$: Releases from Reservoir C (t = season 1, 2, or 3)
$R_{D,t}$: Releases from Reservoir D (t = season 1, 2, or 3)
$I_{B,t}$: Water diverted to Irrigation B (t = season 1, 2, or 3)
$I_{C,t}$: Water diverted to Irrigation C (t = season 1, 2, or 3)
$I_{D,t}$: Water diverted to Irrigation D (t = season 1, 2, or 3)
T_t : Water diverted to the Transfer (t = season 1, 2, or 3)

Other variables and parameters

B : Annual benefits ($)
C : Annual costs ($)
CC : Total construction costs ($)
θ_1 : Price of agricultural products ($/Ha)
θ_2 : Price of electricity ($/MWh)
θ_3 : Discount rate (%)
θ_4 : General increase or decrease in constr. costs (%)
θ_5 : general increase or decrease in irrigation water demands
$L_{s,t}$: Land irrigated at Irrigation s in season t (Ha)
L_{Bt} : land irrigated in Irrigation B in season t
L_{Ct} : land irrigated in Irrigation C in season t
L_{Dt} : land irrigated in Irrigation D in season t
$P_{s,t}$: Power produced at Plant s in season t (MWh)
$P_{A,t}$: power produced at Plant A in season t (t = 1, 2, 3)
$P_{C,t}$: power produced at Plant C in season t
n : Projects lifetime (years)
α_s : Variable costs of Reservoir s ($/$Hm^3$)
β_s : Variable costs of Irrigation s ($/Ha)
τ_s : Variable costs of Plant s ($/MW)

μ : Variable costs of Transfer [$/(m^3/s)]
FV_s : Fixed costs of Reservoir s ($)
FA_s : Fixed costs of Irrigation s ($)
FC_s : Fixed costs of Plant s ($)
FT : Fixed costs of Transfer ($)
YV_s : Integer variable for Reservoir s:
If Reservoir s is built: $YV_s = 1$
If Reservoir s is not built: $YV_s = 0$
YA_s : Integer variable for Irrigation s:
If Irrigation s is built: $YA_s = 1$
If Irrigation s is not built: $YA_s = 0$
YC_s : Integer variable for Plant s:
If Plant s is built: $YC_s = 1$
If Plant s is not built: $YC_s = 0$
YT : Integer variable for Transfer:
If Transfer is built: $YT_s = 1$
If Transfer is not built: $YT_s = 0$
$S_{A,t}$: Storage in Reservoir A in season t (t = 1, 2, 3)
$S_{B,t}$: Storage in Reservoir B in season t (t = 1, 2, 3)
$S_{C,t}$: Storage in Reservoir C in season t (t = 1, 2, 3)
$S_{D,t}$: Storage in Reservoir D in season t (t = 1, 2, 3)
R_{At} : Releases from Reservoir A in season t
R_{Bt} : Releases from Reservoir B in season t
R_{Ct} : Releases from Reservoir C in season t
R_{Dt} : Releases from Reservoir D in season t
I_{Bt} : Inflows in Reservoir B in season t
I_{Dt} : Inflows in Reservoir D in season t
D_{Bt} : Water diverted to Irrigation B in season t
D_{Ct} : Water diverted to Irrigation C in season t
D_{Dt} : Water diverted to Irrigation D in season t
e_{At} : evaporation coefficient of Reservoir A in season t
e_{Bt} : evaporation coefficient of Reservoir B in season t
e_{Ct} : evaporation coefficient of Reservoir C in season t
e_{Dt} : evaporation coefficient of Reservoir D in season t
f_{1t} : Inflows of the left branch of the river in season t
f_{2t} : Inflows of the center branch of the river in season t
f_{3t} : Inflows of the right branch of the river in season t
RI_{Bt} : Water that return to the river in season t from Irrigation B
RI_{Ct} : Water that return to the river in season t from Irrigation C
RI_{Dt} : Water that return to the river in season t from Irrigation D
ϵ_B : water losses in Irrigation B channels
ϵ_C : water losses in Irrigation C channels
ϵ_D : water losses in Irrigation D channels
Γ_t : irrigation water demands in season t (t = 1, 2)
Ω_{lt} : water non consumed in season l (l = 1, 2) that return to the river in season t (t = 1, 2, 3)

Φ : water consumed by crops
H_A : head of Plant A
H_C : head of Plant C
s_A : efficiency of Plant A
s_C : efficiency of Plant C
k_t : number of seconds in season t
h_t : number of hours in season t ($t = 1, 2, 3$)
lf : load factor
u : factor of utilization
TR_t : Flow of the Transfer in season t ($t = 1, 2, 3$)

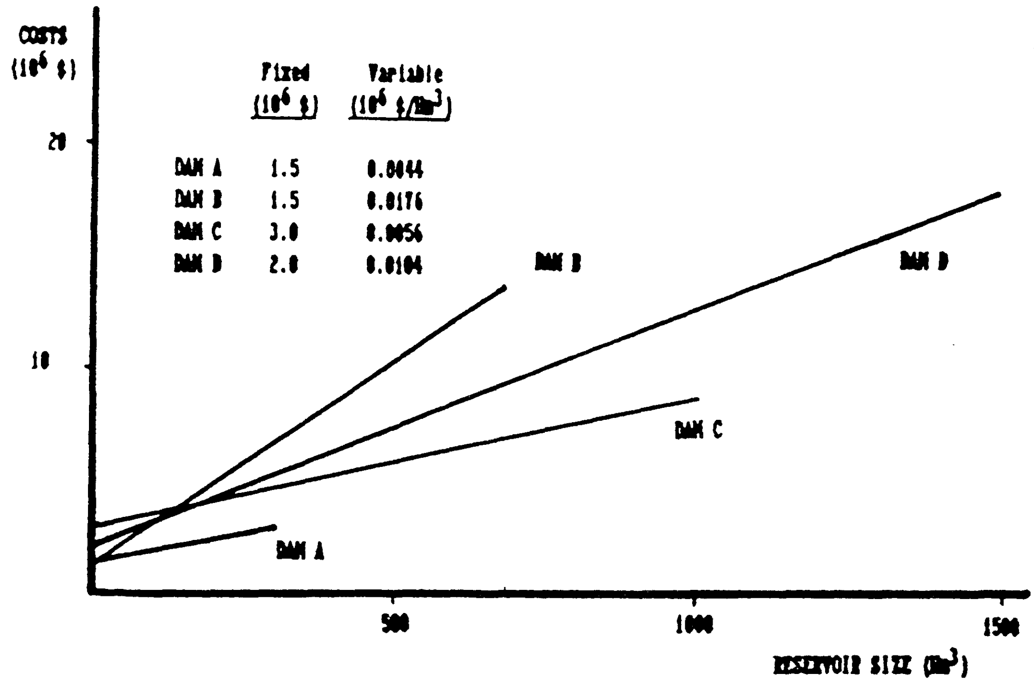

FIGURE A-1: *Construction costs of the dams*

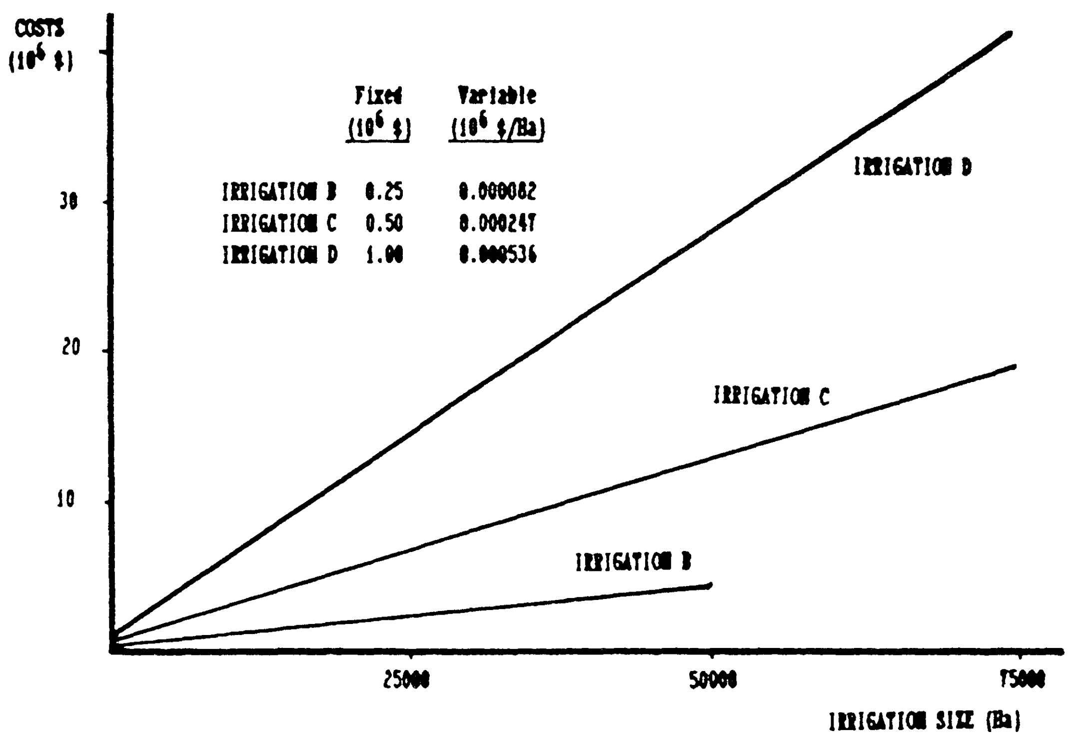

FIGURE A-2: *Costruction costs of the irrigations*

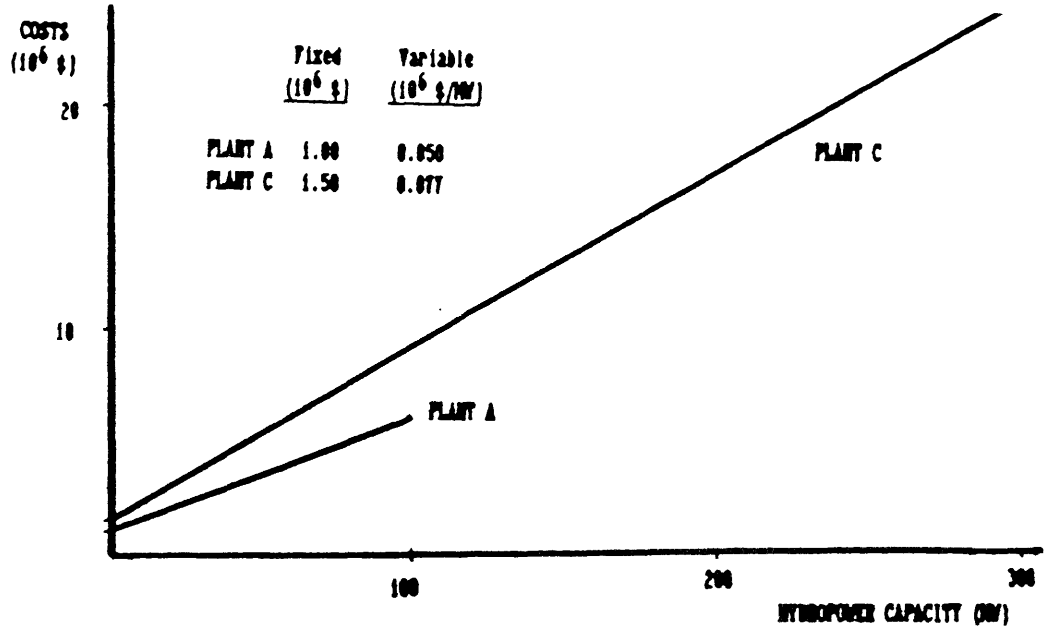

FIGURE A-3: *Construction costs of the power plants*

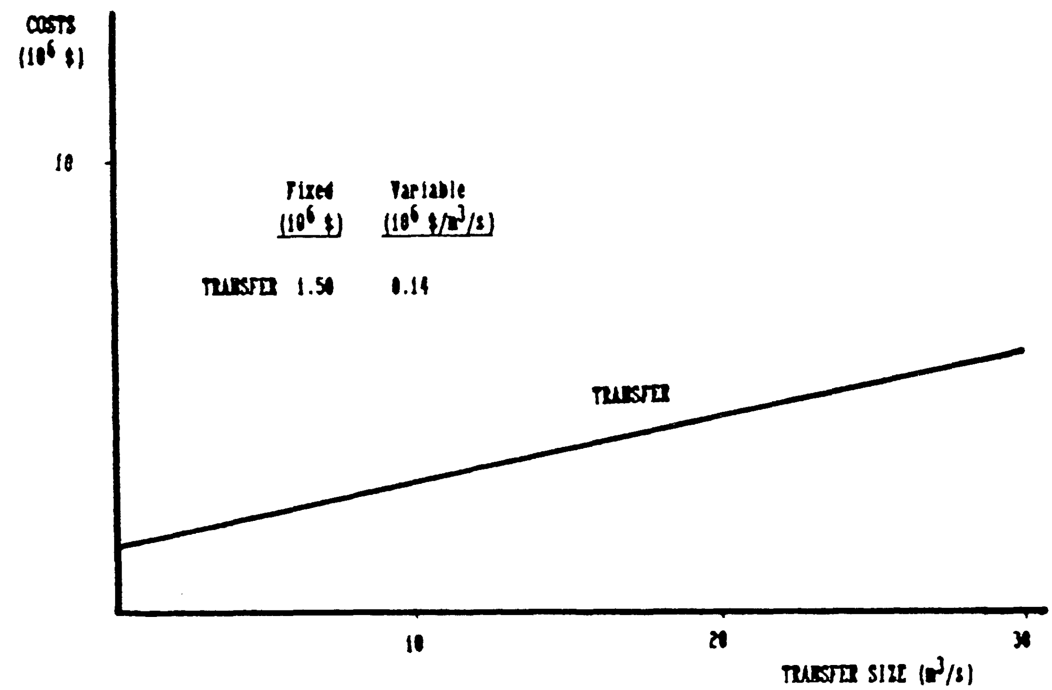

FIGURE A-4: *Construction costs of the transfer*

APPENDIX B

TABLE B-1: *Probabilities of the 243 elements of the uncertain parameter vector Θ*

