WATER RESOURCES INVESTMENT PLANNING IN AN UNCERTAIN ENVIRONMENT

by:

SUTARDI

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WATER RESOURCES INVESTMENT PLANNING IN AN UNCERTAIN ENVIRONMENT

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A Thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

ABSTRACT

Various types of uncertainties affect water resources investment planning. Three types of these uncertainties are analyzed in this study: (a) uncertainty of investment outcome, (b) budgetary uncertainty/fluctuation , and (c) imprecision of input data. Implications of other types of uncertainties, such as those related to socio-economic factors, are aggregated into the uncertainty associated with investment outcome in order to provide the decision makers (DM's) with aggregated information regarding certainty of outcome which is required in making a final investment/funding decision.

Due to the limitations of existing stochastic programming techniques for handling problems of sequential decision making under both outcome and input budgetary uncertainty as well as imprecision of input data, an integrated formulation of Stochastic Dynamic Programming (SDP) and Fuzzy Chance Constrained Integer Goal Programming (FCCIGP) is proposed to assist the investment planning processes.

Time dependent budgetary uncertainty is incorporated in the SDP model through transformation probabilities. Since the distribution of the probabilities which underly budgetary uncertainty cannot be determined objectively, a subjective model consisting of a combination of historical data as a basic rate, a functional relationship between inter-related components within the SDP, subjective inputs elicited from an individual assessor or a group of assessors using a collective opinion technique, and definitions of scenarios of future budget availability, is applied to generate the transformation probabilities. The level of development at the beginning of a scheduling horizon (stage) and the level of funding actually received in the previous scheduling horizon are the two state variables for the problem. The transformation function changes the level of development existing at the beginning of the period to a new level of development at the end of the scheduling horizon on the basis of the funds received for development. The return is the economic benefit that accrues as a result of that increment in development.

The return for each level of possible funding decision at each stage of the SDP in terms of Net Present Value of Benefit (NPVB) is obtained by the FCCIGP taking into account goals and criteria preferences, the extent of the scheduling horizon considered in the SDP model, and a range of critical confidence limits on the Net Present Value of Benefits. The

optimal planning/funding decision in any scheduling horizon, and its expected optimal return can then be identified for each combination of the level of development, the level of funding existing from the previous period, and the confidence limit on NPVB. In addition to these features, the Analytic Hierarchy Process is used to obtain the preferences toward uncertainties inherent in budgetary and investment outcome from a group of DMs or a large number of assessors.

The uncertainty in investment outcome factor is handled within the approach by using historical data, and a probabilistic economic analysis involving specific statistical procedures consisting of the contingency index and first and second order moments approaches to determine the dispersion of outcomes. The probabilistic description of the economic criterion derived from this analysis is then incorporated into the FCCIGP formulation through chance constraints. This process enables the DMs to identify "risky" projects and to allow the preferences toward uncertainty to be taken into account directly in the decision processes.

Uncertainty arising from social factors inherent in the agricultural production and marketing subsystems which control the rate of utilization of completed schemes but which cannot be quantified in monetary terms, is incorporated in the FCCIGP model through selection criteria constraints. A scoring-criterion-based optimization is then performed using the modified Partitioning Algorithm to select a combination of projects in hierarchial manner according to criteria preferences.

The problems associated with imprecise setting of goals and targets, and imprecise specification of budget limits and preferences within the optimization model are handled by the application of fuzzy set theory.

The procedure is demonstrated by application to the problem of water resources development in Indonesia over a 25 year period consisting of five stages each of 5 years (equivalent to "Repelitas"). This problem is characterized by the range of factors for which the procedure is developed, namely, uncertainty (fluctuation), in spite of the planning decision made, in the budget allocated to each scheduling horizon (stage), the major role of socio-economic factors in affecting the rate at which projects reach full productive capacity, a range of objectives for the water resources development itself, and significant uncertainty in the costs and benefits

accruing to each project. The results of the application of the model to the problem indicate that the procedure is a very useful technique for addressing the range of uncertainties inherent in many types of water resources planning activities.

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Chapter 1

INTRODUCTION

The objectives of water resources development can be characterized as National Economic Development (NED), Regional Economic Development (RED), Other Social Effects (OSE), and increasingly, Environmental Quality (EQ) (Goodman, 1984). No matter which objective is the primary goal, effective long term development requires careful planning to ensure that benefits and costs are correctly evaluated, social and evironmental issues are properly addressed and that the projects themselves are "completed". In many cases, particularly in developing countries, the uncertainty in future budget allocations, and priorities for development, may cause substantial uncertainty in: 1) the budget available for future development activities, 2) whether these budgets will match those anticipated in the planning exercise, and 3) whether the budgets that are allocated are in fact sufficient to complete the projects in the expected time or, in the worst case, for the project to be completed at all (an example of 'not-completed' projects is given in Chapter 3). In addition to this budgetary uncertainty, water resources investment planning is subject to various other types of uncertainties such as: uncertainties in socio-economic inputs and outcomes, uncertainties arising from variations in the natural environment and general imprecision of input data. These types of uncertainties affect prediction of investment outcomes generally by overestimating benefits and underestimating costs.

Such uncertain investment outcomes may cause non-optimal investment planning decisions. Non-optimal investment planning decisions for water resources may cause economic losses and/or adverse social and political effects in the economy of any nation. The problems related to adverse socio-economic and political impacts arising from non-optimal planning are especially relevant in developing countries. To select policies that consider NED, RED, OSE and EQ goals, water resources investment planning should explicitly consider the various uncertainties inherent in the development processes. This research is directed toward the development of a formal model for multiobjective water resources investment planning with recognition of some of those uncertainties. More specifically, the following two objectives are addressed by this study:

1. To identify specific sources and types of uncertainty relevant to water resources planning and to examine their influence on the results and process of planning and implementation of water resources development.

2. To provide a planning framework, or more specifically a multiobjective portfolio investment model, which is able to satisfy various goal and criteria preferences and to recognize and minimize the implications of uncertainties. Such a model should be able to develop investment decision policies for selection and scheduling of combinations of projects for implementation under a range of budgetary and socio-economic uncertainty and imprecision of input data.

Water resources investment planning are performed in an uncertain environment. Current water resources investment planning in Indonesia illutrates this fact. Hundreds of medium and large scale irrigation projects have been rescheduled, and some even have been postponed, due to year-to-year budgetary fluctuations originating from fluctuations of the world oil price during the last twenty years (Sutardi et al. , 1991a). In addition to this problem, uncertainty inherent in the investment outcome has also caused problems. Examination and evaluation of economic performance of completed irrigation schemes reveal that most of project benefits have been overestimated due to insufficient information on the complex interrelated socio-economic factors and to a lesser extent the randomness of natural phenomena. The importance of social-technical and political factors, which underlie the agricultural production and marketing subsystems, to the success of completed irrigation schemes is further indicated by the fact that many hundreds of thousands of hectares of completed irrigation facilities have not been utilized to the maximum potential level because of the inability of existing approaches to recognize those social responses which control the rate of utilization of these schemes.

The nature of the problems illustrated above suggests that any approach proposed to address the investment planning problem should integrate both mathematical and subjective models within a structured framework to enable both quantitative and qualitative parameters to be formulated in a manner that that reflects the real world problems as adequately as possible.

Anderson (1977) and Dempster (1980) have reported on the application of stochastic modelling approaches such as chance-constrained, two stage linear programming, stochastic linear programming, decision trees, discrete stochastic programming, decision making analysis and focus loss constrained programming, for handling the inherent problem of uncertainty of outcome in private or public investment. However these approaches were only examined in terms of single objectives. More recently, Davis et al. (1987) and Erlenkotter et al. (1989) proposed general mathematical models for determining the timing for initiating a project under uncertain future demands. However, these models are limited only to dealing with the timing problems arising from uncertain future demands. Furthermore, the practicality of such approaches, including the more recent multiobjective stochastic programming approaches, e.g., PROTRADE (Goicoechea, 1979) and STRANGE (Teghem et al., 1986), for handling the types of uncertainty inherent in the problem under consideration in this study, i.e., budgetary uncertainty (externally imposed uncertainty), investment outcome uncertainty (external risks), and imprecise input data (fuzzy environment), simultaneously appears to be very limited. These limitations include: 1) the approaches (with exception of STRANGE). are designed only to handle those types of uncertainty in which the uncertain parameters can be defined statistically, 2) they do not provide a means of easily incorporating collective opinion techniques which are required for public investment problems in which some of the decisions have to be determined by a political process in which a large number of assessors may participate, and 3) there is no consideration for handling the problems of imprecision in the input specifications.