DISCOUNT RATE: 8 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	0.375%	0.600%	0.525%	0.375%	0.600%	0.525%	0.375%	0.600%	0.525%
COSTS=	Agr.Pr.=40	0.500%	0.800%	0.700%	0.500%	0.800%	0.700%	0.500%	0.800%	0.700%
-25 %	Agr.Pr.=50	0.375%	0.600%	0.525%	0.375%	0.600%	0.525%	0.375%	0.600%	0.525%
CONSTR.	Agr.Pr.=30	0.262%	0.420%	0.367%	0.262%	0.420%	0.367%	0.262%	0.420%	0.367%
COSTS=	Agr.Pr.=40	0.350%	0.560%	0.490%	0.350%	0.560%	0.490%	0.350%	0.560%	0.490%
even	Agr.Pr.=50	0.262%	0.420%	0.367%	0.262%	0.420%	0.367%	0.262%	0.420%	0.367%
CONSTR.	Agr.Pr.=30	0.112%	0.180%	0.157%	0.112%	0.180%	0.157%	0.112%	0.180%	0.157%
COSTS=	Agr.Pr.=40	0.150%	0.240%	0.210%	0.150%	0.240%	0.210%	0.150%	0.240%	0.210%
+25 %	Agr.Pr.=50	0.112%	0.180%	0.157%	0.112%	0.180%	0.157%	0.112%	0.180%	0.157%

DISCOUNT RATE: 10 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	0.625%	1.000%	0.875%	0.625%	1.000%	0.875%	0.625%	1.000%	0.875%
COSTS=	Agr.Pr.=40	0.833%	1.333%	1.167%	0.833%	1.333%	1.167%	0.833%	1.333%	1.167%
-25 %	Agr.Pr.=50	0.625%	1.000%	0.875%	0.625%	1.000%	0.875%	0.625%	1.000%	0.875%
CONSTR.	Agr.Pr.=30	0.437%	0.700%	0.612%	0.437%	0.700%	0.612%	0.437%	0.700%	0.612%
COSTS=	Agr.Pr.=40	0.583%	0.933%	0.817%	0.583%	0.933%	0.817%	0.583%	0.933%	0.817%
even	Agr.Pr.=50	0.437%	0.700%	0.612%	0.437%	0.700%	0.612%	0.437%	0.700%	0.612%
CONSTR.	Agr.Pr.=30	0.187%	0.300%	0.262%	0.187%	0.300%	0.262%	0.187%	0.300%	0.262%
COSTS=	Agr.Pr.=40	0.250%	0.400%	0.350%	0.250%	0.400%	0.350%	0.250%	0.400%	0.350%
+25 %	Agr.Pr.=50	0.187%	0.300%	0.262%	0.187%	0.300%	0.262%	0.187%	0.300%	0.262%

DISCOUNT RATE: 12 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	0.250%	0.400%	0.350%	0.250%	0.400%	0.350%	0.250%	0.400%	0.350%
COSTS=	Agr.Pr.=40	0.333%	0.533%	0.467%	0.333%	0.533%	0.467%	0.333%	0.533%	0.467%
-25 %	Agr.Pr.=50	0.250%	0.400%	0.350%	0.250%	0.400%	0.350%	0.250%	0.400%	0.350%
CONSTR.	Agr.Pr.=30	0.175%	0.280%	0.245%	0.175%	0.280%	0.245%	0.175%	0.280%	0.245%
COSTS=	Agr.Pr.=40	0.233%	0.373%	0.327%	0.233%	0.373%	0.327%	0.233%	0.373%	0.327%
even	Agr.Pr.=50	0.175%	0.280%	0.245%	0.175%	0.280%	0.245%	0.175%	0.280%	0.245%
CONSTR.	Agr.Pr.=30	0.075%	0.120%	0.105%	0.075%	0.120%	0.105%	0.075%	0.120%	0.105%
COSTS=	Agr.Pr.=40	0.100%	0.160%	0.140%	0.100%	0.160%	0.140%	0.100%	0.160%	0.140%
+25 %	Agr.Pr.=50	0.075%	0.120%	0.105%	0.075%	0.120%	0.105%	0.075%	0.120%	0.105%

TABLE B-2: *Optimal sizes of Dam A*

DISCOUNT RATE: 8 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	0.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	0.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-25 %	Agr.Pr.=50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CONSTR.	Agr.Pr.=30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	0.84	0.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00
even	Agr.Pr.=50	0.84	0.84	0.84	0.00	0.00	0.00	0.00	0.00	0.00
CONSTR.	Agr.Pr.=30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
+25 %	Agr.Pr.=50	0.84	0.84	0.84	0.00	0.00	0.00	0.00	0.00	0.00

DISCOUNT RATE: 10 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	0.84	0.84	0.84	0.00	0.00	0.00	0.00	0.00	0.00
-25 %	Agr.Pr.=50	0.84	0.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CONSTR.	Agr.Pr.=30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
even	Agr.Pr.=50	0.84	0.84	0.84	0.00	0.00	0.00	0.00	0.00	0.00
CONSTR.	Agr.Pr.=30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
+25 %	Agr.Pr.=50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

DISCOUNT RATE: 12 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	0.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-25 %	Agr.Pr.=50	0.84	0.84	0.84	0.00	0.00	0.00	0.00	0.00	0.00
CONSTR.	Agr.Pr.=30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
even	Agr.Pr.=50	0.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CONSTR.	Agr.Pr.=30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
+25 %	Agr.Pr.=50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TABLE B-3: *Optimal sizes of Dam B*

DISCOUNT RATE: 8 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	0.00	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
COSTS=	Agr.Pr.=40	0.00	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
-25 %	Agr.Pr.=50	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
CONSTR.	Agr.Pr.=30	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
COSTS=	Agr.Pr.=40	0.00	0.00	0.84	0.84	0.84	0.84	0.84	0.84	0.84
even	Agr.Pr.=50	0.00	0.00	0.00	0.84	0.84	0.84	0.84	0.84	0.84
CONSTR.	Agr.Pr.=30	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
COSTS=	Agr.Pr.=40	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
+25 %	Agr.Pr.=50	0.00	0.00	0.00	0.84	0.84	0.84	0.84	0.84	0.84

DISCOUNT RATE: 10 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
COSTS=	Agr.Pr.=40	0.00	0.00	0.00	0.84	0.84	0.84	0.84	0.84	0.84
-25 %	Agr.Pr.=50	0.00	0.00	0.84	0.84	0.84	0.84	0.84	0.84	0.84
CONSTR.	Agr.Pr.=30	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.00
COSTS=	Agr.Pr.=40	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
even	Agr.Pr.=50	0.00	0.00	0.00	0.84	0.84	0.84	0.84	0.84	0.84
CONSTR.	Agr.Pr.=30	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
COSTS=	Agr.Pr.=40	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
+25 %	Agr.Pr.=50	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84

DISCOUNT RATE: 12 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
COSTS=	Agr.Pr.=40	0.00	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
-25 %	Agr.Pr.=50	0.00	0.00	0.00	0.84	0.84	0.84	0.84	0.84	0.84
CONSTR.	Agr.Pr.=30	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
COSTS=	Agr.Pr.=40	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
even	Agr.Pr.=50	0.00	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
CONSTR.	Agr.Pr.=30	0.84	0.84	0.84	0.84	0.84	0.84	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
+25 %	Agr.Pr.=50	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84

TABLE B-4: *Optimal sizes of Dam C*

DISCOUNT RATE: 8 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	1.05	0.00	0.00	1.05	1.05	0.00	1.05	0.00	0.00
COSTS=	Agr.Pr.=40	1.05	0.00	0.00	1.05	0.00	0.00	1.05	1.05	0.00
-25 %	Agr.Pr.=50	1.05	0.00	0.00	1.05	0.00	0.00	1.05	1.05	0.00
CONSTR.	Agr.Pr.=30	1.05	1.05	0.00	1.05	1.05	0.00	1.05	0.00	0.00
COSTS=	Agr.Pr.=40	1.05	1.05	0.00	1.05	1.05	0.00	1.05	1.05	0.00
even	Agr.Pr.=50	1.05	1.05	0.00	1.05	1.05	0.00	1.05	1.05	0.00
CONSTR.	Agr.Pr.=30	1.05	1.05	1.05	1.05	1.05	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	1.05	1.05	0.00	1.05	1.05	1.05	1.05	0.00	0.00
+25 %	Agr.Pr.=50	1.05	1.05	0.00	1.05	1.05	1.05	1.05	1.05	0.00

DISCOUNT RATE: 10 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	1.05	1.05	0.00	1.05	1.05	0.00	1.05	0.00	0.00
COSTS=	Agr.Pr.=40	1.05	1.05	0.00	1.05	1.05	0.00	1.05	1.05	0.00
-25 %	Agr.Pr.=50	1.05	1.05	0.00	1.05	1.05	0.00	1.05	1.05	0.00
CONSTR.	Agr.Pr.=30	1.05	1.05	1.05	1.05	1.05	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	1.05	1.05	0.00	1.05	1.05	1.05	1.05	0.00	0.00
even	Agr.Pr.=50	1.05	1.05	0.00	1.05	1.05	1.05	1.05	1.05	0.00
CONSTR.	Agr.Pr.=30	1.05	1.05	1.05	1.05	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	1.05	1.05	1.05	1.05	1.05	1.05	0.00	0.00	0.00
+25 %	Agr.Pr.=50	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	0.00

DISCOUNT RATE: 12 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	1.05	1.05	0.00	1.05	1.05	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	1.05	1.05	0.00	1.05	1.05	1.05	1.05	1.05	0.00
-25 %	Agr.Pr.=50	1.05	1.05	0.00	1.05	1.05	0.00	1.05	1.05	1.05
CONSTR.	Agr.Pr.=30	1.05	1.05	1.05	1.05	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	1.05	1.05	1.05	1.05	1.05	1.05	0.00	0.00	0.00
even	Agr.Pr.=50	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	0.00
CONSTR.	Agr.Pr.=30	1.05	1.05	1.05	0.00	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	1.05	1.05	1.05	1.05	1.05	0.00	0.00	0.00	0.00
+25 %	Agr.Pr.=50	1.05	1.05	1.05	1.05	1.05	1.05	0.00	0.00	0.00

TABLE B-5: *Optimal sizes of Dam D*

DISCOUNT RATE: 8 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	0.21	1.23	1.23	0.00	0.00	1.23	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	0.21	1.22	1.22	0.00	1.23	1.23	0.00	0.00	1.23
-25 %	Agr.Pr.=50	0.21	1.22	1.22	0.21	1.23	1.23	0.00	0.00	1.23
CONSTR.	Agr.Pr.=30	0.00	0.00	1.23	0.00	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	0.21	0.21	1.23	0.00	0.00	1.23	0.00	0.00	0.00
even	Agr.Pr.=50	0.21	0.21	1.23	0.00	0.00	1.23	0.00	0.00	1.23
CONSTR.	Agr.Pr.=30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	0.00	0.00	1.23	0.00	0.00	0.00	0.00	0.00	0.00
+25 %	Agr.Pr.=50	0.21	0.21	1.23	0.00	0.00	0.00	0.00	0.00	0.00

DISCOUNT RATE: 10 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	0.00	0.00	1.23	0.00	0.00	1.23	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	0.21	0.21	1.23	0.00	0.00	1.23	0.00	0.00	0.00
-25 %	Agr.Pr.=50	0.21	0.21	1.22	0.00	0.00	1.23	0.00	0.00	1.23
CONSTR.	Agr.Pr.=30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	0.00	0.00	1.23	0.00	0.00	0.00	0.00	0.00	0.00
even	Agr.Pr.=50	0.21	0.21	1.23	0.00	0.00	0.00	0.00	0.00	0.00
CONSTR.	Agr.Pr.=30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
+25 %	Agr.Pr.=50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

DISCOUNT RATE: 12 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	0.00	0.00	1.23	0.00	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	0.21	0.21	1.23	0.00	0.00	0.00	0.00	0.00	0.00
-25 %	Agr.Pr.=50	0.21	0.21	1.23	0.00	0.00	1.23	0.00	0.00	0.00
CONSTR.	Agr.Pr.=30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
even	Agr.Pr.=50	0.21	0.21	0.21	0.00	0.00	0.00	0.00	0.00	0.00
CONSTR.	Agr.Pr.=30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
+25 %	Agr.Pr.=50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TABLE B-6: *Optimal sizes of Irrigation B*

DISCOUNT RATE: 8 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	16.75	16.55	16.55	16.55	16.55	16.55	16.55	16.55	16.55
COSTS=	Agr.Pr.=40	16.75	27.88	27.88	16.55	16.55	16.55	16.55	16.55	16.55
-25 %	Agr.Pr.=50	27.88	27.88	27.88	16.55	16.55	16.55	16.55	16.55	16.55
CONSTR.	Agr.Pr.=30	16.55	16.55	16.55	16.55	16.55	16.55	16.55	16.55	16.55
COSTS=	Agr.Pr.=40	16.75	16.75	16.55	16.55	16.55	16.55	16.55	16.55	16.55
even	Agr.Pr.=50	16.75	16.75	16.75	16.55	16.55	16.55	16.55	16.55	16.55
CONSTR.	Agr.Pr.=30	16.55	16.55	16.55	16.55	16.55	16.55	16.55	16.55	16.55
COSTS=	Agr.Pr.=40	16.55	16.55	16.55	16.55	16.55	16.55	16.55	16.55	16.55
+25 %	Agr.Pr.=50	16.75	16.75	16.75	16.55	16.55	16.55	16.55	16.55	16.55

DISCOUNT RATE: 10 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	16.55	16.55	16.55	16.55	16.55	16.55	16.55	16.55	16.55
COSTS=	Agr.Pr.=40	16.75	16.75	16.75	16.55	16.55	16.55	16.55	16.55	16.55
-25 %	Agr.Pr.=50	16.75	16.75	27.88	16.55	16.55	16.55	16.55	16.55	16.55
CONSTR.	Agr.Pr.=30	16.55	16.55	16.55	16.55	16.55	16.55	16.55	16.55	0.00
COSTS=	Agr.Pr.=40	16.55	16.55	16.55	16.55	16.55	16.55	16.55	16.55	16.55
even	Agr.Pr.=50	16.75	16.75	16.75	16.55	16.55	16.55	16.55	16.55	16.55
CONSTR.	Agr.Pr.=30	16.55	16.55	16.55	16.55	16.55	16.55	16.55	16.55	16.55
COSTS=	Agr.Pr.=40	16.55	16.55	16.55	16.55	16.55	16.55	16.55	16.55	16.55
+25 %	Agr.Pr.=50	16.55	16.55	16.55	16.55	16.55	16.55	16.55	16.55	16.55

DISCOUNT RATE: 12 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	16.55	16.55	16.55	16.55	16.55	16.55	16.55	16.55	16.55
COSTS=	Agr.Pr.=40	16.75	16.55	16.55	16.55	16.55	16.55	16.55	16.55	16.55
-25 %	Agr.Pr.=50	16.75	16.75	16.75	16.55	16.55	16.55	16.55	16.55	16.55
CONSTR.	Agr.Pr.=30	16.55	16.55	16.55	16.55	16.55	16.55	16.55	16.55	16.55
COSTS=	Agr.Pr.=40	16.55	16.55	16.55	16.55	16.55	16.55	16.55	16.55	16.55
even	Agr.Pr.=50	16.75	16.55	16.55	16.55	16.55	16.55	16.55	16.55	16.55
CONSTR.	Agr.Pr.=30	16.55	16.55	16.55	16.55	16.55	16.55	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	16.55	16.55	16.55	16.55	16.55	16.55	16.55	16.55	16.55
+25 %	Agr.Pr.=50	16.55	16.55	16.55	16.55	16.55	16.55	16.55	16.55	16.55

TABLE B-7: *Optimal sizes of Irrigation C*

DISCOUNT RATE: 8 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	19.66	0.00	0.00	18.47	18.47	0.00	18.47	0.00	0.00
COSTS=	Agr.Pr.=40	19.66	0.00	0.00	18.47	0.00	0.00	18.47	18.47	0.00
-25 %	Agr.Pr.=50	19.66	0.00	0.00	19.66	0.00	0.00	18.47	18.47	0.00
CONSTR.	Agr.Pr.=30	18.47	18.47	0.00	18.47	18.47	0.00	18.47	0.00	0.00
COSTS=	Agr.Pr.=40	19.66	19.66	0.00	18.47	18.47	0.00	18.47	18.47	0.00
even	Agr.Pr.=50	19.66	19.66	0.00	18.47	18.47	0.00	18.47	18.47	0.00
CONSTR.	Agr.Pr.=30	18.47	18.47	18.47	18.47	18.47	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	18.47	18.47	0.00	18.47	18.47	18.47	18.47	0.00	0.00
+25 %	Agr.Pr.=50	19.66	19.66	0.00	18.47	18.47	18.47	18.47	18.47	0.00

DISCOUNT RATE: 10 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	18.47	18.47	0.00	18.47	18.47	0.00	18.47	0.00	0.00
COSTS=	Agr.Pr.=40	19.66	19.66	0.00	18.47	18.47	0.00	18.47	18.47	0.00
-25 %	Agr.Pr.=50	19.66	19.66	0.00	18.47	18.47	0.00	18.47	18.47	0.00
CONSTR.	Agr.Pr.=30	18.47	18.47	18.47	18.47	18.47	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	18.47	18.47	0.00	18.47	18.47	18.47	18.47	0.00	0.00
even	Agr.Pr.=50	19.66	19.66	0.00	18.47	18.47	18.47	18.47	18.47	0.00
CONSTR.	Agr.Pr.=30	18.47	18.47	18.47	18.47	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	18.47	18.47	18.47	18.47	18.47	18.47	0.00	0.00	0.00
+25 %	Agr.Pr.=50	18.47	18.47	18.47	18.47	18.47	18.47	18.47	18.47	0.00

DISCOUNT RATE: 12 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	18.47	18.47	0.00	18.47	18.47	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	19.66	19.66	0.00	18.47	18.47	18.47	18.47	18.47	0.00
-25 %	Agr.Pr.=50	19.66	19.66	0.00	18.47	18.47	0.00	18.47	18.47	18.47
CONSTR.	Agr.Pr.=30	18.47	18.47	18.47	18.47	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	18.47	18.47	18.47	18.47	18.47	18.47	0.00	0.00	0.00
even	Agr.Pr.=50	19.66	19.66	19.66	18.47	18.47	18.47	18.47	18.47	0.00
CONSTR.	Agr.Pr.=30	18.47	18.47	18.47	0.00	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	18.47	18.47	18.47	18.47	18.47	0.00	0.00	0.00	0.00
+25 %	Agr.Pr.=50	18.47	18.47	18.47	18.47	18.47	18.47	0.00	0.00	0.00

TABLE B-8: *Optimal sizes of Irrigation D*

DISCOUNT RATE: 8 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	1.65	20.67	20.67	0.00	0.00	20.67	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	1.65	20.84	20.84	0.00	20.67	20.67	0.00	0.00	20.67
-25 %	Agr.Pr.=50	1.72	20.84	20.84	1.55	20.67	20.67	0.00	0.00	20.67
CONSTR.	Agr.Pr.=30	0.00	0.00	20.67	0.00	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	1.65	1.65	20.67	0.00	0.00	20.67	0.00	0.00	0.00
even	Agr.Pr.=50	1.65	1.65	20.77	0.00	0.00	20.67	0.00	0.00	20.67
CONSTR.	Agr.Pr.=30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	0.00	0.00	20.67	0.00	0.00	0.00	0.00	0.00	0.00
+25 %	Agr.Pr.=50	1.65	1.65	20.77	0.00	0.00	0.00	0.00	0.00	0.00

DISCOUNT RATE: 10 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	0.00	0.00	20.67	0.00	0.00	20.67	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	1.65	1.65	20.77	0.00	0.00	20.67	0.00	0.00	0.00
-25 %	Agr.Pr.=50	1.65	1.65	20.84	0.00	0.00	20.67	0.00	0.00	20.67
CONSTR.	Agr.Pr.=30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	0.00	0.00	20.67	0.00	0.00	0.00	0.00	0.00	0.00
even	Agr.Pr.=50	1.65	1.65	20.77	0.00	0.00	0.00	0.00	0.00	0.00
CONSTR.	Agr.Pr.=30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
+25 %	Agr.Pr.=50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

DISCOUNT RATE: 12 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	0.00	0.00	20.67	0.00	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	1.65	1.55	20.67	0.00	0.00	0.00	0.00	0.00	0.00
-25 %	Agr.Pr.=50	1.65	1.65	20.77	0.00	0.00	20.67	0.00	0.00	0.00
CONSTR.	Agr.Pr.=30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
even	Agr.Pr.=50	1.65	1.55	1.55	0.00	0.00	0.00	0.00	0.00	0.00
CONSTR.	Agr.Pr.=30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
+25 %	Agr.Pr.=50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TABLE B-9: *Optimal sizes of hydropower Plant A*

DISCOUNT RATE: 8 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
COSTS=	Agr.Pr.=40	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
-25 %	Agr.Pr.=50	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
CONSTR.	Agr.Pr.=30	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
COSTS=	Agr.Pr.=40	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
even	Agr.Pr.=50	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
CONSTR.	Agr.Pr.=30	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
COSTS=	Agr.Pr.=40	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
+25 %	Agr.Pr.=50	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09

DISCOUNT RATE: 10 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
COSTS=	Agr.Pr.=40	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
-25 %	Agr.Pr.=50	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
CONSTR.	Agr.Pr.=30	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
COSTS=	Agr.Pr.=40	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
even	Agr.Pr.=50	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
CONSTR.	Agr.Pr.=30	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
COSTS=	Agr.Pr.=40	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
+25 %	Agr.Pr.=50	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09

DISCOUNT RATE: 12 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
COSTS=	Agr.Pr.=40	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
-25 %	Agr.Pr.=50	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
CONSTR.	Agr.Pr.=30	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
COSTS=	Agr.Pr.=40	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
even	Agr.Pr.=50	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
CONSTR.	Agr.Pr.=30	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
COSTS=	Agr.Pr.=40	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
+25 %	Agr.Pr.=50	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09

TABLE B-10: *Optimal sizes of hydropower Plant C*

DISCOUNT RATE: 8 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	0.00	0.06	0.06	0.00	0.00	0.06	0.00	0.06	0.06
COSTS=	Agr.Pr.=40	0.00	0.06	0.06	0.00	0.06	0.06	0.00	0.00	0.06
-25 %	Agr.Pr.=50	0.00	0.06	0.06	0.00	0.06	0.06	0.00	0.00	0.06
CONSTR.	Agr.Pr.=30	0.00	0.00	0.06	0.00	0.00	0.06	0.00	0.06	0.06
COSTS=	Agr.Pr.=40	0.00	0.00	0.06	0.00	0.00	0.06	0.00	0.00	0.06
even	Agr.Pr.=50	0.00	0.00	0.06	0.00	0.00	0.06	0.00	0.00	0.06
CONSTR.	Agr.Pr.=30	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.06	0.06
COSTS=	Agr.Pr.=40	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.06	0.06
+25 %	Agr.Pr.=50	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.06

DISCOUNT RATE: 10 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	0.00	0.00	0.06	0.00	0.00	0.06	0.00	0.06	0.06
COSTS=	Agr.Pr.=40	0.00	0.00	0.06	0.00	0.00	0.06	0.00	0.00	0.06
-25 %	Agr.Pr.=50	0.00	0.00	0.06	0.00	0.00	0.06	0.00	0.00	0.06
CONSTR.	Agr.Pr.=30	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.06	0.10
COSTS=	Agr.Pr.=40	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.06	0.06
even	Agr.Pr.=50	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.06
CONSTR.	Agr.Pr.=30	0.00	0.00	0.00	0.00	0.06	0.06	0.00	0.06	0.06
COSTS=	Agr.Pr.=40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.06
+25 %	Agr.Pr.=50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06

DISCOUNT RATE: 12 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	0.00	0.00	0.06	0.00	0.00	0.06	0.06	0.06	0.06
COSTS=	Agr.Pr.=40	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.06
-25 %	Agr.Pr.=50	0.00	0.00	0.06	0.00	0.00	0.06	0.00	0.00	0.00
CONSTR.	Agr.Pr.=30	0.00	0.00	0.00	0.00	0.06	0.06	0.00	0.06	0.06
COSTS=	Agr.Pr.=40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.06
even	Agr.Pr.=50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
CONSTR.	Agr.Pr.=30	0.00	0.00	0.00	0.00	0.06	0.06	0.00	0.06	0.10
COSTS=	Agr.Pr.=40	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.06	0.06
+25 %	Agr.Pr.=50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.06

TABLE B-11: *Optimal sizes of Transfer*

DISCOUNT RATE: 8 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-25 %	Agr.Pr.=50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CONSTR.	Agr.Pr.=30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
even	Agr.Pr.=50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CONSTR.	Agr.Pr.=30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
+25 %	Agr.Pr.=50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

DISCOUNT RATE: 10 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-25 %	Agr.Pr.=50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CONSTR.	Agr.Pr.=30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.00
COSTS=	Agr.Pr.=40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
even	Agr.Pr.=50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CONSTR.	Agr.Pr.=30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
+25 %	Agr.Pr.=50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

DISCOUNT RATE: 12 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-25 %	Agr.Pr.=50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CONSTR.	Agr.Pr.=30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COSTS=	Agr.Pr.=40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
even	Agr.Pr.=50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CONSTR.	Agr.Pr.=30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.00
COSTS=	Agr.Pr.=40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
+25 %	Agr.Pr.=50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