Two issues of investment planning, namely sequential decision making and the flexibility aspect are addressed in the model proposed in this thesis. The first issue is sequential decision making. Planning problems tend to be sequential decision making problems by nature, characterized by a situation in which decisions can be influenced both by earlier decisions and by outcomes of the stochastic parameters whose values become known to the decision maker after the earlier decisions have been taken. In this thesis, the stochastic parameter addressed in the model is the level of budget actually available for investment in each scheduling horizon, which is generally never exactly known in advance and is subject to uncertainty due to fluctuations of levels of budget available for investment originating from uncertain socio-economic and political factors. The funding decision itself has to be selected by the model is the 'optimal' funding decision/policy from among the complete range of possible funding decisions with their associated 'optimal' multiobjective project portfolios to be implemented with those funding levels. The use of the term 'optimal' associated with the most desired investment decisions has two meanings. The first meaning relates to the fact that such investment decisions have to recognize the possibility that actual funding is significantly different (normally less than) from anticipated. This concern is to reduce the possibility of project delays, rescheduling, postponement, and even cancellation due to budgetary fluctuations. The second meaning is to obtain the multiobjective portfolio of projects that yields the satisficing 'return' with respect to the preferred objectives and criteria of a DM or group of DM's.

The second issue, namely that of flexibility in planning, refers to the fact that the component of the system, e.g., the scale of the system, can be adjusted in accordance with changing conditions. This consideration indicates that flexibility is a capability which can be employed in the planning process to ensure that uncertainties regarding the future can be reasonably anticipated and handled appropriately. Two aspects of flexibility in planning are required to operationalize this 'flexible' plan, i.e., *staged development* and *trade-offs between alternatives.* Staged development addresses such questions as which part of the plan should be implemented immediately, what portions are to be staged for future consideration, and when they might be constructed under various scenarios of future budget availability. Trade-offs between alternatives which take into consideration this budgetary uncertainty problem, e.g., goal achievements vs. confidence limit on the preferred goal, shorter vs. longer scheduling horizon are often required.

To date there has been no attempt reported in the literature to incorporate the uncertainty of funding availability due to budgetary fluctuations, the uncertainty of investment outcome, and the imprecision of input specifications simultaneously in a multiobjective-multicriteria portfolio approach to water resources investment planning. This thesis reports on a new approach and an effective framework for rational interpretation of these uncertainties and their inclusion in the planning process by integrating two optimization techniques. The two optimization techniques used in the approach are:

1. Stochastic Dynamic Programming (SDP) to determine the optimal investment planning decisions in an environment characterized by uncertain budgetary fluctuation in each scheduling horizon (stage) within a given planning horizon, and

2. Fuzzy Chance Constrained Integer Goal Programming (FCCIGP) to determine the return for each level of possible funding decision through selecting, scheduling, and budgeting the projects considered in each scheduling horizon (stage) of the SDP model under an environment of multiobjective-multicriteria decision making for economic and social objectives but with the added complexity of explicit consideration of uncertain economic (net benefit) and social outcomes, and imprecision in the specification of parameters of input data.

Chapter 2 of this thesis gives a more detailed review of the literature on planning and policy issues for water resources and on mathematical programming for investment analysis as it relates to uncertainty and multiobjective analysis. Chapter 3 discusses strategies for appraising various types of uncertainties in water resources planning. Chapter 4 highlights existing measures for handling uncertainty in current planning practice and outlines the proposed measures for handling problems similar to those in this study. Chapters 5 and 6 describe the theoretical background and formulation of the proposed approach. The application of the integrated model for problems of water resources investment planning in Indonesia, and subsequently the evaluation of the proposed model in terms of its strengths and weaknesses, are presented in Chapter 7. Finally the summary and conclusions of the study are given in Chapter 8.

Chapter 2

LITERATURE REVIEW

Characterization of uncertainty in the literature fall into two basic categories. The first type is primarily concerned with the broad issues of water resources planning including general planning, long term planning, multiobjective planning , Benefit-Cost analysis, inclusion and treatment of uncertainty in the planning process, and socio-economic policy issues including socio-political and environmental objectives. The second type is primarily concerned with the application of mathematical programming in its deterministic and stochastic forms to appraise private and public investments, especially in water resources projects, taking into account multiobjective issues and socio-economic uncertainties in a broader sense.

2.1 Planning

Water resources planning activities consist of the general process and the detailed methodologies that are used in planning of projects related to water and land resources. Planning activities include the identification, formulation, and analysis of projects; they also include subsequent phases of project implementation, such as design, construction, and operation.

Over the past 50 years, water resources planning methods have evolved from relatively straightforward approaches to a complex procedure (Goodman, 1984). Planning now is more broadly based. Instead of a historical emphasis on a single project to meet a specific defined requirement, all needs and opportunities for water resources development of a region or a river basin are now considered. Many projects are planned for more than one purpose and objective, and may include both structural and non-structural measures (Goodman, 1984). Hence, from engineering and economic viewpoints, the planning of water resource projects is now a multiunit, multipurpose, multiobjective, 'regional-context' problem and to a large degree involves consideration of uncertainty in terms of budget availability and future demands on the resources. Major changes have also resulted from the inclusion of non-traditional areas of consideration that are not quantifiable in a traditional engineering sense. These non-traditional areas cover such topics as regional, socio-political , environmental issues. This evolution has resulted in a more sophisticated approach and now involves systems analysis, operations research and computer modelling. However, in spite these developments relatively little has been reported on the inclusion of non-traditional uncertainties related to such factors as budgetary availability, variations from expected benefits and costs, and socio-economic implications on project outcome.

This section reviews the various types of planning procedures which appear in the literature. Inclusion and treatment of uncertainty and social objectives in the planning process are also reviewed. Other problems related to some critical issues in the Benefit-Cost analysis procedure are included in this section.

2.1.1 Planning Principles in Developed Countries

It has been recognized that planning procedures in developed countries, e.g., United States are evolving to accomodate dynamic changes in society's needs. In particular, multiobjective planning and, to a lesser extent, inclusion of uncertainty in the planning process has received increasingly greater attention in recent years in developed countries. An executive agency, the U.S. Water Resources Council (WRC), was established in 1965. In 1973, this agency issued a set of "Principles and Standards for Planning Water and Related Land Resources". In the various revisions of "Principles and Standard for Planning Water and Related Land Resources," in 1973, 1979 and 1980 and again in 1983, the decision criteria were broadened beyond the narrow concepts of economic efficiency to take into account other issues such as equity, risk, redistribution of national wealth, environmental quality and social welfare all of which are now considered as having importance close to that of economic efficiency. Concern about uncertainty is explicitly stated in the last guidelines as follows:

> "The assessment of risk and uncertainty in project evaluation should be reported and displayed in a manner that makes clear to the decision maker the types and degrees of risk and uncertainty believed to characterize the benefit and cost of the alternative plans considered"(The "Principles and Guidelines" of the U.S. Water Resources Council (1983), p 17).

General planning procedures that might be applied to water resources planning problems have been addressed by Hall (1969) who offers a generalized systems engineering planning framework , namely: a) defining the problem; b) setting objectives and developing alternatives; c) modelling alternatives; d) evaluating the alternatives; e) selecting an alternative; f) planning for implementation. This framework clearly defines a role of systems analysis in a way that might be applicable for a range of fields and disciplines besides water resources planning.

Concerns about changes in water resources planning in the United States from a limited purpose engineering function into a complex multiobjective process and the implications of this change have also been addressed by Johnson (1972). Johnson (1972) utilized the Delphi method to identify and assess the implication of potential changes in social values and priorities that may frame and define water resources requirements of the future. These changes have the potential to introduce a range of new variations of uncertainties which are different from the typical engineering uncertainties associated with design of physical works.

2.1.2 Planning Principles in Developing Countries

United Nations Industrial Development Organization (UNIDO) (Dasgupta et al., 1972) has issued guidelines for project evalution in developing countries that take into account the following objectives: 1) aggregate consumption; 2) income distribution; 3) growth rates of national income; 4) employment level; 5) self reliance and 6) merit wants. It should be noted that in developing countries such as Indonesia, goals (rather than resources) are the orienting factor in generating initiatives aimed at achieving specified ends. Water resources development is very often a part, rather than an objective, of these initiatives. Comprehensive and explicit inclusion of uncertainty in terms of budget and uncertainty of outcome of investment has not traditionally been addressed in the investment planning procedure and decision making process.