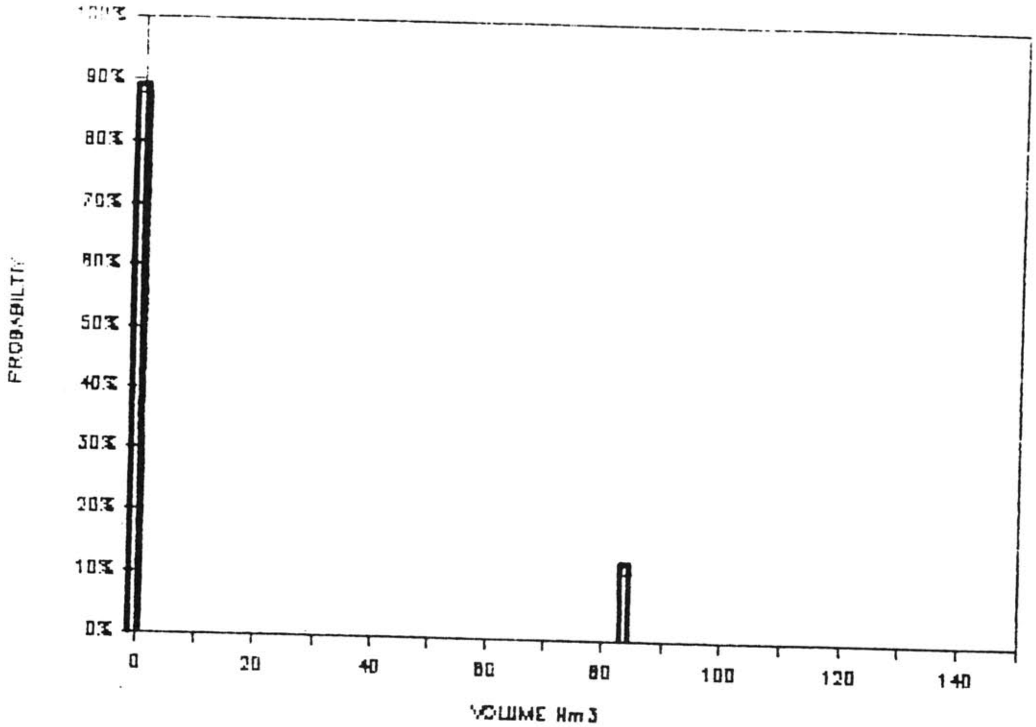

FIGURE B-1: *Bar graph of the probability distribution of the sizes of Dam A*

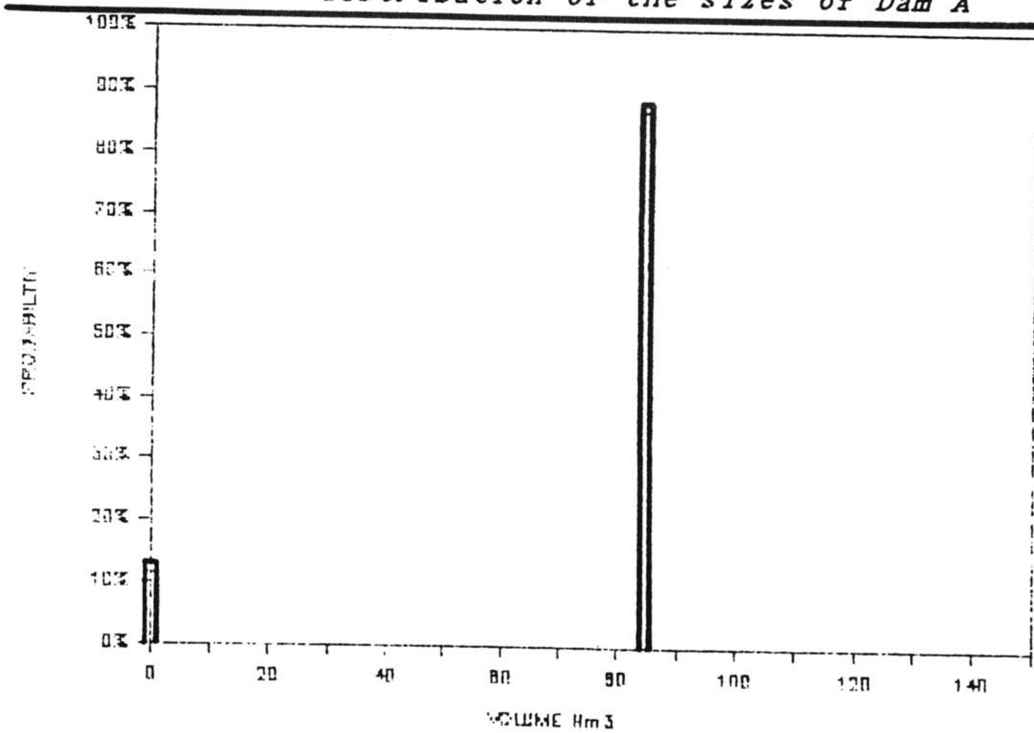

FIGURE B-2: *Bar graph of the probability distribution of the sizes of Dam B*

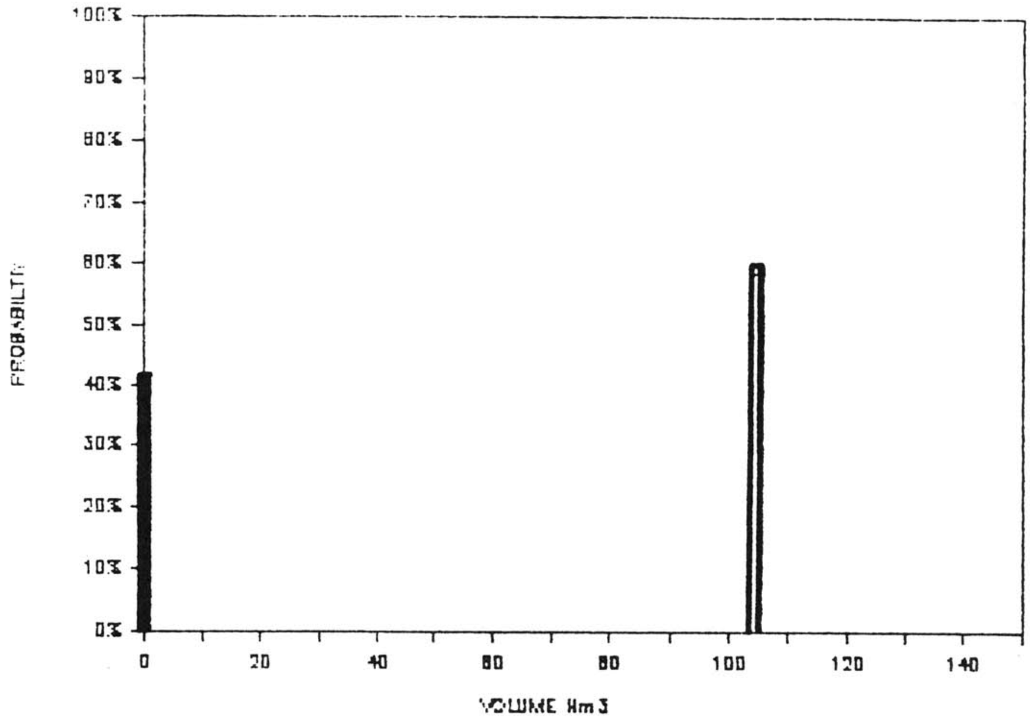

FIGURE B-3: *Bar graph of the probability distribution of the sizes of Dam C*

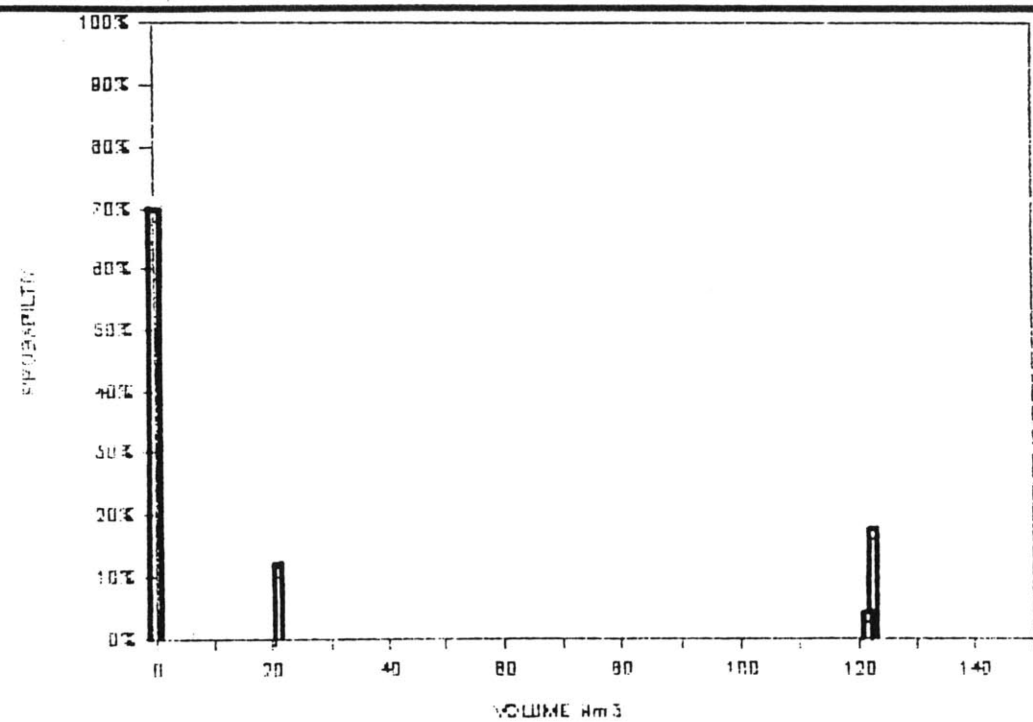

FIGURE B-4: *Bar graph of the probability distribution of the sizes of Dam D*

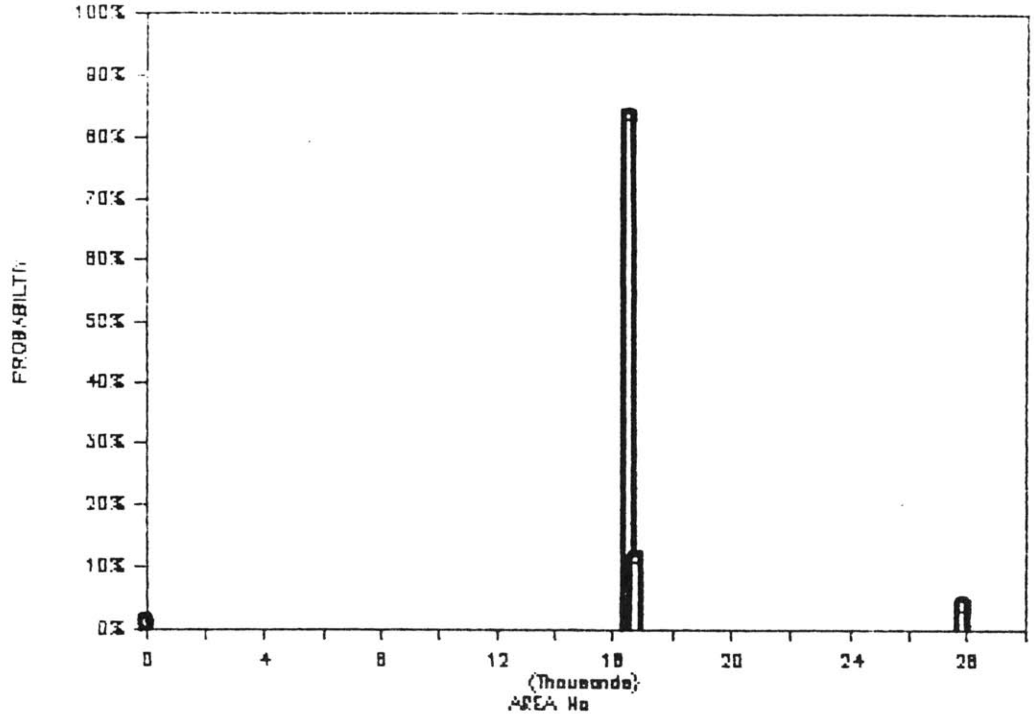

FIGURE B-5: *Bar graph of the probability distribution of the sizes of Irrigation B*

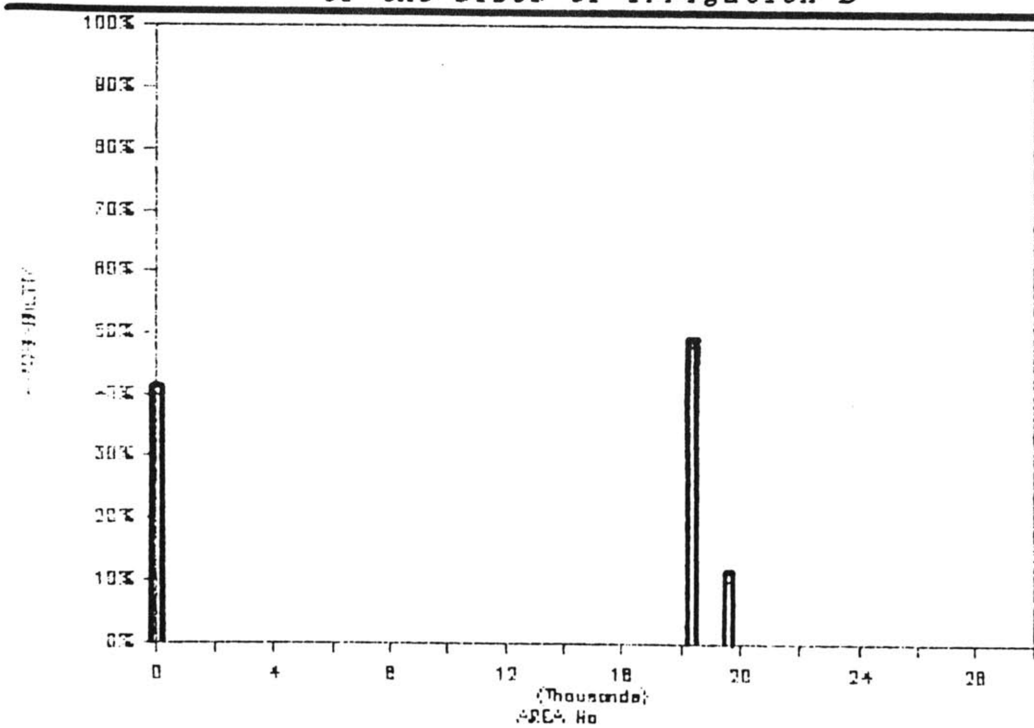

FIGURE B-6: *Bar graph of the probability distribution of the sizes of Irrigation C*

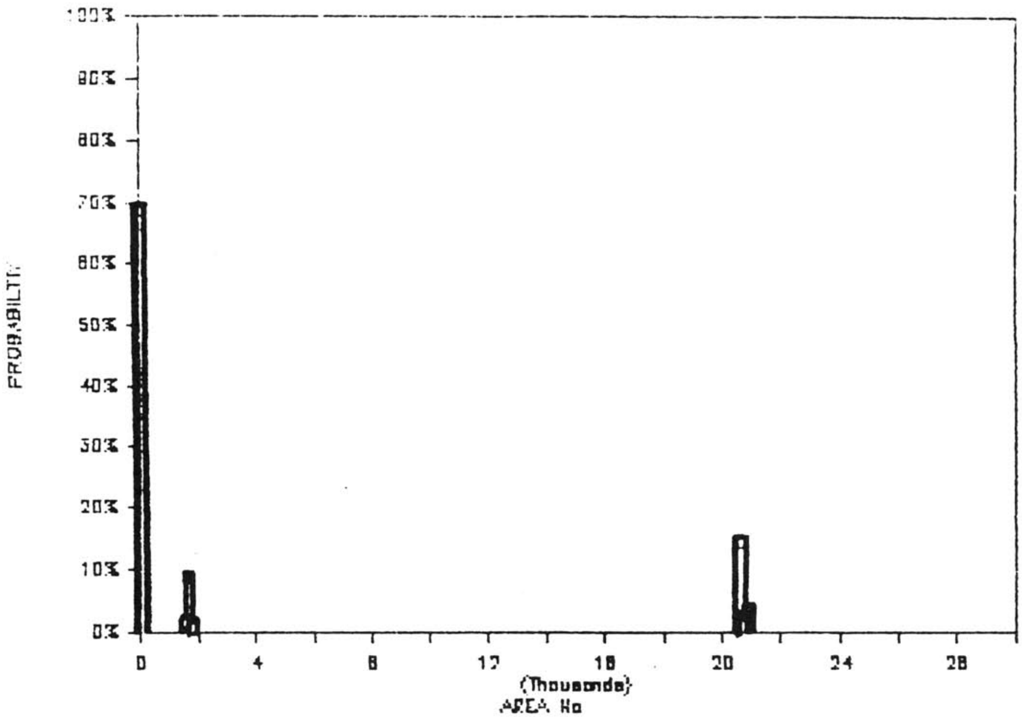

FIGURE B-7: *Bar graph of the probability distribution of the sizes of Irrigation D*