Wiener (1972) describes and analyses approaches to regional and national water development in the context of long term planning in developing countries. Wiener (1972) argues that the goal oriented approach is preferable for developing countries in which socio-economic objectives form the main emphasis for the welfare of society. On the other hand a resources oriented approach might be suitable for developed countries in which economic objectives are the main emphasis. In relation to this study, Wiener's statements provides justification for the use of Goal Programming (GP) approach as a basis of optimization procedure. The use of GP approach enables the DMs/analysts to explore the relationship between resources capacities and goals/targets attainment explicitly.

A broad water resources planning approach going beyond economic objectives has also been discussed by David (1975). That study identifies four main components of river basin development: 1) socio-economic development; 2) socio-economic needs development; 3) resources needed for river basin development and 4) engineering activities. It is then argued that the evaluation of alternative development policies and strategies based on these components and a satisfactory solution can be attained by a combination of optimization techniques and mathematical models. The comprehensive planning which is inherent in this approach and which is also considered as a part of the systems analysis approach, should therefore simultaneously cover technical, economic, social, legal and administrative aspects including the problem of uncertainties. However there is no discussion in that paper regarding the types of uncertainties that should be addressed in the investment planning process.

In line with the suggestion of David (1975) that systems analysis be used in water resources planning, Simonovic (1989) demonstrates application of water resources system to the formulation of a water master plan in a developing country. The four step planning procedure in Simonovic's work includes: i) evaluation of the available water resources, ii) estimation of the water demands, iii) generation of technical alternatives for satisfying water demands from available water resources, and iv) ranking of the alternative solutions in accordance with a prespecified set of objectives. Although the physical (hydrologic) uncertainties normally considered in water resources planning were addressed in the study there was no recognition given to budgetary and in particular socio-economic uncertainties which usually are more profound in developing countries. The concern about budgetary uncertainty is relevant in developing countries because most planning situations are dynamic and involve rapidly changing preferences and planning environments. The final compromise may be, in fact more a function of time and money available for planning than of any other factor.

2.1.3 Planning Under Uncertainty

Although inclusion of uncertainty in the investment planning of water resources development has begun receiving increasingly greater attention in recent years, relatively few articles on the subject are found in the literature, particularly in comparison with the work on inclusion of hydrologic uncertainty in water resources operation and management. Those articles which have appeared on uncertainty in planning include the following:

"Subjective Inputs and Uncertainty in Decision Making (Ferrel, 1972)"

Ferrel (1972), addresses the necessity for, and the roles of, subjective inputs to well defined decision problems. Three types of subjective input are distinguished: creative, valuative and judgemental. The author concludes that subjective inputs to decision making are a necessity and not just a compromise that must be tolerated. Creative, valutional, and judgemental inputs are required, both to formulate a decision theory problem, and to make the measurements needed to solve it.

"Subjective Planning : A Model For Water Resource Development (Erskine and Shih, 1972)"

This paper presents an analysis for optimum decision-making based on utility concepts to form an adaptive procedure for the planning and control of urban water resources. The primary worth of decision and utility theory lies in its ability to evaluate unquantifiable factors or concepts. These concepts attempt to include intangible factors relevant to the evaluation of alternatives in addition to the monetary considerations of cost and profit. Weights are applied to indicate the relative importance of those intangible factors relative to the others. A rating scheme to allow comparison of the alternatives against given factors is then assigned. The main advantages of this method (weighting and rating scheme) for the users is that it is easy to understand and relatively simple to apply. However, as pointed out by Palmer and Lund (1985), relative to the more current method of subjective weighting such as the Analytic Hierarchy Process (Saaty, 1977), this method suffers from uncertainty related to the particular scale chosen to quantify non-quantifiable factors, is not sensitive to the effects of changing marginal returns on criteria, and does not provide an internal check on the consistency of the weights generated.

"Risk and Uncertainty in Water Resources Planning and Operation (Yevjevich, 1983)"

This work asserts that the two economic criteria of expected benefit-cost ratio and net benefit no longer seem adequate for selection of water projects. It is suggested that the components of benefits and costs should be treated as random variables. Once the benefits and costs are defined as the random variables, with their probability distributions specified, the problem becomes one of finding the probability distribution of the benefit cost ratio (BCR). The confidence limits of this distribution then can be used in the decision making process.

"Multiobjective Analysis with Subjective Information (Palmer and Lund, 1985)"

In this paper an approach for incorporating subjective information into multiobjective evaluation using the Analytic Hierarchy Process method proposed by Saaty (1977) is presented. The method is based upon an eigenvalue and eigenvector analysis and structures multiobjective evaluation into a series of hierarchies in which pairwise comparisons are made. The approach addresses measures of subjective inconsistency, the sensitivity of inconsistency to pairwise comparisons, subjective scaling factors, and sensitivity of final, multiobjective weights. In spite of its limitations, e.g., its application is limited to a linear scale of judgment and poor consideration of diminishing or increasing marginal returns to scale, the authors noted its potential applicability. The authors also argue that its ease of use and simple format enable the AHP method to be used as an analytic technique where judgment inputs may be subject to negotiation by multiple decision makers.

2.1.4 Economic Issues

Critical Issues in Benefit-Cost Analysis

There are three objectives of economic evaluation of projects (Au, 1988: Halvorsen and Ruby, 1981): (1) determine if a given project is economically desirable; (2) economic evaluation should identify the most economically desirable design for a particular project from a number of potential alternatives; and (3) rank desirable projects Over the past 32 years benefit-cost analysis has experienced thorough reviews and criticisms in terms of its performance with respect to these evaluation objectives (Eckstein 1958; Viscussi 1972; Hanke and Walker 1974; Halvorsen and Ruby 1981; and Lund 1992). The concerns in these works relate to difficulties associated with benefit-cost analysis such as identification of project impacts, measurement of those impacts, discounting, the length of the evaluation horizon and instability of the benefit/cost ratio for project comparison. Potential alternatives to the benefit-cost ratio include net present value (NPV), annualized NPV, internal rate of return (IRR) and the project payback period. Theoretical examination of these alternatives shows clearly that NPV and annualized NPV have the fewest computational and economic pitfalls in evaluation of a project desirability (Eckstein, 1958; Au, 1988) and it gives the better results (Neely and North, 1976).

Uncertainty in Benefit-Cost Analysis

"Estimation Deviations: Their Effect upon the Benefit-Cost Ratio (Lutz and Cowles, 1971)"

In this work the authors propose a contingency index to correct any consistent bias of the benefit-cost ratio resulting from overestimation of benefits and underestimation of costs. The contingency index, derived from an analysis of historical data, is used to examine how well the benefits, costs, and benefit-cost ratio (BCR) have been estimated in the past relative to actual outcomes of projects. The deviations observed constitute starting points for estimation of future performance.

Application of the contingency index analysis to 48 United States Bureau of Reclamation projects completed prior to 1939 revealed that the benefits had been overestimated by 32.42% on average resulting in a 44.2% deviation from the estimated BCR. With variations of this magnitude, it is important to provide the DM with information about the likely BCR by providing the probabilities of the possible outcomes.

"The Weibull Probability Assignment Techniques: An Application to Benefit-Cost Analysis (Mercer and Morgan, 1975)"

"Measurement of Economic Uncertainty in Public Water Resource Development: An Extension (Mercer and Morgan, 1978)"

Both articles illustrate the use of the Weibull distribution to provide the standard deviation, central tendency measures of the output (net benefit, BCR, etc) of projects. The information necessary for each input variable is: a) the most likely value of the inputs, X_0, b) the estimated low values for the inputs, X_1, c) the probability $P(L)$ that the actual input value might be lower than the estimated low value, i.e., $P_1(X < X_1) = P(L)$, d) the estimated high value for the input, X_2 and, e) the probability $P(H)$ that the actual input value might be higher than the estimated high value i.e., $P_2(X > X_2) = P(H)$

The limitation of both approaches is that they rely heavily on subjective estimate for estimating upper and lower bounds of future outcomes.

"The Measurement of Economic Uncertainty in Public Water Resource Development (Taylor et al., 1976)"

The authors offer a realistic practical alternative to the existing deterministic benefit-cost evaluation procedures in water resources development. The methodology used to measure project uncertainty in terms of a mean and standard deviation for the benefits, costs, BCR and NPV is a Monte-Carlo simulation model employing triangular, subjective probability distributions. Subjective estimates from experienced managers are used to develop estimates of uncertain parameters, i.e., pessimistic, most likely and optimistic. It is also assumed that there are no correlations among benefits contributed from different categories of project purposes, e.g., flood control, hydro power, water supply, irrigation, etc. Biased estimates of experienced managers/experts is the weakness of this approach.

"An Approach to Risk and Uncertainty in Benefit-Cost Analysis of Water Resources Projects (Goicoechea et al., 1982a)"

The paper suggests that the probability density functions (pdf) of project benefits and costs may be characterized by subjectively derived mean, pessimistic, and optimistic values. An optimistic estimate reflects "the maximum estimate benefit (or minimum cost) that could be realized if everything went right." A pessimistic estimate is "the minimum benefit (or maximum cost) that could be realized if everything went wrong."

The authors propose a statistical manipulation to examine the expected value of BCR assuming that each individual benefit component of a proposed project is statistically independent of each cost component and vice versa. Furthermore, benefits and costs are assumed to be stationary in time with the errors due to this assumption being negligible.

"An Approximate Method for the Analysis of Uncertainty in Benefit-Cost Ratios (Dandy, 1985)"

This study proposes a statistical manipulation based on the first-order second-moment (FOS-M) method (Benjamin and Cornell, 1970) that provides estimates of the following parameters: 1) the mean and variance of each component of benefit and cost, 2) the correlation coefficient between each pair of benefit and cost components, 3) the variance of the total project benefits, 4) the correlation coefficient between project benefits and project cost, 5) the approximate mean and variance of the BCR and, 6) approximation of the pdf of the BCR using standard statistical tables of the appropriate distribution, e.g., normal, lognormal or gamma, using the data derived from step 5.

In terms of the objectives of the works described in this thesis, it is useful to note that Dandy (1985) also noted the necessity of recognizing the uncertainty inherent in the Benefit-Cost ratio when making project selection.

"Probability Distribution for Benefit/Cost Ratio and Net Benefit (Tung, 1992)"

This paper undertakes an extensive analysis of the appropriateness of various commonly used probability distributions in describing the random nature of the benefit/cost (B/C) ratio and net benefit criteria. The probability models examined are: normal; lognormal; gamma; Weibull and Fisher-Cornish (FC). The performances of each measure are then compared to the true or exact probability density function of the net benefit or B/C obtained from a Monte Carlo simulation. The results indicate that the FC method is the best probability model for both B/C and net benefit (NB). The second best is the normal distribution for NB and the lognormal for B/C ratio. However, Tung (1992) concludes, that the difference between FC and normal distribution is insignificant. Therefore, adoption of normal distribution for the NB in probabilistic B/C analysis should be acceptable.

2.1.5 Social Issues

The first part of this review will focus on papers relevant to the role of socio-economic parameters in water resources planning and the need for social factors to be considered explicitly in the planning process. Concerns about the need of staging development to take into account the evolving need of society are also reviewed. The second part reviews the measurement of the social impact of water resources projects using statistical analysis.

"Quantifying Societal Goals: Development of a Weighting Methodology (Gum et al., 1976)"

"Social Accounting Sytem for Evaluating Water Resouces (Dinius, 1972)"

Both of these articles present the use of a weighting methodology to quantify and evaluate social parameters related to the contribution of water resources use to social goals. By developing hierarchial goals, subgoal structures and measures of the lowest level subgoal, preference weights can be used to provide measures of attainment of all goals and subgoals within the hierarchial structure. Societal goals are quantified in a manner which provides useful information to decision makers.

"Staged Development of Waste Water Treatment Works (Lynn, 1964)"

"Economic Planning For Staged Development (Sorensen and Jackson, 1967)"

Both articles address the need for staged development for water resources projects. This issue is very significant for developing countries where budget limitation requiring staging of projects is generally a dominant problem. The first article suggests the use of linear programming to perform a more valid and detailed economic analysis in which all parameters under consideration appear in the model as they actually occur. Sensitivity analysis of the model over a wide range of parameters is then suggested. The second article discusses the economic analysis of staged development. Perhaps the most important feature of the second paper for this thesis is its recommendation that project arrangements and designs allow the maximum flexibility for future changes in function and operation.

"Prioritizing Flow Alternatives For Social Objectives (Flug and Ahmed, 1990)"

In this paper priority weighting and ranking of importance are proposed to determine quantitative and objective scores to evaluate flow alternatives with social objectives. The paper shows how an easy-to-use multiobjective technique such as a ranking and weighting scheme has been satisfactorily applied in real-world projects related to social and environmental objectives. A similar approach, i.e., the point allocation and weighting method is proposed in this thesis to enable social factors contributing to the success of water resources projects to be incorporated in a multiobjective-multicriteria portfolio investment planning model.

"Sociotechnical Analysis of Irrigation Drainage in Central California (Hukkinen, 1991)"

A sociotechnical framework is used in this paper to systematically investigate interactions between water agencies and proposed technical solutions. A sociotechnical matrix for indentifying potential sources of conflict and uncertainty is then applied. This matrix is designed to facilitate the explication of linkages between physical activities and organizational activities.

"Regional Economic Growth From Irrigation Development: Evidence From Northern High-Plains Ogallala Groundwater Resouce (Mann et al., 1987)"

The impact of irrigation development on regional economies in developed nations is examined in this paper using linear regression techniques. The results indicate that, if people (employment), rather than water, land, or dollars are to be the measure of importance, modern, capital-intensive irrigation development cannot be regarded as a very effective instrument for regional development policies. This observation obviously also has some relevance to water resources development in developing countries.

"Role of Sociodemographic Characteristics in Projections of Water Use (Murdock et al., 1991)"

In this paper the effects of demographic and other socioeconomic variables (other than total population size) are used in projections of water use using regression and standard projection-simulation techniques. The results suggest that demographic and socioeconomic variables, such as the age of the householder, racial or ethical status, and household consumption, markedly affect water use, and are often of relatively greater importance than economic, climatic, or other physical factors in explaining per capita water use.

2.2 Mathematical Programming

In assessing the usefulness of Operations Research (Mathematical Programming) for public systems decision making, two issues are should be considered. The first issue is to discover the limitations of the methodology. Several researchers have addressed this concern, e.g., Zeleny (1975), Liebman (1976), Mintzberg (1980), Fiksel (1982), and Rogers and Fiering (1986). Some of these limitations can be delineated as follows:

1. The methodology relies on mathematical formulation and "hard" (quantitative) data by assuming complex public systems are reducible into mathematical symbolisms and descriptions. This step is in conflict with today's real world public systems which characterized by complex inter-related socio- economic factors in the sense of being

messy, fuzzy, ill-structured and represented by "soft"(qualitative) data.

2. The fact that it is the model that is optimized, not the actual system, implies that the inadequacies in the modelling and measurement activities can lead to spurious "optimal" solutions.

3. It cannot handle the critical "soft" data, derived from purposeful systems such as human being or societies.

4. There is a lack of means for embracing participation from the DM in the form of subjective inputs and intuitive approaches.

The second issue relates to the potential use of mathematical programming for the public systems decision making and can be described as follows:

1. It is highly effective in a situation where the system under study is clearly understood, and can be reduced to a mechanistic model in the sense that the objective function is clearcut, easy to formulate, and noncontroversial, and most of the constraints are relatively obvious.

2. A combination of analytic and intuitive approaches might seem to be appropriate to handle real world public systems that are neither purely analytic nor purely intuitive as they have the potential to combine both components in an intricate interaction.

The possible roles of a mathematical model in the decision making process in this case can be delineated as follows:

- It can provide the DM with another perspective in the decision making, a perspective which he or she may have a tendency to overlook.
- It can help in the diagnosis of decision problems.
- It can conduct useful "real-time" analysis for the DM under pressure.

In this thesis, an integration of both mathematical and subjective models within a structured framework (meta-modelling) to handle complex problems of water resources investment planning in an uncertain environment is developed. In the following sections a number of papers related to mathematical programming of single and multiobjective planning problems for public, especially water resources, investment in its deterministic and stochastic forms are reviewed.

2.2.1 Investment Planning in Deterministic Form

The general capital-budgeting problem using a portfolio approach, without consideration of uncertainty in the economic selection of projects, has been addressed extensively in the literature, e.g., Steiner (1959), Weingartner (1967), Quirin (1967), and Clark et al. (1984), in water resources by Lesso (1971), Lauria (1973), Morin (1973), Neely and North (1976) and Whitlach and Kolesar (1987). The papers most relevant to this study will be addressed.