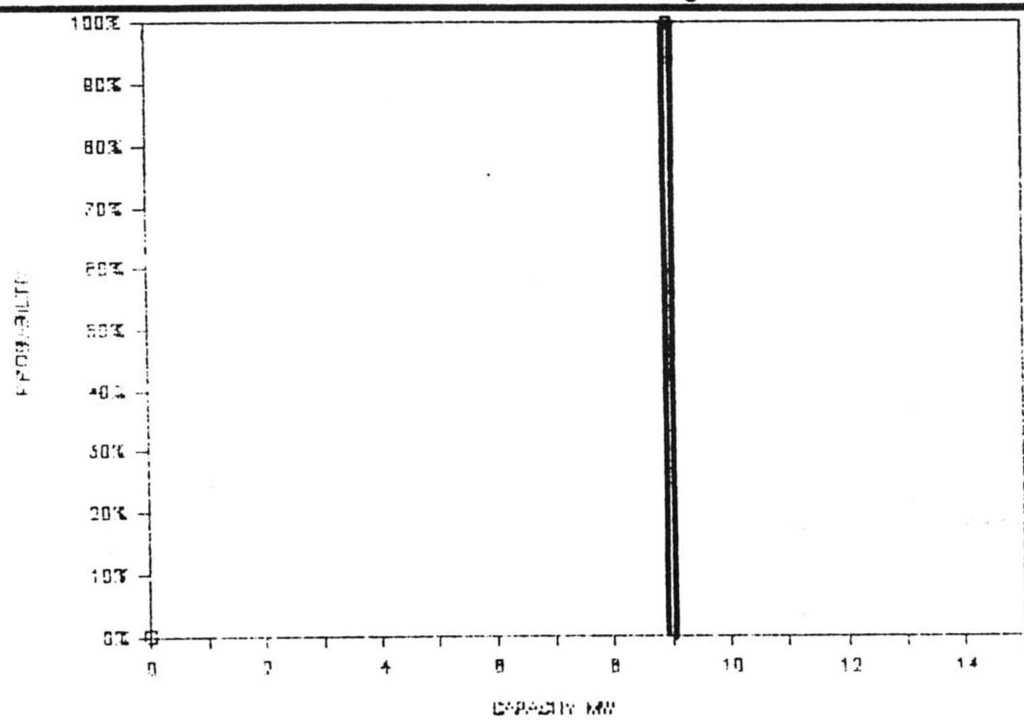

FIGURE B-8: *Bar graph of the probability distribution of the sizes of hydropower Plant A*

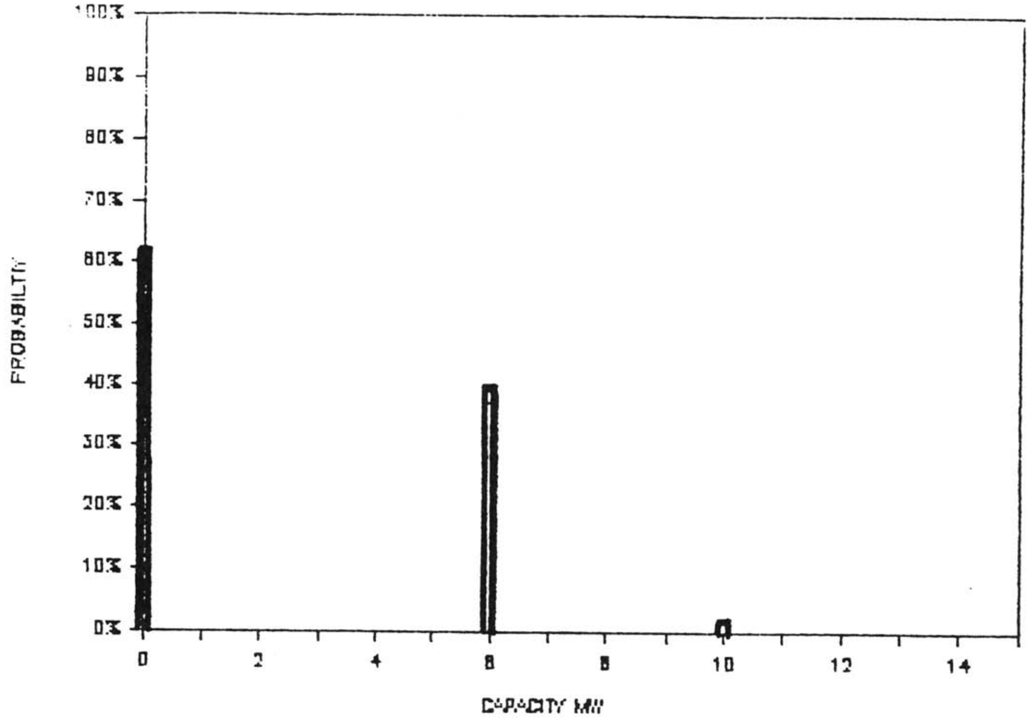

FIGURE B-9: *Bar graph of the probability distribution of the sizes of hydropower Plant C*

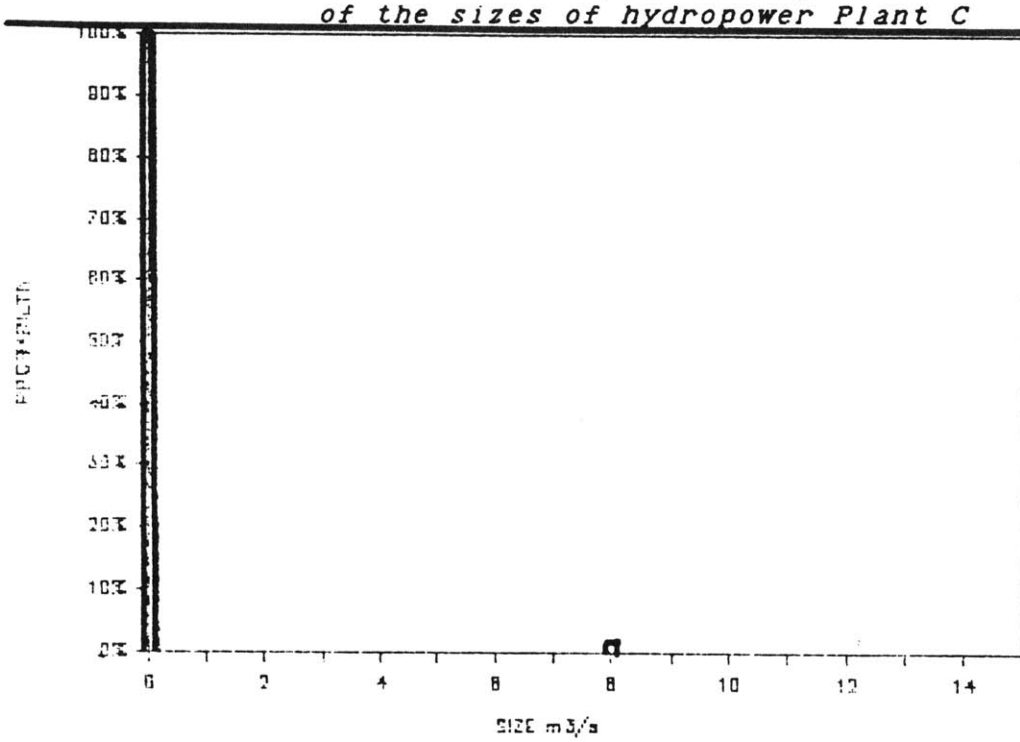

FIGURE B-10: *Bar graph of the probability distribution of the sizes of Transfer*

APPENDIX C

TABLE C-1: *Net benefits of Alternative A*

DISCOUNT RATE: 8 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	0.21	0.51	0.81	0.21	0.51	0.81	0.21	0.51	0.81
COSTS=	Agr.Pr.=40	0.21	0.51	0.81	0.21	0.51	0.81	0.21	0.51	0.81
-25 %	Agr.Pr.=50	0.21	0.51	0.81	0.21	0.51	0.81	0.21	0.51	0.81
CONSTR.	Agr.Pr.=30	0.18	0.48	0.78	0.18	0.48	0.78	0.18	0.48	0.78
COSTS=	Agr.Pr.=40	0.18	0.48	0.78	0.18	0.48	0.78	0.18	0.48	0.78
even	Agr.Pr.=50	0.18	0.48	0.78	0.18	0.48	0.78	0.18	0.48	0.78
CONSTR.	Agr.Pr.=30	0.15	0.45	0.75	0.15	0.45	0.75	0.15	0.45	0.75
COSTS=	Agr.Pr.=40	0.15	0.45	0.75	0.15	0.45	0.75	0.15	0.45	0.75
+25 %	Agr.Pr.=50	0.15	0.45	0.75	0.15	0.45	0.75	0.15	0.45	0.75

DISCOUNT RATE: 10 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	0.19	0.49	0.79	0.19	0.49	0.79	0.19	0.49	0.79
COSTS=	Agr.Pr.=40	0.19	0.49	0.79	0.19	0.49	0.79	0.19	0.49	0.79
-25 %	Agr.Pr.=50	0.19	0.49	0.79	0.19	0.49	0.79	0.19	0.49	0.79
CONSTR.	Agr.Pr.=30	0.15	0.45	0.75	0.15	0.45	0.75	0.15	0.45	0.75
COSTS=	Agr.Pr.=40	0.15	0.45	0.75	0.15	0.45	0.75	0.15	0.45	0.75
even	Agr.Pr.=50	0.15	0.45	0.75	0.15	0.45	0.75	0.15	0.45	0.75
CONSTR.	Agr.Pr.=30	0.12	0.41	0.71	0.12	0.41	0.71	0.12	0.41	0.71
COSTS=	Agr.Pr.=40	0.12	0.41	0.71	0.12	0.41	0.71	0.12	0.41	0.71
+25 %	Agr.Pr.=50	0.12	0.41	0.71	0.12	0.41	0.71	0.12	0.41	0.71

DISCOUNT RATE: 12 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	0.17	0.47	0.76	0.17	0.47	0.76	0.17	0.47	0.76
COSTS=	Agr.Pr.=40	0.17	0.47	0.76	0.17	0.47	0.76	0.17	0.47	0.76
-25 %	Agr.Pr.=50	0.17	0.47	0.76	0.17	0.47	0.76	0.17	0.47	0.76
CONSTR.	Agr.Pr.=30	0.12	0.42	0.72	0.12	0.42	0.72	0.12	0.42	0.72
COSTS=	Agr.Pr.=40	0.12	0.42	0.72	0.12	0.42	0.72	0.12	0.42	0.72
even	Agr.Pr.=50	0.12	0.42	0.72	0.12	0.42	0.72	0.12	0.42	0.72
CONSTR.	Agr.Pr.=30	0.08	0.38	0.68	0.08	0.38	0.68	0.08	0.38	0.68
COSTS=	Agr.Pr.=40	0.08	0.38	0.68	0.08	0.38	0.68	0.08	0.38	0.68
+25 %	Agr.Pr.=50	0.08	0.38	0.68	0.08	0.38	0.68	0.08	0.38	0.68

TABLE C-2: *Net benefits of Alternative B*

DISCOUNT RATE: 8 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	1.91	2.21	2.51	0.92	1.22	1.52	0.59	0.89	1.19
COSTS=	Agr.Pr.=40	2.57	2.87	3.17	1.25	1.55	1.85	0.81	1.11	1.41
-25 %	Agr.Pr.=50	3.24	3.53	3.83	1.58	1.88	2.18	1.03	1.33	1.63
CONSTR.	Agr.Pr.=30	1.79	2.09	2.39	0.80	1.10	1.39	0.47	0.76	1.06
COSTS=	Agr.Pr.=40	2.45	2.75	3.05	1.13	1.43	1.72	0.69	0.99	1.28
even	Agr.Pr.=50	3.11	3.41	3.71	1.46	1.76	2.06	0.91	1.21	1.50
CONSTR.	Agr.Pr.=30	1.67	1.96	2.26	0.67	0.97	1.27	0.34	0.64	0.94
COSTS=	Agr.Pr.=40	2.33	2.63	2.92	1.00	1.30	1.60	0.56	0.86	1.16
+25 %	Agr.Pr.=50	2.99	3.29	3.59	1.34	1.63	1.93	0.78	1.08	1.38

DISCOUNT RATE: 10 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	1.83	2.12	2.42	0.83	1.13	1.43	0.50	0.80	1.10
COSTS=	Agr.Pr.=40	2.49	2.79	3.08	1.16	1.46	1.76	0.72	1.02	1.32
-25 %	Agr.Pr.=50	3.15	3.45	3.75	1.49	1.79	2.09	0.94	1.24	1.54
CONSTR.	Agr.Pr.=30	1.67	1.97	2.27	0.68	0.98	1.28	0.35	0.65	0.95
COSTS=	Agr.Pr.=40	2.33	2.63	2.93	1.01	1.31	1.61	0.57	0.87	1.17
even	Agr.Pr.=50	3.00	3.29	3.59	1.34	1.64	1.94	0.79	1.09	1.39
CONSTR.	Agr.Pr.=30	1.52	1.82	2.12	0.53	0.83	1.13	0.20	0.50	0.79
COSTS=	Agr.Pr.=40	2.18	2.48	2.78	0.86	1.16	1.46	0.42	0.72	1.01
+25 %	Agr.Pr.=50	2.84	3.14	3.44	1.19	1.49	1.79	0.64	0.94	1.24

DISCOUNT RATE: 12 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	1.74	2.04	2.34	0.75	1.05	1.34	0.42	0.71	1.01
COSTS=	Agr.Pr.=40	2.40	2.70	3.00	1.08	1.38	1.67	0.64	0.94	1.23
-25 %	Agr.Pr.=50	3.06	3.36	3.66	1.41	1.71	2.01	0.86	1.16	1.45
CONSTR.	Agr.Pr.=30	1.56	1.86	2.16	0.57	0.86	1.16	0.24	0.53	0.83
COSTS=	Agr.Pr.=40	2.22	2.52	2.82	0.90	1.20	1.49	0.46	0.75	1.05
even	Agr.Pr.=50	2.88	3.18	3.48	1.23	1.53	1.82	0.68	0.97	1.27
CONSTR.	Agr.Pr.=30	1.38	1.68	1.97	0.38	0.68	0.98	0.05	0.35	0.65
COSTS=	Agr.Pr.=40	2.04	2.34	2.64	0.72	1.01	1.31	0.27	0.57	0.87
+25 %	Agr.Pr.=50	2.70	3.00	3.30	1.05	1.34	1.64	0.50	0.79	1.09