2.2.2 Mathematical Programming for Portfolio Analysis

"An Analysis of Some Portfolio Selection Models for Research and Development (Lockett et al., 1971)"

Two managerial issues are addressed in this paper. One is consideration of uncertainty for which two types are examined. The first is uncertainty in return, which is addressed by maximizing the expected utility of programme return using the parameter μ (expected value of return) and σ (standard deviation of return), and uncertainty in inputs. The paper suggests the use of a decision tree format for description of individual project description combined with the application of simulation and linear/integer programming to actually select the projects. The second type of uncertainty relates to the possibility of incomplete projects. To solve this problem the author suggests running the model with complete projects and without complete projects and comparing the solutions. The consideration of incomplete projects is relevant to the research proposed in this thesis because the problem being investigated is one in which uncertain budgets may cause projects to be delayed, postponed indefinitely or even cancelled.

"Use of Linear Programming in Capital Budgeting with Multiple Goals (Candler and Boehlje, 1971)"

This article addresses linearization of an integer non linear programming problem for capital budgeting with multiple objectives. When the goal function is one that is typically measured in monetary terms, the function can be directly linearized in monetary terms. When the goal function cannot be easily measured in monetary terms, an arbitrary scale must be devised. The authors suggest that if a serious conflict arises in the definition of the goal function, it may be resolved in one of two ways: 1) by expanding the number of goal functions to achieve a set for which reasonable agreement on scaling can be achieved; or 2) by accepting more than one scaling of the goal function and running the capital budget for each scaling.

However, some conflicts may still arise as to the relative importance among these goals and, if different scalings are accepted, as to which of the resulting capital budgetary solutions is the best.

"A Portfolio Approach to Public Water Project Decision Making (Neely and North, 1976)"

This article suggests use of a portfolio approach for selection of proposed water resources projects to maximize net present value (NPV). The authors suggest two improvements to the existing means of project evaluation and ranking by the Benefit-Cost Ratio (BCR), namely:

1. Substitution of NPV as the criterion for project selection, since it improves the achievement of NPV produced by a BCR functional approach of maximizing BCR as a criterion by 23.5%.

2. Adoption of a portfolio approach to the ranking and selection of projects for construction.

The authors also noted that the lack of information on future project and budgets could present the greatest challenge to an operational programming model. They suggest that such budget uncertainties may be incorporated in a parametric programming model and by the analysis of many different budget sets.

In the research described in this thesis budgetary uncertainty is treated by assuming budget sets as random variables. "Subjective probabilities" are then assigned to each level of budget sets. The generated probability matrix is then used as transition probabilities in SDP framework (Sutardi et al., 1991b).

"Construction Grants Program: Capital Budgeting (Whitlach and Kolesar, 1987)"

This article suggests the use of Integer Programming (IP) for waste water project selection on the basis of the priority-to- cost ratio (PCR) in order to improve on the achievement of the conventional priority score ranking approaches. The objective function in this case becomes maximization of total priority points subject to such constraints as the total funds available for construction grant in the relevant fiscal year.

2.2.3 Multiobjective Planning and Investment

Consistent with the need to consider multiobjective issues in the planning process it is important to review some methods relevant to the type of decision making process being considered in this thesis. Such a review leads naturally to the area of Multiple Criteria Decision Making (MCDM) in which several methods such as Goal Programming (GP), Multiobjective Programming (MOP), Compromise Programming (CP) and Multiattribute Utility Theory (MAUT) have been suggested. The most important aspect of MCDM is that in the decision making processes the decision maker (DM) does not optimize a defined single objective but seeks an optimal compromise among several conflicting objectives or among the achievement of satisficing levels in the goals.

GP, which was originally formulated by Charnes et al., (1955) is perhaps the oldest and most extensively applied method for decision. As pointed out by Romero (1991), the most appealing feature of GP is its capacity to operationalize the "satisficing philosophy" conceptualized by Simon [(1955), (1957)] who conjectured that, in today's complex organizations such as government agencies, big companies, etc, the environment is defined by incomplete information, limited resources, conflict of interest, etc. Under this kind of environment the

DM does not try to maximize a poorly defined objective function but rather tries to achieve a set of goals as close as possible to a set of targets. In this sense the GP approach obviously provides a fruitful framework.

Despite the wide use of GP the approach is not free from deficiencies. In the last decade several authors have exposed possible drawbacks inherent in GP models. Perhaps the most representative works in this respect are due to Zeleny [(1973), (1981)] and Cohon and Marks (1975). However, some researchers, e.g., Hannan (1985) and most recently Romero (1991), have made some assessments of the severity of the associated shortcoming and have attempted to identify those conditions under which the use of GP is most theoretically defensible. These studies concluded that the shortcomings can be overcome, or at least considerably mitigated, when GP is used with a thorough understanding of the theoretical and operational aspects underlying the approach.

The relative advantages and disadvantages of GP with respect to the other MCDM approaches of MOP, CP, MAUT, etc will depend on characteristics of the problem under consideration (Romero, 1991). For a decision making problem involving many attributes, for example, eight objectives with several hundred constraints and decision variables it is quite cumbersome to make use of the MOP or MAUT approach. However, this type of problem is quite manageable within a GP framework. The GP method is also suitable for an environment under which the DM feels very confident with the values of the targets.

Some of the papers related to the critical issues in GP approach are as follows.

"Goal Programming for Decision Analysis of Multiple Objectives (Lee, 1972)"

This paper examines the capabilities and limitations of the GP approach. An important property of GP discussed in the paper is its ability to handle management problems involving multiple incompatible goals through an assigned importance of the goals. However, due to inappropriate use of weighting scales and inappropriate setting of goal levels, local optima may result. To overcome this problem parametric programming can be used to determine the impacts of the different target levels and priorities which might be imposed (Sutardi et al., 1990 and 1991a).

"A Review of Goal Programming: A Tool for Multiobjective Analysis (Ignizio, 1978)"

"Goal Programming and Multiple Objective Optimisation (Charnes and Cooper, 1977)"

The first article addresses a preemptive priority structure problem, presenting the general GP model as a practical, realistic, and natural representation of a wide variety of many real world problems. The second article recognizes that weighting assignments have the dual purpose of specifying preemptive weights and for assigning relative weights. A similar weighting system was used by Sutardi et al. (1990), (1991a). The impact of weight assignment on the level of goal achievement relative to the ideal solution is then verified. If the DM is not satisfied with a solution generated by the approach an interactive process can be performed until a satisfactory solution can be reached. The flexibility of GP in this respect is appealing since the DM is more oriented toward achievement values for the objectives than towards indirect measures such as weights.

"The Pros and Cons of Goal Programming (Zeleny, 1981)"

This author notes that the shortcoming of GP in that the solution obtained by the GP is not necessarily the "best" one available to the DM because it may be dominated by another feasible solution, especially in a situation where the goals were set too low. Zeleny (1981) also argues that desirable levels of goals should be policy outputs rather than inputs of analysis. In some current papers, e.g., Hannan (1985) and Romero (1991), it has been demonstrated that such difficulties can be overcome or at least mitigated by a proper use of GP.

"A Linear Goal Programming Model for Developing Economies with an Illustration from the Agricultural Sector in Egypt (Bazaraa and Boucher, 1981)"

This article presents an application of GP in a multi-regional agricultural planning in a single time period in a developing economy. In addition to specifying different levels of input and output for each activity, the authors describe explicit crop interdependencies which account for crop rotation. Constraints are developed for land, labor, water, machinery, fertilizer and capital resources. The model can be adjusted to take coordination with the economy as a whole into account. This article confirms the usefulness of the GP approach for an economic planning of developing countries in which a sectoral target is set within a centrally planned economy.

"Goal Programming Methods and Applications-A Survey (Soyibo, 1985)"

This survey article highlights the broad applications of GP in various areas. The use of the GP approach is advocated for economic planning in developing countries because economic plans in these countries are usually set in terms of sectorial targets (goals) that have to be met in a specified time horizon. The limitations of GP approach, as addressed by Morse (1976) and Morse and Clark (1979), in terms of the problem faced by the DM in setting targets, specifying weights and priorities and interpreting the range of non-dominated solution, are recognized however. Fortunately, some researchers have been making efforts to improve the GP methodology by developing techniques aimed at reducing these weaknesses. For example Gass (1986) has proposed a proceess for determining priorities and weight for large scale GP problems while Hannan (1980), (1985) developed a procedure to test if a GP solution is efficient and subsequently provided a procedure to establish a set of GP-efficient solutions.

"Goal Programming and Multiple Criteria Decision Making in Farm Planning: An Expository Analysis (Romero and Rechman, 1985)"

In this paper the authors explain the structure of a GP model by deriving it from linear programming. This paper is interesting in relation to the study reported in this thesis in that it clarifies previous misconceptions of the application of GP in the farm planning area. Instead of straight forward reporting of the exercise of applying GP, this article examines the following topics: a) why orthodox LP is not generally suitable for dealing with multiple criteria, b) the conceptual and logical structure of GP and its main variants, c) how GP handles multiple criteria, and d) the pitfalls that might be encountered when applying GP.

"An Assessment of Some Criticisms of Goal Programming, (Hannan, 1985)"

In this work the author notes that a dominated GP solution can occur when the associated value function is monotonic and suggests that an alternative optimal solution can be used to identify the existence of an inferior solution. A procedure to convert the inferior solution into a non-dominated solution is then proposed. It is interesting to note that Hannan (1985) then argues that the problem of dominated solutions should not eliminate the prospect of GP from consideration in solving multiple objective problems. He also notes that a goal-based interaction may maintain the GP approach as a major tool of multiobjective decision making as most of criticism of the standard GP methodology is not applicable to the interactive methods.

"Handbook of Critical Issues in Goal Programming, (Romero, 1991)"

In this work the author provides an extensive bibliographical survey from a wide range of GP applications in a categorized manner. Some critical issues including some remarks on poor modelling practices are addressed. Measures to relieve some difficulties associated with the GP approach are also offered. It is noted that in many cases these criticisms have exaggerated such difficulties and that a number of applications have demonstrated that the problem can be overcome, or at least mitigated, by 'proper' use of GP.

2.2.4 Multiobjective Water Resources Planning

Multiobjective programming techniques for water resources problems have been classified and evaluated by a number of investigators, including Cohon and Marks (1975), Haimes (1975), Taylor et al. (1975) and Loucks et al. (1981). These assesments have compared the utilities of the techniques using different criteria. Cohon and Marks (1975) do not favor the GP method because of its deficiencies such as it produces a dominated solution and the difficulties associated with the weighting assignment. However, more favorable reviews to GP method can be found in Taylor et al. (1975) and Loucks et al. (1981). Subsequent improvement of the GP approach since the earlier critiques, e.g., by Hannan (1980), (1985), Gass (1986), and Romero (1991) have also overcome some of the deficiencies perceived in those critiques.

A more detailed review of the applications of multiobjective analysis to water resources planning is as follows.

"Applied Water Resources System Planning (Major and Lenton, 1979)"

In this work the implementation of multiobjective planning theory for the development of a river basin project configuration and development schedule in South America is discussed. Three mathematical models, namely, a screening model, a simulation model and a sequencing model, were used to take into consideration socio-political objectives and government policies constraints in addition to the traditional economic and engineering objectives and constraints. However, the study did not explicitly take into account the presence of uncertainties related to budgetary and socio-economic factors in terms of changes in government policies and uncertainty of outcome, which are generally dominant issues in developing countries in which the final compromise is perhaps more a function of time and money available for implementation than of any other factor. Further multiobjective portfolio based modelling developments are proposed for the problem under consideration in this thesis to accomodate the presence of various types of uncertainties in the model formulation and examine their implications on the decision making process.

Others relevant papers in the literature which address the topic of river basin planning and which have similar characteristics are:

- Long Range Planning of Water Resources: A Multiobjective Approach (David and Duckstein, 1975)
- Multiobjective Optimization in River Basin Development (Duckstein and Opricovic, 1980)
- Multiobjective River Basin Planning with Qualitative Criteria (Gershon et al. 1982)
- Multiobjective Approaches to River Basin Planning (Gershon and Duckstein, 1983)

These four papers approach multiobjective problems in a similar manner. A comprehensive cost effectiveness approach is adopted to define goals, specifications, criteria, alternatives and their capabilities. Specifications include demands that might be given in probabilistic terms. These articles also cover important factors involving social elements, such as land use, that might be described by both monetary quantities and qualitative appreciations. The first and second papers also offer the term of flexibility to recognize implicitly several types of uncertainties, such as the natural uncertainty inherent in forecasting, the strategic uncertainty due to the unknown future allocation policy, the economic uncertainty pertaining to cost and loss functions and technological uncertainty. Multicriterion algorithms such as Electre, Compromise Programming and Multi attribute utility theory are then used to rank systems and reduce the problem to the trade off between only two alternatives.

However, these papers do not address the problem of comparing and selecting of alternatives for a range of river basins with potential projects. Moreover, the cost effectiveness solutions do not directly refer to all sectorial or subsectorial objectives, in terms of their achievement of, or contribution, to the target goals under the conditions of budget limitations and budgetary fluctuations often associated with water resources development in developing countries. It should be noted that the cost effectiveness approach also does not answer the problem of optimum budget allocation among competing regional goals and projects, often the most important issue in developing countries which tend to have centrally planned and funded development (It is recognized that the same problems exist in developed countries but they are more exaggerated in developing countries). And lastly, none of those approaches provides a mean to incorporate several types of uncertainties in its formulation simultaneously.

Application of GP Approach in Water Resources

"Approaches to Multiobjective Planning in Water Resources Projects (Taylor et al., 1975)"

Several alternative approaches to the benefit-cost analysis method for multiobjective planning of water resources project evaluation in terms of economic efficiency, environmental quality protection and socio-regional economic factors are reviewed in this paper. These alternatives are categorized into two classes: Mathematical Programming, and Value Determination. In the mathematical programming class two techniques, namely, a goal programming and the surrogate worth trade off method are reviewed. In the second area of value determination, two techniques, namely environmental evaluation systems (EES) and personal value determination are reviewed. It is concluded that no one methodology offers a complete solution to the evaluation problem. However, of the four methods described GP appears to be the most workable since it considers all objectives within a single model framework with a minimal degree of complexity and also a minimal degree of subjective judgment. Some limitations of GP such as specification of weighting, priorities and target levels, all characterized by subjectivity are also pointed out as being problems which must be overcome to keep the problems at a minimal level.

"Planning and Selecting Multiobjective Projects by Goal Programming (Neely et al., 1976)"

"An Operational Approach to Multiple Objective Decision Making for Public Water Resources Project Using Integer Goal Programming (Neely et al., 1977)"

The first article proposes the use of the GP approach for multiple goal planning of public water resources projects. The second article reports on the application of the Integer Goal Programming (IGP) approach for selection and scheduling of multiple objective water resources projects. Both articles justify the use of a GP approach on the basis of its ability to handle multiple and often conflicting goals quite easily.

However, in order to be useful as a planning approach for the types of problems to be addressed in problems examined in this thesis, the model formulation must be broadened to include factors of uncertainty.

2.2.5 Investment Planning Model in Stochastic Form

A number of linear and non-linear forms of stochastic models have been developed and reported in the literature. The main objective of these models is to assist decision making involving uncertainty. The models themselves can be classified according to the basic techniques underlying them as follows:

1. Stochastic Programming

   - Discrete Stochastic Programming:
     "Discrete Stochastic Programming" (Cocks, 1968)
     "Stochastic Programming, Utility and Sequential Decision Problems in Farm Management" (Rae, 1971)

   - Decision Tree Approach:
     "Investment Analysis Under Uncertainty" (Wilson, 1969)

   - Stochastic Decision Tree Approach:
     "Stochastic Decision Trees for the Analysis of Investment Decisions" (Hespos and Strassmann, 1965)
     "A Stochastic Programming Model for Project Selection (Lockett et al., 1980)
     "Decision Making Allowing for Uncertainty of Future Investment Opportunities" (Kaplan and Barish, 1967)

   - Stochastic Control Theory:
     "Optimal Capacity Expansion Under Uncertainty" (Davis et al., 1987)
     "Planning for Surprise: Water Resources Development Under Demand and Supply Uncertainty I The General Model" (Erlenkotter et al., 1989)

   - Stochastic Dynamic Programming:
     "Stochastic Dynamic Programming Operating Model" (Loucks et al., 1981)
     "Stochastic Dynamic Programming" (Kennedy, 1986)
     "Water Resources Planning Under Budgetary Uncertainty: The Case in Indonesia" (Sutardi et al., 1991b)

2. Stochastic Linear Programming

   - Two Stage Linear Progamming:
     "On the Solution of Two-Stage Linear Programs under Uncertainty" (Dantzig and Madansky, 1961)

"A Sequential Programming Model of Growth and Capital Accumulation of a Farm Under Uncertainty" (Yaron and Horowitz, 1972)

- Stochastic Linear Programming:
  "On Some Theorems of Stochastic Linear Programming with Applications" (Sengupta et al., 1963)
  "Stochastic Programming" (Kall, 1982)
  "Time Horizon, Objective Function, and Uncertainty in a Multiperiod Model of Firm Growth" (Boussard, 1971)

3. Chance-Constrained Programming (CCP)

- Chance-Constrained Programming:
  " Chance-Constrained Programming" (Charnes and Cooper, 1959)
  "Deterministic Equivalent for Optimizing and Satisficing Under Chance Constraints" (Charnes and Cooper, 1963)
  "Optimization Modelling of Water Quality in an Uncertain Environment" (Burn and McBean, 1985)

The general mathematical formulations of these group of models, i.e., Stochastic Programming, Stochastic Linear Programming, and Chance-Constrained Programming are discussed in detail in Subsection 4.2.3 of Chapter 4.