TABLE C-3: *Net benefits of Alternative C*

DISCOUNT RATE: 8 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	1.91	2.21	2.51	0.92	1.22	1.52	0.59	0.89	1.19
COSTS=	Agr.Pr.=40	2.57	2.87	3.17	1.25	1.55	1.85	0.81	1.11	1.41
-25 %	Agr.Pr.=50	3.24	3.53	3.83	1.58	1.88	2.18	1.03	1.33	1.63
CONSTR.	Agr.Pr.=30	1.79	2.09	2.39	0.80	1.10	1.39	0.47	0.76	1.06
COSTS=	Agr.Pr.=40	2.45	2.75	3.05	1.13	1.43	1.72	0.69	0.99	1.28
even	Agr.Pr.=50	3.11	3.41	3.71	1.46	1.76	2.06	0.91	1.21	1.50
CONSTR.	Agr.Pr.=30	1.67	1.96	2.26	0.67	0.97	1.27	0.34	0.64	0.94
COSTS=	Agr.Pr.=40	2.33	2.63	2.92	1.00	1.30	1.60	0.56	0.86	1.16
+25 %	Agr.Pr.=50	2.99	3.29	3.59	1.34	1.63	1.93	0.78	1.08	1.38

DISCOUNT RATE: 10 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	1.83	2.12	2.42	0.83	1.13	1.43	0.50	0.80	1.10
COSTS=	Agr.Pr.=40	2.49	2.79	3.08	1.16	1.46	1.76	0.72	1.02	1.32
-25 %	Agr.Pr.=50	3.15	3.45	3.75	1.49	1.79	2.09	0.94	1.24	1.54
CONSTR.	Agr.Pr.=30	1.67	1.97	2.27	0.68	0.98	1.28	0.35	0.65	0.95
COSTS=	Agr.Pr.=40	2.33	2.63	2.93	1.01	1.31	1.61	0.57	0.87	1.17
even	Agr.Pr.=50	3.00	3.29	3.59	1.34	1.64	1.94	0.79	1.09	1.39
CONSTR.	Agr.Pr.=30	1.52	1.82	2.12	0.53	0.83	1.13	0.20	0.50	0.79
COSTS=	Agr.Pr.=40	2.18	2.48	2.78	0.86	1.16	1.46	0.42	0.72	1.01
+25 %	Agr.Pr.=50	2.84	3.14	3.44	1.19	1.49	1.79	0.64	0.94	1.24

DISCOUNT RATE: 12 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	1.74	2.04	2.34	0.75	1.05	1.34	0.42	0.71	1.01
COSTS=	Agr.Pr.=40	2.40	2.70	3.00	1.08	1.38	1.67	0.64	0.94	1.23
-25 %	Agr.Pr.=50	3.06	3.36	3.66	1.41	1.71	2.01	0.86	1.16	1.45
CONSTR.	Agr.Pr.=30	1.56	1.86	2.16	0.57	0.86	1.16	0.24	0.53	0.83
COSTS=	Agr.Pr.=40	2.22	2.52	2.82	0.90	1.20	1.49	0.46	0.75	1.05
even	Agr.Pr.=50	2.88	3.18	3.48	1.23	1.53	1.82	0.68	0.97	1.27
CONSTR.	Agr.Pr.=30	1.38	1.68	1.97	0.38	0.68	0.98	0.05	0.35	0.65
COSTS=	Agr.Pr.=40	2.04	2.34	2.64	0.72	1.01	1.31	0.27	0.57	0.87
+25 %	Agr.Pr.=50	2.70	3.00	3.30	1.05	1.34	1.64	0.50	0.79	1.09

TABLE C-4: *Net benefits of Alternative D*

DISCOUNT RATE: 8 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	1.89	2.18	2.48	0.89	1.19	1.48	0.56	0.86	1.15
COSTS=	Agr.Pr.=40	2.55	2.85	3.14	1.23	1.52	1.81	0.78	1.08	1.37
-25 %	Agr.Pr.=50	3.21	3.51	3.80	1.56	1.85	2.15	1.00	1.30	1.59
CONSTR.	Agr.Pr.=30	1.76	2.05	2.35	0.76	1.06	1.35	0.43	0.73	1.02
COSTS=	Agr.Pr.=40	2.42	2.71	3.01	1.09	1.39	1.68	0.65	0.95	1.24
even	Agr.Pr.=50	3.08	3.38	3.67	1.43	1.72	2.01	0.87	1.17	1.46
CONSTR.	Agr.Pr.=30	1.63	1.92	2.21	0.63	0.93	1.22	0.30	0.59	0.89
COSTS=	Agr.Pr.=40	2.29	2.58	2.88	0.96	1.26	1.55	0.52	0.82	1.11
+25 %	Agr.Pr.=50	2.95	3.25	3.54	1.29	1.59	1.88	0.74	1.04	1.33

DISCOUNT RATE: 10 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	1.80	2.09	2.38	0.80	1.10	1.39	0.47	0.76	1.06
COSTS=	Agr.Pr.=40	2.46	2.75	3.05	1.13	1.43	1.72	0.69	0.98	1.28
-25 %	Agr.Pr.=50	3.12	3.42	3.71	1.46	1.76	2.05	0.91	1.21	1.50
CONSTR.	Agr.Pr.=30	1.63	1.93	2.22	0.64	0.93	1.23	0.31	0.60	0.90
COSTS=	Agr.Pr.=40	2.30	2.59	2.88	0.97	1.26	1.56	0.53	0.82	1.12
even	Agr.Pr.=50	2.96	3.25	3.55	1.30	1.60	1.89	0.75	1.04	1.34
CONSTR.	Agr.Pr.=30	1.47	1.76	2.06	0.48	0.77	1.06	0.15	0.44	0.73
COSTS=	Agr.Pr.=40	2.13	2.43	2.72	0.81	1.10	1.40	0.37	0.66	0.95
+25 %	Agr.Pr.=50	2.80	3.09	3.38	1.14	1.43	1.73	0.59	0.88	1.18

DISCOUNT RATE: 12 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	1.70	2.00	2.29	0.71	1.00	1.30	0.38	0.67	0.97
COSTS=	Agr.Pr.=40	2.37	2.66	2.95	1.04	1.34	1.63	0.60	0.89	1.19
-25 %	Agr.Pr.=50	3.03	3.32	3.62	1.37	1.67	1.96	0.82	1.11	1.41
CONSTR.	Agr.Pr.=30	1.51	1.80	2.10	0.52	0.81	1.10	0.19	0.48	0.77
COSTS=	Agr.Pr.=40	2.17	2.47	2.76	0.85	1.14	1.44	0.41	0.70	0.99
even	Agr.Pr.=50	2.84	3.13	3.42	1.18	1.47	1.77	0.63	0.92	1.22
CONSTR.	Agr.Pr.=30	1.32	1.61	1.91	0.32	0.62	0.91	-0.01	0.29	0.58
COSTS=	Agr.Pr.=40	1.98	2.27	2.57	0.66	0.95	1.24	0.21	0.51	0.80
+25 %	Agr.Pr.=50	2.64	2.94	3.23	0.99	1.28	1.57	0.43	0.73	1.02

TABLE C-5: *Net benefits of Alternative E*

DISCOUNT RATE: 8 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	1.98	2.46	2.95	0.99	1.47	1.96	0.66	1.14	1.63
COSTS=	Agr.Pr.=40	2.64	3.13	3.61	1.32	1.80	2.29	0.88	1.36	1.85
-25 %	Agr.Pr.=50	3.30	3.79	4.27	1.65	2.13	2.62	1.10	1.58	2.07
CONSTR.	Agr.Pr.=30	1.82	2.30	2.79	0.82	1.31	1.79	0.49	0.98	1.46
COSTS=	Agr.Pr.=40	2.48	2.96	3.45	1.15	1.64	2.12	0.71	1.20	1.68
even	Agr.Pr.=50	3.14	3.62	4.11	1.49	1.97	2.46	0.93	1.42	1.90
CONSTR.	Agr.Pr.=30	1.65	2.14	2.62	0.66	1.15	1.63	0.33	0.81	1.30
COSTS=	Agr.Pr.=40	2.31	2.80	3.28	0.99	1.48	1.96	0.55	1.04	1.52
+25 %	Agr.Pr.=50	2.98	3.46	3.95	1.32	1.81	2.29	0.77	1.26	1.74

DISCOUNT RATE: 10 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	1.86	2.35	2.83	0.87	1.36	1.84	0.54	1.03	1.51
COSTS=	Agr.Pr.=40	2.53	3.01	3.50	1.20	1.69	2.17	0.76	1.25	1.73
-25 %	Agr.Pr.=50	3.19	3.67	4.16	1.53	2.02	2.50	0.98	1.47	1.95
CONSTR.	Agr.Pr.=30	1.66	2.15	2.63	0.67	1.15	1.64	0.34	0.82	1.31
COSTS=	Agr.Pr.=40	2.32	2.81	3.29	1.00	1.49	1.97	0.56	1.04	1.53
even	Agr.Pr.=50	2.98	3.47	3.95	1.33	1.82	2.30	0.78	1.26	1.75
CONSTR.	Agr.Pr.=30	1.46	1.94	2.43	0.47	0.95	1.44	0.14	0.62	1.11
COSTS=	Agr.Pr.=40	2.12	2.61	3.09	0.80	1.28	1.77	0.36	0.84	1.33
+25 %	Agr.Pr.=50	2.78	3.27	3.75	1.13	1.61	2.10	0.58	1.06	1.55

DISCOUNT RATE: 12 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	1.75	2.23	2.72	0.76	1.24	1.73	0.43	0.91	1.40
COSTS=	Agr.Pr.=40	2.41	2.90	3.38	1.09	1.57	2.06	0.65	1.13	1.62
-25 %	Agr.Pr.=50	3.07	3.56	4.04	1.42	1.90	2.39	0.87	1.35	1.84
CONSTR.	Agr.Pr.=30	1.51	1.99	2.48	0.52	1.00	1.49	0.19	0.67	1.16
COSTS=	Agr.Pr.=40	2.17	2.66	3.14	0.85	1.33	1.82	0.41	0.89	1.38
even	Agr.Pr.=50	2.83	3.32	3.80	1.18	1.66	2.15	0.63	1.11	1.60
CONSTR.	Agr.Pr.=30	1.27	1.75	2.24	0.28	0.76	1.25	-0.05	0.43	0.92
COSTS=	Agr.Pr.=40	1.93	2.42	2.90	0.61	1.09	1.58	0.17	0.65	1.14
+25 %	Agr.Pr.=50	2.59	3.08	3.56	0.94	1.42	1.91	0.39	0.87	1.36

TABLE C-6: *Net benefits of Alternative F*

DISCOUNT RATE: 8 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	3.60	3.89	4.19	1.50	1.79	2.09	0.80	1.09	1.39
COSTS=	Agr.Pr.=40	5.00	5.30	5.59	2.20	2.49	2.79	1.26	1.56	1.86
-25 %	Agr.Pr.=50	6.40	6.70	6.99	2.90	3.19	3.49	1.73	2.03	2.33
CONSTR.	Agr.Pr.=30	3.30	3.59	3.89	1.19	1.49	1.79	0.49	0.79	1.09
COSTS=	Agr.Pr.=40	4.70	4.99	5.29	1.89	2.19	2.49	0.96	1.26	1.56
even	Agr.Pr.=50	6.10	6.39	6.69	2.60	2.89	3.19	1.43	1.73	2.03
CONSTR.	Agr.Pr.=30	2.99	3.29	3.59	0.89	1.19	1.49	0.19	0.49	0.79
COSTS=	Agr.Pr.=40	4.39	4.69	4.99	1.59	1.89	2.19	0.66	0.96	1.26
+25 %	Agr.Pr.=50	5.79	6.09	6.39	2.29	2.59	2.89	1.13	1.43	1.72

DISCOUNT RATE: 10 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	3.38	3.68	3.98	1.28	1.58	1.88	0.58	0.88	1.18
COSTS=	Agr.Pr.=40	4.78	5.08	5.38	1.98	2.28	2.58	1.05	1.35	1.65
-25 %	Agr.Pr.=50	6.18	6.48	6.78	2.68	2.98	3.28	1.52	1.81	2.11
CONSTR.	Agr.Pr.=30	3.01	3.31	3.61	0.91	1.21	1.51	0.21	0.51	0.81
COSTS=	Agr.Pr.=40	4.41	4.71	5.01	1.61	1.91	2.21	0.68	0.98	1.27
even	Agr.Pr.=50	5.81	6.11	6.41	2.31	2.61	2.91	1.14	1.44	1.74
CONSTR.	Agr.Pr.=30	2.64	2.94	3.24	0.54	0.84	1.13	-0.16	0.14	0.43
COSTS=	Agr.Pr.=40	4.04	4.34	4.64	1.24	1.54	1.84	0.30	0.60	0.90
+25 %	Agr.Pr.=50	5.44	5.74	6.04	1.94	2.24	2.54	0.77	1.07	1.37

DISCOUNT RATE: 12 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	3.17	3.47	3.77	1.07	1.37	1.67	0.37	0.67	0.97
COSTS=	Agr.Pr.=40	4.57	4.87	5.17	1.77	2.07	2.37	0.84	1.14	1.44
-25 %	Agr.Pr.=50	5.97	6.27	6.57	2.47	2.77	3.07	1.31	1.60	1.90
CONSTR.	Agr.Pr.=30	2.73	3.03	3.33	0.63	0.93	1.23	-0.07	0.23	0.53
COSTS=	Agr.Pr.=40	4.13	4.43	4.73	1.33	1.63	1.93	0.40	0.70	0.99
even	Agr.Pr.=50	5.53	5.83	6.13	2.03	2.33	2.63	0.86	1.16	1.46
CONSTR.	Agr.Pr.=30	2.29	2.59	2.89	0.19	0.49	0.78	-0.51	-0.21	0.08
COSTS=	Agr.Pr.=40	3.69	3.99	4.29	0.89	1.19	1.49	-0.05	0.25	0.55
+25 %	Agr.Pr.=50	5.09	5.39	5.69	1.59	1.89	2.19	0.42	0.72	1.02