Except the model proposed by Sutardi et al. (1991b), all of these models are characterized by the fact that it is assumed that the type of uncertainty being handled in the models can be statistically defined, i.e., past or multiple observations are available and can be used to estimate the likelihood of future events. Such assumptions may not valid for some of real world problems in which past or repeated observations are not available or possible, due to the unique, irreproducible nature of any event dealing with a purposeful system (such as human being or societies).

A more detailed review of the relevant models whose characteristics are useful to this thesis are as follows.

"Chance-Constrained Programming (Charnes and Cooper, 1959)"

"Deterministic Equivalent for Optimizing and Satisficing Under Chance Constraints (Charnes and Cooper, 1963)"

The approach of Chance Constrained Programming (CCP) is to maximize the expected value of objective function subject to economic/resources constraints for which violation due to random variations in the system is permitted for some given percentage of the time. In this case CCP approach may be viewed as a technique for providing appropriate safety margins.

In spite of its limitations, such as i) it is impractical if several stochastic constraints are to be accomodated, and ii) it suffers from a potential arbitrary choice of probability levels, the CCP approach has been applied to a range of industrial, economic and water resources designs. Justification for use of such models in these applications lies largely in their tractability rather than in the realism with which they reflect the DM's true preferences (Anderson, 1977).

"Optimization Modelling of Water Quality in an Uncertain Environment (Burn and McBean, 1985)"

The paper reports the application of CCP to accomodate uncertainties present in the water quality management problems. Although not specifically related to investment planning under stochastic condition the paper is interesting because the authors point out the inherent advantage of using CCP, namely, the inclusion of stochastic consideration in the CCP does not increase the model size from that of the deterministic formulation and the probabilistic violation of the constraints can be easily examined. Both issues are of interest for the problem being examined in this thesis.

"Stochastic Dynamic Programming (Kennedy, 1986)"

In this work the author provides a fundamental theoretical basis for development of a stochastic dynamic programming (SDP) approach relevant for the investment planning model proposed in this thesis. For many decision problems, the state transformation depends not only on the state of the system and the decision taken, but also on unpredictable events beyond the control of the DM. In this case the stage return may partly depend on unpredictable events outside the control of the DM. Therefore the problem may be formulated as a stochastic dynamic program. Furthermore, Kennedy notes that transformation probabilities governing state transformations can be determined objectively as well as subjectively depending the nature of the problems being optimized.

However as discussed in later section, the characteristics of the problems under consideration in this thesis require that the SDP approach should be extended to be a two-state SDP model.

"Optimal Capacity Expansion Under Uncertainty (Davis et al., 1987)"

"Planning for Surprise: Water Resources Development Under Demand and Supply Uncertainty I. The General Model (Erlenkotter et al., 1989)"

The first paper addresses the use of stochastic control theory for optimization of the capacity expansion problem under uncertain future demands by assuming that the DM controls the rate of investment and that the distribution of uncertain parameters is known to the DM.

The second paper discusses the optimal timing of a single capacity increment with fixed lead time to meet a demand that is linearly increasing except for a future random "surprise" time at which the demand goes up and down. The properties of random parameters required for optimal investment then are derived by a stochastic model.

In terms of defining random parameters both papers rely on assumption that complex public systems characterized by socio-economic and political factors is reducible into mathematical symbolisms and descriptions. On this basis, it can be concluded that both models depend highly on how adequate the modelling and measurement activities are relative to the actual systems. In cases where the match between reality and the model is poor, spurious "optimal" solutions can result.

As mentioned earlier, in this study the use of a combination of mathematical and subjective models is proposed to handle problems of public investment planning under uncertain environment. This use of a combination of mathematical and subjective models overcomes some of the problems related to a mismatch between reality and the model and/or inadequacy of the modelling and measurement activities.

"Water Resources Planning Under Budgetary Uncertainty: the case in Indonesia (Sutardi et al., 1991b)"

In this paper a Stochastic Dynamic Programming modelling framework is proposed to assist in the planning process under budgetary uncertainty. Probabilities of the funding levels in any time period defined as a function of time period, level of existing development, level of previous funding, level of possible decision and level of actual funding, and derived subjectively, are employed to handle budgetary uncertainty. Application of the model primarily yields an optimal planning policy that recognizes the possibility that actual funding received may be less than anticipated and therefore the projects being implemented under the anticipated budget have the potential to be interrupted. Explicit consideration of these possibilities within the planning model (process) in this manner significantly reduces the existing problems of project rescheduling and cancellation. assessors.

Multiobjective Stochastic Programming (MOSP)

Relatively very few papers concerning MOSP exist in the literature. Although several applications of Chance-Constrained Goal Programming (CCGP) in the area of financial and industrial problems have been reported, Stancu-Minasian (1984) in a survey of this subject concluded that the most commonly used approach seems to be the PROTRADE concept proposed by Goicoechea (1979). The most recent approach that appears in the literature is STRANGE as developed by Teghem et al. (1986).

A more detailed review of the application of multiobjective stochastic programming as it relates to this study is as follows.

"A Stochastic Approach to Goal Programming (Contini, 1968)"

A theoretical background for a stochastic interpretation of the goal programming problem is provided in this paper. Specifically the paper deals with the problem of attaining a set of targets (goals) through a set of subgoals when the relation between the two groups of variables, i.e., target/goal vector and decision variables, can be expressed with a linear system of stochastic equations. The objective function in this case consists of the maximization of the probability that realisation of targets will lie in a confidence region of predetermined size. Under suitable normality assumptions the stochastic goal programming problem is equivalent to a quadratic programming problem in standard form, and therefore can be solved by existing algorithms. However, no practical application based on this approach has been reported to date.

"A Chance Constrained Goal Programming Model For Working Capital Management (Kweon and Martin, 1977)"

"A Chance Constrained Goal Programming Model for Bank Liquidity Management (Kweon, 1978)"

The rationale for applying Chance Constrained Goal Programming (CCGP) to problems of uncertainty and multiple conflicting objectives which characterize financial problems of a firm is described in these two studies. The GP approach was considered a suitable tool for these application because of resource limitations which made complete attaintment of all objectives impossible. The problem of uncertainty was incorporated into the model through the use of chance- constrained programming in which the probability level α_i, at which it is desired that the constraint or goal should hold, is explicitly selected. Risk is then taken into consideration in determining the probability levels, α_i, at which the goals must hold. The more risk averse the management, the higher the probability level at which they will cover this goal. Sensitivity analysis on the probability level α_i is performed to examine the risk-return relationship for each goal.

In the present thesis this approach is extended to accomodate the problems of sequential decision making and budgetary fluctuations over time.

"Multi-national Capital Budgeting Using Chance-Constrained Goal Programming (Choi and Levary, 1989)"

This paper describes the application of the CCGP method to solve multi- national capital budgeting problems which are characterized by multiple and conflicting goals, and uncertainty. In this paper the NPV of return is assumed to be a random variable and is handled through chance constraints rather than through goal statement constraints. Zero-one decision variables are introduced to accomodate the "go or no go" decision for the projects under consideration. This "go or no go" aspect is relevant to this research described in this thesis in that it addresses the possibility of projects not being completed under budget allocation and the need to ensure that projects once started are actually completed.

" Multiple Objectives Under Uncertainty: An Illustrative Application of PROTRADE (Goicoechea, 1979)"

PROTRADE is a multi-objective probabilistic approach involving formulation of an initial surrogate objective function (SOF), estimation of a multi-attribute utility function reflecting the DM's preferences, redefinition of the SOF, and use of a cutting-plane technique to solve a general nonlinear problem. In PROTRADE, the DM is able to "trade off" the levels of the objective function and their respective probabilities of achievement against one another. Giocoechea (1979) demonstrated the use of this approach in water resources planning. The great advantages of this method are that it is interactive and that it applies to a very general class of problems with non-linear constraints and random coefficients for linear objectives.

However, the approach is not free from difficulties, particularly in terms of, the practical construction of a utility function which is often not satisfied in practice and an insuffient dispersion of values of the objective being evaluated.