TABLE C-7: *Net benefits of Alternative G*

DISCOUNT RATE: 8 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR. COSTS= -25 %	Agr.Pr.=30	3.45	3.75	4.05	1.22	1.52	1.82	0.47	0.77	1.07
	Agr.Pr.=40	4.94	5.24	5.54	1.96	2.26	2.56	0.97	1.27	1.57
	Agr.Pr.=50	6.43	6.73	7.03	2.71	3.01	3.30	1.47	1.77	2.06
CONSTR. COSTS= even	Agr.Pr.=30	3.01	3.31	3.61	0.78	1.08	1.38	0.04	0.34	0.63
	Agr.Pr.=40	4.50	4.80	5.10	1.53	1.82	2.12	0.53	0.83	1.13
	Agr.Pr.=50	5.99	6.29	6.59	2.27	2.57	2.87	1.03	1.33	1.63
CONSTR. COSTS= +25 %	Agr.Pr.=30	2.58	2.88	3.17	0.34	0.64	0.94	-0.40	-0.10	0.20
	Agr.Pr.=40	4.07	4.36	4.66	1.09	1.39	1.69	0.10	0.39	0.69
	Agr.Pr.=50	5.55	5.85	6.15	1.83	2.13	2.43	0.59	0.89	1.19

DISCOUNT RATE: 10 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR. COSTS= -25 %	Agr.Pr.=30	3.14	3.44	3.74	0.91	1.21	1.51	0.16	0.46	0.76
	Agr.Pr.=40	4.63	4.93	5.23	1.65	1.95	2.25	0.66	0.96	1.26
	Agr.Pr.=50	6.12	6.42	6.72	2.40	2.70	2.99	1.16	1.46	1.75
CONSTR. COSTS= even	Agr.Pr.=30	2.60	2.90	3.20	0.37	0.67	0.96	-0.38	-0.08	0.22
	Agr.Pr.=40	4.09	4.39	4.69	1.11	1.41	1.71	0.12	0.42	0.72
	Agr.Pr.=50	5.58	5.88	6.18	1.86	2.16	2.45	0.62	0.91	1.21
CONSTR. COSTS= +25 %	Agr.Pr.=30	2.06	2.36	2.66	-0.17	0.13	0.42	-0.92	-0.62	-0.32
	Agr.Pr.=40	3.55	3.85	4.15	0.57	0.87	1.17	-0.42	-0.12	0.18
	Agr.Pr.=50	5.04	5.34	5.63	1.32	1.61	1.91	0.08	0.37	0.67

DISCOUNT RATE: 12 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR. COSTS= -25 %	Agr.Pr.=30	2.84	3.14	3.43	0.60	0.90	1.20	-0.14	0.16	0.46
	Agr.Pr.=40	4.33	4.62	4.92	1.35	1.65	1.94	0.36	0.65	0.95
	Agr.Pr.=50	5.81	6.11	6.41	2.09	2.39	2.69	0.85	1.15	1.45
CONSTR. COSTS= even	Agr.Pr.=30	2.19	2.49	2.79	-0.04	0.26	0.56	-0.78	-0.48	-0.19
	Agr.Pr.=40	3.68	3.98	4.28	0.71	1.00	1.30	-0.29	0.01	0.31
	Agr.Pr.=50	5.17	5.47	5.77	1.45	1.75	2.05	0.21	0.51	0.81
CONSTR. COSTS= +25 %	Agr.Pr.=30	1.55	1.85	2.15	-0.68	-0.38	-0.08	-1.43	-1.13	-0.83
	Agr.Pr.=40	3.04	3.34	3.64	0.06	0.36	0.66	-0.93	-0.63	-0.33
	Agr.Pr.=50	4.53	4.83	5.13	0.81	1.11	1.40	-0.43	-0.13	0.16

TABLE C-8: *Net benefits of Alternative H*

DISCOUNT RATE: 8 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	3.14	3.44	3.73	0.79	1.09	1.39	0.01	0.31	0.61
COSTS=	Agr.Pr.=40	4.70	5.00	5.30	1.58	1.87	2.17	0.53	0.83	1.13
-25 %	Agr.Pr.=50	6.26	6.56	6.86	2.36	2.65	2.95	1.06	1.35	1.65
CONSTR.	Agr.Pr.=30	2.52	2.82	3.12	0.18	0.48	0.78	-0.60	-0.30	-0.00
COSTS=	Agr.Pr.=40	4.08	4.38	4.68	0.96	1.26	1.56	-0.08	0.22	0.52
even	Agr.Pr.=50	5.64	5.94	6.24	1.74	2.04	2.34	0.44	0.74	1.04
CONSTR.	Agr.Pr.=30	1.91	2.21	2.50	-0.44	-0.14	0.16	-1.22	-0.92	-0.62
COSTS=	Agr.Pr.=40	3.47	3.77	4.07	0.35	0.64	0.94	-0.70	-0.40	-0.10
+25 %	Agr.Pr.=50	5.03	5.33	5.63	1.13	1.42	1.72	-0.18	0.12	0.42

DISCOUNT RATE: 10 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	2.70	3.00	3.30	0.36	0.66	0.96	-0.42	-0.12	0.18
COSTS=	Agr.Pr.=40	4.26	4.56	4.86	1.14	1.44	1.74	0.10	0.40	0.70
-25 %	Agr.Pr.=50	5.82	6.12	6.42	1.92	2.22	2.52	0.62	0.92	1.22
CONSTR.	Agr.Pr.=30	1.94	2.24	2.54	-0.40	-0.10	0.20	-1.18	-0.88	-0.59
COSTS=	Agr.Pr.=40	3.50	3.80	4.10	0.38	0.68	0.98	-0.66	-0.36	-0.06
even	Agr.Pr.=50	5.06	5.36	5.66	1.16	1.46	1.76	-0.14	0.16	0.46
CONSTR.	Agr.Pr.=30	1.18	1.48	1.78	-1.16	-0.86	-0.57	-1.94	-1.64	-1.35
COSTS=	Agr.Pr.=40	2.74	3.04	3.34	-0.38	-0.08	0.22	-1.42	-1.12	-0.83
+25 %	Agr.Pr.=50	4.30	4.60	4.90	0.40	0.70	1.00	-0.90	-0.60	-0.30

DISCOUNT RATE: 12 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	2.27	2.57	2.87	-0.07	0.23	0.53	-0.85	-0.55	-0.25
COSTS=	Agr.Pr.=40	3.83	4.13	4.43	0.71	1.01	1.31	-0.33	-0.03	0.27
-25 %	Agr.Pr.=50	5.39	5.69	5.99	1.49	1.79	2.09	0.19	0.49	0.79
CONSTR.	Agr.Pr.=30	1.37	1.67	1.97	-0.97	-0.68	-0.38	-1.75	-1.46	-1.16
COSTS=	Agr.Pr.=40	2.93	3.23	3.53	-0.19	0.11	0.40	-1.23	-0.94	-0.64
even	Agr.Pr.=50	4.49	4.79	5.09	0.59	0.89	1.18	-0.71	-0.42	-0.12
CONSTR.	Agr.Pr.=30	0.46	0.76	1.06	-1.88	-1.58	-1.28	-2.66	-2.36	-2.06
COSTS=	Agr.Pr.=40	2.03	2.32	2.62	-1.10	-0.80	-0.50	-2.14	-1.84	-1.54
+25 %	Agr.Pr.=50	3.59	3.89	4.18	-0.32	-0.02	0.28	-1.62	-1.32	-1.02

TABLE C-9: *Net benefits of Alternative I*

DISCOUNT RATE: 8 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	1.95	2.44	2.92	0.96	1.44	1.92	0.63	1.11	1.59
COSTS=	Agr.Pr.=40	2.62	3.10	3.58	1.29	1.77	2.25	0.85	1.33	1.81
-25 %	Agr.Pr.=50	3.28	3.76	4.24	1.62	2.10	2.58	1.07	1.55	2.03
CONSTR.	Agr.Pr.=30	1.78	2.26	2.74	0.79	1.27	1.75	0.46	0.94	1.42
COSTS=	Agr.Pr.=40	2.45	2.93	3.41	1.12	1.60	2.08	0.68	1.16	1.64
even	Agr.Pr.=50	3.11	3.59	4.07	1.45	1.93	2.41	0.90	1.38	1.86
CONSTR.	Agr.Pr.=30	1.61	2.09	2.57	0.62	1.10	1.58	0.29	0.77	1.25
COSTS=	Agr.Pr.=40	2.27	2.76	3.24	0.95	1.43	1.91	0.51	0.99	1.47
+25 %	Agr.Pr.=50	2.94	3.42	3.90	1.28	1.76	2.24	0.73	1.21	1.69

DISCOUNT RATE: 10 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	1.83	2.31	2.79	0.84	1.32	1.80	0.51	0.99	1.47
COSTS=	Agr.Pr.=40	2.50	2.98	3.46	1.17	1.65	2.13	0.73	1.21	1.69
-25 %	Agr.Pr.=50	3.16	3.64	4.12	1.50	1.98	2.46	0.95	1.43	1.91
CONSTR.	Agr.Pr.=30	1.62	2.10	2.58	0.63	1.11	1.59	0.30	0.78	1.26
COSTS=	Agr.Pr.=40	2.28	2.77	3.25	0.96	1.44	1.92	0.52	1.00	1.48
even	Agr.Pr.=50	2.95	3.43	3.91	1.29	1.77	2.25	0.74	1.22	1.70
CONSTR.	Agr.Pr.=30	1.41	1.89	2.37	0.42	0.90	1.38	0.08	0.56	1.05
COSTS=	Agr.Pr.=40	2.07	2.55	3.03	0.75	1.23	1.71	0.31	0.79	1.27
+25 %	Agr.Pr.=50	2.74	3.22	3.70	1.08	1.56	2.04	0.53	1.01	1.49

DISCOUNT RATE: 12 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	1.71	2.19	2.68	0.72	1.20	1.68	0.39	0.87	1.35
COSTS=	Agr.Pr.=40	2.38	2.86	3.34	1.05	1.53	2.01	0.61	1.09	1.57
-25 %	Agr.Pr.=50	3.04	3.52	4.00	1.38	1.86	2.34	0.83	1.31	1.79
CONSTR.	Agr.Pr.=30	1.46	1.94	2.42	0.47	0.95	1.43	0.14	0.62	1.10
COSTS=	Agr.Pr.=40	2.13	2.61	3.09	0.80	1.28	1.76	0.36	0.84	1.32
even	Agr.Pr.=50	2.79	3.27	3.75	1.13	1.61	2.09	0.58	1.06	1.54
CONSTR.	Agr.Pr.=30	1.21	1.69	2.17	0.22	0.70	1.18	-0.12	0.37	0.85
COSTS=	Agr.Pr.=40	1.87	2.35	2.83	0.55	1.03	1.51	0.11	0.59	1.07
+25 %	Agr.Pr.=50	2.54	3.02	3.50	0.88	1.36	1.84	0.33	0.81	1.29

TABLE C-10: *Net benefits of Alternative J*

DISCOUNT RATE: 8 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	3.59	3.89	4.18	1.48	1.77	2.07	0.78	1.07	1.36
COSTS=	Agr.Pr.=40	5.00	5.29	5.59	2.18	2.48	2.77	1.24	1.54	1.83
-25 %	Agr.Pr.=50	6.41	6.70	7.00	2.89	3.18	3.48	1.71	2.01	2.30
CONSTR.	Agr.Pr.=30	3.28	3.58	3.87	1.17	1.46	1.76	0.47	0.76	1.05
COSTS=	Agr.Pr.=40	4.69	4.98	5.28	1.87	2.17	2.46	0.94	1.23	1.52
even	Agr.Pr.=50	6.10	6.39	6.69	2.58	2.87	3.17	1.40	1.70	1.99
CONSTR.	Agr.Pr.=30	2.97	3.27	3.56	0.86	1.16	1.45	0.16	0.45	0.74
COSTS=	Agr.Pr.=40	4.38	4.68	4.97	1.57	1.86	2.15	0.63	0.92	1.21
+25 %	Agr.Pr.=50	5.79	6.08	6.38	2.27	2.56	2.86	1.10	1.39	1.68

DISCOUNT RATE: 10 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	3.37	3.67	3.96	1.26	1.55	1.85	0.56	0.85	1.14
COSTS=	Agr.Pr.=40	4.78	5.07	5.37	1.96	2.26	2.55	1.03	1.32	1.61
-25 %	Agr.Pr.=50	6.19	6.48	6.78	2.67	2.96	3.26	1.49	1.79	2.08
CONSTR.	Agr.Pr.=30	2.99	3.28	3.58	0.88	1.17	1.47	0.17	0.47	0.76
COSTS=	Agr.Pr.=40	4.40	4.69	4.99	1.58	1.88	2.17	0.64	0.94	1.23
even	Agr.Pr.=50	5.81	6.10	6.40	2.29	2.58	2.87	1.11	1.41	1.70
CONSTR.	Agr.Pr.=30	2.61	2.90	3.20	0.50	0.79	1.08	-0.21	0.09	0.38
COSTS=	Agr.Pr.=40	4.02	4.31	4.60	1.20	1.49	1.79	0.26	0.56	0.85
+25 %	Agr.Pr.=50	5.43	5.72	6.01	1.90	2.20	2.49	0.73	1.02	1.32

DISCOUNT RATE: 12 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	3.16	3.45	3.74	1.04	1.34	1.63	0.34	0.63	0.93
COSTS=	Agr.Pr.=40	4.57	4.86	5.15	1.75	2.04	2.34	0.81	1.10	1.40
-25 %	Agr.Pr.=50	5.97	6.27	6.56	2.45	2.75	3.04	1.28	1.57	1.87
CONSTR.	Agr.Pr.=30	2.70	3.00	3.29	0.59	0.88	1.18	-0.11	0.18	0.47
COSTS=	Agr.Pr.=40	4.11	4.41	4.70	1.29	1.59	1.88	0.36	0.65	0.94
even	Agr.Pr.=50	5.52	5.81	6.11	2.00	2.29	2.59	0.83	1.12	1.41
CONSTR.	Agr.Pr.=30	2.25	2.54	2.84	0.14	0.43	0.72	-0.57	-0.27	0.02
COSTS=	Agr.Pr.=40	3.66	3.95	4.25	0.84	1.13	1.43	-0.10	0.20	0.49
+25 %	Agr.Pr.=50	5.07	5.36	5.65	1.55	1.84	2.13	0.37	0.67	0.96

TABLE C-11: *Net benefits of Alternative K*

DISCOUNT RATE: 8 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	3.43	3.73	4.02	1.19	1.49	1.78	0.45	0.74	1.04
COSTS=	Agr.Pr.=40	4.92	5.22	5.51	1.94	2.23	2.53	0.95	1.24	1.53
-25 %	Agr.Pr.=50	6.41	6.71	7.00	2.69	2.98	3.27	1.44	1.74	2.03
CONSTR.	Agr.Pr.=30	2.99	3.28	3.57	0.75	1.04	1.34	0.00	0.30	0.59
COSTS=	Agr.Pr.=40	4.48	4.77	5.07	1.49	1.79	2.08	0.50	0.79	1.09
even	Agr.Pr.=50	5.97	6.26	6.56	2.24	2.53	2.83	1.00	1.29	1.59
CONSTR.	Agr.Pr.=30	2.54	2.83	3.13	0.30	0.60	0.89	-0.44	-0.15	0.15
COSTS=	Agr.Pr.=40	4.03	4.33	4.62	1.05	1.34	1.64	0.05	0.35	0.64
+25 %	Agr.Pr.=50	5.52	5.82	6.11	1.79	2.09	2.38	0.55	0.85	1.14

DISCOUNT RATE: 10 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	3.12	3.41	3.70	0.88	1.17	1.47	0.13	0.43	0.72
COSTS=	Agr.Pr.=40	4.61	4.90	5.19	1.62	1.92	2.21	0.63	0.92	1.22
-25 %	Agr.Pr.=50	6.10	6.39	6.69	2.37	2.66	2.96	1.13	1.42	1.72
CONSTR.	Agr.Pr.=30	2.56	2.86	3.15	0.33	0.62	0.92	-0.42	-0.12	0.17
COSTS=	Agr.Pr.=40	4.06	4.35	4.64	1.07	1.37	1.66	0.08	0.37	0.67
even	Agr.Pr.=50	5.55	5.84	6.14	1.82	2.11	2.41	0.58	0.87	1.16
CONSTR.	Agr.Pr.=30	2.01	2.31	2.60	-0.22	0.07	0.37	-0.97	-0.67	-0.38
COSTS=	Agr.Pr.=40	3.51	3.80	4.09	0.52	0.82	1.11	-0.47	-0.18	0.12
+25 %	Agr.Pr.=50	5.00	5.29	5.58	1.27	1.56	1.86	0.03	0.32	0.61

DISCOUNT RATE: 12 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	2.80	3.10	3.39	0.57	0.86	1.16	-0.18	0.12	0.41
COSTS=	Agr.Pr.=40	4.30	4.59	4.88	1.31	1.61	1.90	0.32	0.61	0.91
-25 %	Agr.Pr.=50	5.79	6.08	6.38	2.06	2.35	2.65	0.82	1.11	1.40
CONSTR.	Agr.Pr.=30	2.15	2.44	2.74	-0.09	0.21	0.50	-0.83	-0.54	-0.24
COSTS=	Agr.Pr.=40	3.64	3.94	4.23	0.66	0.95	1.25	-0.33	-0.04	0.25
even	Agr.Pr.=50	5.13	5.43	5.72	1.40	1.70	1.99	0.16	0.46	0.75
CONSTR.	Agr.Pr.=30	1.50	1.79	2.08	-0.74	-0.45	-0.15	-1.49	-1.19	-0.90
COSTS=	Agr.Pr.=40	2.99	3.28	3.58	0.00	0.30	0.59	-0.99	-0.70	-0.40
+25 %	Agr.Pr.=50	4.48	4.77	5.07	0.75	1.04	1.34	-0.49	-0.20	0.10

TABLE C-12: *Net benefits of Alternative L*

DISCOUNT RATE: 8 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR. COSTS= -25 %	Agr.Pr.=30	3.14	3.44	3.73	0.78	1.08	1.37	-0.00	0.29	0.59
	Agr.Pr.=40	4.72	5.01	5.30	1.57	1.86	2.16	0.52	0.82	1.11
	Agr.Pr.=50	6.29	6.58	6.88	2.36	2.65	2.95	1.05	1.34	1.63
CONSTR. COSTS= even	Agr.Pr.=30	2.52	2.81	3.11	0.16	0.45	0.75	-0.63	-0.33	-0.04
	Agr.Pr.=40	4.09	4.39	4.68	0.95	1.24	1.54	-0.10	0.19	0.49
	Agr.Pr.=50	5.67	5.96	6.25	1.73	2.03	2.32	0.42	0.72	1.01
CONSTR. COSTS= +25 %	Agr.Pr.=30	1.90	2.19	2.49	-0.46	-0.17	0.13	-1.25	-0.95	-0.66
	Agr.Pr.=40	3.47	3.76	4.06	0.32	0.62	0.91	-0.72	-0.43	-0.14
	Agr.Pr.=50	5.04	5.34	5.63	1.11	1.40	1.70	-0.20	0.09	0.39

DISCOUNT RATE: 10 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR. COSTS= -25 %	Agr.Pr.=30	2.70	3.00	3.29	0.34	0.64	0.93	-0.44	-0.15	0.14
	Agr.Pr.=40	4.28	4.57	4.86	1.13	1.42	1.72	0.08	0.37	0.67
	Agr.Pr.=50	5.85	6.14	6.44	1.92	2.21	2.50	0.60	0.90	1.19
CONSTR. COSTS= even	Agr.Pr.=30	1.93	2.23	2.52	-0.43	-0.13	0.16	-1.21	-0.92	-0.63
	Agr.Pr.=40	3.50	3.80	4.09	0.36	0.65	0.95	-0.69	-0.40	-0.10
	Agr.Pr.=50	5.08	5.37	5.67	1.15	1.44	1.73	-0.17	0.13	0.42
CONSTR. COSTS= +25 %	Agr.Pr.=30	1.16	1.46	1.75	-1.20	-0.90	-0.61	-1.98	-1.69	-1.40
	Agr.Pr.=40	2.73	3.03	3.32	-0.41	-0.12	0.18	-1.46	-1.17	-0.87
	Agr.Pr.=50	4.31	4.60	4.90	0.37	0.67	0.96	-0.94	-0.64	-0.35

DISCOUNT RATE: 12 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR. COSTS= -25 %	Agr.Pr.=30	2.27	2.56	2.86	-0.09	0.20	0.50	-0.88	-0.58	-0.29
	Agr.Pr.=40	3.84	4.13	4.43	0.69	0.99	1.28	-0.35	-0.06	0.23
	Agr.Pr.=50	5.41	5.71	6.00	1.48	1.77	2.07	0.17	0.46	0.76
CONSTR. COSTS= even	Agr.Pr.=30	1.35	1.65	1.94	-1.01	-0.71	-0.42	-1.79	-1.50	-1.21
	Agr.Pr.=40	2.93	3.22	3.51	-0.22	0.07	0.37	-1.27	-0.98	-0.68
	Agr.Pr.=50	4.50	4.79	5.09	0.57	0.86	1.15	-0.75	-0.45	-0.16
CONSTR. COSTS= +25 %	Agr.Pr.=30	0.44	0.73	1.02	-1.92	-1.63	-1.34	-2.71	-2.42	-2.12
	Agr.Pr.=40	2.01	2.30	2.60	-1.14	-0.84	-0.55	-2.19	-1.89	-1.60
	Agr.Pr.=50	3.58	3.88	4.17	-0.35	-0.06	0.24	-1.66	-1.37	-1.07

TABLE C-13: *Net benefits of Alternative M*

DISCOUNT RATE	CONSTR. COSTS		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
			El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
8 %	-25 %	Agr.Pr.=30	3.52	4.00	4.49	1.29	1.77	2.26	0.54	1.03	1.51
		Agr.Pr.=40	5.01	5.49	5.98	2.03	2.51	3.00	1.04	1.52	2.01
		Agr.Pr.=50	6.50	6.98	7.47	2.77	3.26	3.74	1.53	2.02	2.50
	even	Agr.Pr.=30	3.04	3.53	4.01	0.81	1.29	1.78	0.06	0.55	1.03
		Agr.Pr.=40	4.53	5.01	5.50	1.55	2.04	2.52	0.56	1.04	1.53
		Agr.Pr.=50	6.02	6.50	6.99	2.30	2.78	3.27	1.06	1.54	2.03
	+25 %	Agr.Pr.=30	2.56	3.05	3.53	0.33	0.82	1.30	-0.41	0.07	0.56
		Agr.Pr.=40	4.05	4.54	5.02	1.07	1.56	2.04	0.08	0.57	1.05
		Agr.Pr.=50	5.54	6.03	6.51	1.82	2.30	2.79	0.58	1.06	1.55
10 %	-25 %	Agr.Pr.=30	3.18	3.67	4.15	0.95	1.43	1.92	0.20	0.69	1.17
		Agr.Pr.=40	4.67	5.15	5.64	1.69	2.18	2.66	0.70	1.18	1.67
		Agr.Pr.=50	6.16	6.64	7.13	2.44	2.92	3.41	1.20	1.68	2.17
	even	Agr.Pr.=30	2.59	3.07	3.56	0.36	0.84	1.33	-0.39	0.10	0.58
		Agr.Pr.=40	4.08	4.56	5.05	1.10	1.59	2.07	0.11	0.59	1.08
		Agr.Pr.=50	5.57	6.05	6.54	1.85	2.33	2.82	0.60	1.09	1.57
	+25 %	Agr.Pr.=30	2.00	2.48	2.97	-0.23	0.25	0.74	-0.98	-0.49	-0.01
		Agr.Pr.=40	3.49	3.97	4.46	0.51	1.00	1.48	-0.48	0.00	0.49
		Agr.Pr.=50	4.98	5.46	5.95	1.26	1.74	2.22	0.01	0.50	0.98
12 %	-25 %	Agr.Pr.=30	2.85	3.33	3.82	0.61	1.10	1.58	-0.13	0.35	0.84
		Agr.Pr.=40	4.34	4.82	5.31	1.36	1.84	2.33	0.37	0.85	1.34
		Agr.Pr.=50	5.82	6.31	6.79	2.10	2.59	3.07	0.86	1.35	1.83
	even	Agr.Pr.=30	2.15	2.63	3.12	-0.09	0.40	0.88	-0.83	-0.35	0.14
		Agr.Pr.=40	3.63	4.12	4.60	0.66	1.14	1.63	-0.34	0.15	0.63
		Agr.Pr.=50	5.12	5.61	6.09	1.40	1.89	2.37	0.16	0.65	1.13
	+25 %	Agr.Pr.=30	1.44	1.93	2.41	-0.79	-0.30	0.18	-1.53	-1.05	-0.56
		Agr.Pr.=40	2.93	3.42	3.90	-0.04	0.44	0.93	-1.04	-0.55	-0.07
		Agr.Pr.=50	4.42	4.91	5.39	0.70	1.18	1.67	-0.54	-0.06	0.43

TABLE C-14: *Net benefits of Alternative N*

DISCOUNT RATE: 8 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	3.50	3.98	4.46	1.26	1.74	2.22	0.52	1.00	1.48
COSTS=	Agr.Pr.=40	4.99	5.47	5.95	2.01	2.49	2.97	1.01	1.49	1.97
-25 %	Agr.Pr.=50	6.48	6.96	7.44	2.75	3.23	3.71	1.51	1.99	2.47
CONSTR.	Agr.Pr.=30	3.01	3.49	3.97	0.78	1.26	1.74	0.03	0.51	0.99
COSTS=	Agr.Pr.=40	4.50	4.98	5.46	1.52	2.00	2.48	0.53	1.01	1.49
even	Agr.Pr.=50	5.99	6.48	6.96	2.27	2.75	3.23	1.02	1.50	1.99
CONSTR.	Agr.Pr.=30	2.53	3.01	3.49	0.29	0.77	1.25	-0.46	0.02	0.51
COSTS=	Agr.Pr.=40	4.02	4.50	4.98	1.04	1.52	2.00	0.04	0.52	1.00
+25 %	Agr.Pr.=50	5.51	5.99	6.47	1.78	2.26	2.74	0.54	1.02	1.50

DISCOUNT RATE: 10 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	3.15	3.63	4.11	0.92	1.40	1.88	0.17	0.65	1.13
COSTS=	Agr.Pr.=40	4.64	5.13	5.61	1.66	2.14	2.62	0.67	1.15	1.63
-25 %	Agr.Pr.=50	6.14	6.62	7.10	2.41	2.89	3.37	1.17	1.65	2.13
CONSTR.	Agr.Pr.=30	2.55	3.03	3.51	0.32	0.80	1.28	-0.43	0.05	0.53
COSTS=	Agr.Pr.=40	4.04	4.53	5.01	1.06	1.54	2.02	0.07	0.55	1.03
even	Agr.Pr.=50	5.54	6.02	6.50	1.81	2.29	2.77	0.57	1.05	1.53
CONSTR.	Agr.Pr.=30	1.95	2.43	2.91	-0.28	0.20	0.68	-1.03	-0.55	-0.07
COSTS=	Agr.Pr.=40	3.44	3.93	4.41	0.46	0.94	1.42	-0.53	-0.05	0.43
+25 %	Agr.Pr.=50	4.94	5.42	5.90	1.21	1.69	2.17	-0.04	0.45	0.93

DISCOUNT RATE: 12 %		WATER REQUIREMENTS = -50 %			WATER REQUIREMENTS = even			WATER REQUIREMENTS = +50 %		
		El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30	El.Pr.=10	El.Pr.=20	El.Pr.=30
CONSTR.	Agr.Pr.=30	2.81	3.30	3.78	0.58	1.06	1.54	-0.17	0.31	0.79
COSTS=	Agr.Pr.=40	4.31	4.79	5.27	1.32	1.80	2.28	0.33	0.81	1.29
-25 %	Agr.Pr.=50	5.80	6.28	6.76	2.07	2.55	3.03	0.83	1.31	1.79
CONSTR.	Agr.Pr.=30	2.10	2.58	3.06	-0.13	0.35	0.83	-0.88	-0.40	0.08
COSTS=	Agr.Pr.=40	3.59	4.07	4.55	0.61	1.09	1.57	-0.38	0.10	0.58
even	Agr.Pr.=50	5.08	5.56	6.05	1.36	1.84	2.32	0.11	0.59	1.07
CONSTR.	Agr.Pr.=30	1.39	1.87	2.35	-0.85	-0.37	0.11	-1.59	-1.11	-0.63
COSTS=	Agr.Pr.=40	2.88	3.36	3.84	-0.10	0.38	0.86	-1.10	-0.62	-0.14
+25 %	Agr.Pr.=50	4.37	4.85	5.33	0.64	1.12	1.60	-0.60	-0.12	0.36

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