"Strange: An Interactive Method For Multi-objective Linear Programming under Uncertainty (Teghem et al., 1986)"

"Nuclear Fuel Cycle Optimization Using Multi-objective Stochastic Linear Programming (Kunsch and Teghem, 1987)"

In these papers STRANGE, a multiobjective stochastic linear optimization, is used to address problems of investment planning that involve a time horizon, multiple objectives and uncertainty of basic data. The algorithm extends the STEM (Step Method, developed by Benayoun et al., (1971)) to take into account the random aspects with their subjective probabilities of occurence. Such problems result in a particular structure of multiobjective and stochastic linear programming, in which discrete random coefficients are present in the objective functions and in the RHS of some constraints while some of the coefficients of the LHS of the constraints are deterministic. The uncertainty inherent in random variables is handled by the definition of scenarios with associate subjective probabilities. For each scenario, probabilities of occurence are defined by the experts. These subjective probabilities generally at least cover mean and extreme situations. However, the likelihood of a given scenario is usually difficult to define precisely. Hence, at the end of the analysis, it is necessary to carry out a sensitivity analysis simulating events with a range of subjective probabilities.

An interactive procedure is used to obtain a best compromise for such a problem. Efficiency projection techniques are then used to provide the DM with detailed graphical information on a family of efficient solutions.

Among the existing stochastic programming models addressed in this review, two approaches, i.e., PROTRADE and STRANGE, have a number of feature which are relevant for the problems considered in this thesis because they involve time dependent uncertainty affecting the RHS of some constraints and multiple and conflicting objectives. The strength and weaknesses of these two approaches in relation to this thesis are examined in detail in Chapter 4.

2.2.6 Summary

Conclusion for Uncertainty in Planning Process

Formal justification for the inclusion of factors of uncertainty in the investment planning for implementation for water resources projects can be found in the above papers. However according to the Yevjevich (1983) definition only one type of uncertainty namely socio-economic uncertainty is relevant in this investment planning stage. Other sources of uncertainty, such as physical or natural uncertainty, are assumed to be taken account of during the design process. In this thesis it is assumed that this situation occurs, i.e., the uncertainty arising from physical or natural indicators is addressed in the design stage, while the socio-economic uncertainties related to budget availability, variations in project benefits and costs and socio-economic controls on project success are to be addressed in the planning stage. Furthermore, it can be concluded that, in the case of subjective inputs, the use of weighting and rating schemes to handle nonquantifiable factors, which happen to be the critical issue in this type of uncertainty, is justified.

Although this approach is widely used it is not free of difficulties. For example, inconsistency due to scaling problems may occur. However the severity of the implication of such inconsistency is problem context dependent. Some efforts have been made to identify such inconstitencies and measures to alleviate the problem have been suggested, for example by Saaty (1977) and Saaty and Vargas (1991) on their work of the Analytic Hierarchy Process (AHP). Another important issue related to this type of 'uncertainty' is that it involves two issues, i.e., risk and uncertainty . The difference between risk and uncertainty related to the problems addressed in this thesis is explained in Chapter 3 Section 3.2.

So far, there is no known work that addresses, explicitly and simultaneously, the problems of investment planning under uncertain environment characterized by uncertain socio-economic inputs and outcome and budgetary fluctuations.

Conclusion for Uncertainty in Benefit-Cost Analysis

A comparative review of the papers cited under this heading indicates that the Lutz and Cowles (1971) work was the first to recognize uncertainty and bias in benefit cost analysis and to offer a quantitative approach compensating for their effects in the BCR analysis. Furthermore, unlike other studies, instead of using subjective estimates of uncertain parameters e.g., most likely, upper and lower value of benefit and cost components, Lutz and Cowles (1971) offer a procedure, called the contingency index, that can be used to correct bias in benefit and cost estimations. The corrected benefits and costs figures provide a more reliable starting point for estimation of future performance for the projects under consideration.

The limitations of the procedures proposed in the other studies by, i.e., Mercer and Morgan (1975, 1978), Taylor et al., (1976), Goicoechea (1982a) and Dandy (1985) can be described as follows:

1. They rely on subjective estimates of experienced managers which are inherently prone to such problems as: a) many agency directors may be hesistant to accept probabilistic information of any type for decision making purposes because such information may imply weakness in the analysis (Taylor et al., 1979), and b) the project manager may

make biased estimates (Hanke and Walker, 1974).

2. With exception of Dandy (1985) almost all articles, assume that individual benefit and cost components are statistically independent. The implications of statistical independence are broad, however. For example, it is difficult to imagine a flood control project in which the benefits associated with an increment of flood control would be independent of the benefits accruing to adjacent land or of the costs associated with that increment.

3. The implicit assumption of stationarity is likely to be incorrect in the "real world" (Goldman, 1983). The statistical distribution of costs and benefits can, and normally does, change with time, especially if a project with a long life such as a flood control dam and reservoirs is being evaluated.

Based on the above observations, the approach that is proposed for the inclusion of uncertainty in the benefit-cost analysis in this study will be the combination of the contingency index method offered by Lutz and Cowles (1971) and the first-order second moment (FOS-M) analysis suggested by Benjamin and Cornell, (1970). The reasons for adopting these approaches are :

1. The contingency index, which is derived from historical data, appears to generally provide a better estimate of future conditions than subjective estimates, since trends of the previously completed projects can be reflected in the estimation of the future performance of the similar projects.

2. The second-order-moment analysis is able to incorporate correlation between components of benefit and costs and as such this method provides a more realistic approach to the real life situation.

The use of the contingency index and the FOSM to estimate the dispersion of the Benefit-Cost component under an assumption of normal distribution is also supported by Tung's (1992) observations that the adoption of the normal distribution should be acceptable since it provides a significantly lower computational burden and yet a considerably accurate estimation relative to other approaches such as the FC approach and Monte Carlo simulation.

Using this methodology in combination with appropriate optimization techniques the most reliable projects can be selected. The actual indicator of economic desirability of a benefit cost analysis used in such a process is the net benefit of a project as net benefit is considered to have the fewest pitfalls (Eckstein, 1958 and Au, 1988).

Conclusion for Social Issues

Review of papers related to social issues suggests that it is appropriate to use the weighting and rating scheme to quantify unquantifiable social factors in order to combine these factors appropriately with pure economic and physical factors (Dinius, 1972; Gum et al., 1976; Flug and Ahmed, 1990; Hukkinen, 1991; and Sutardi and Goulter, 1993). Furthermore, it appears that statistical analysis, i.e., regression techniques, can be used to describe relationships between physical (engineering), economic, and social factors for the purpose of prediction and evaluation (Mann et al., 1987; and Murdock et al., 1991).

Conclusion for Mathematical Programming:

Justification for the use of GP in this study is attributed to its ability to explicitly explore the relationship between resource capacities and goal/target attainment which is very relevant for goal oriented planning approach generally applied for developing countries. In addition, as pointed out by Romero (1991), the GP method also has features to operationalize the "satisficing philosophy" in which the DM's do not try to maximize a much less well defined objective function but rather try to achieve a set of goals as close as possible to a set of targets.

To relieve some difficulties associated with the GP approach, the measures suggested by Hannan (1985), and Romero (1991) will be applied. Further goal programming-based modelling development is required to handle problems of uncertain project outcome and imprecision of input and qualitative data.

To handle problems of sequential decision making under budgetary uncertainty the SDP model proposed by Sutardi et al. (1991b) will be applied. Further modelling development is proposed in this thesis, however, in order to improve the effectiveness and consistency of the subjective model. Such improvement is achieved by combining the subjective model with an available collective opinion technique to enable a range of external factors governing the availability of future budget for development to be integrated with subjective inputs originating from an individual or a large number of assessors.

Furthermore, use of the SDP approach can be extended to accomodate application of a second level optimization model to determine the returns generated by a particular allocation of budget at each stage of the SDP and to handle other types of uncertainty and multiobjective issues in the overall approach.

Chapter 3

STRATEGIES FOR APPRAISING UNCERTAINTIES IN WATER RESOURCES PLANNING

3.1 General Planning

3.1.1 Planning Definition

Before analyzing the uncertainties faced by decision makers and planners involved in this broad area of planning of water resources development, utilization and management, it is useful to define the activity termed *planning*.

In general the objectives of water resources development can be summarized as follows: National Economic Development (NED), Regional Economic Development (RED), Other Social Effect (OSE) and, where necessary, Environmental Quality (EQ). From engineering and economic viewpoints, the planning of water resources projects is a multiunit, multipurpose, multiobjective problem involving to varying degrees, uncertainties such as future demands and future resource capacities.

In general, the definitions of planning indicate that it is essentially a sequential decision process in which resources are ideally committed to various activities at given points in time such that the overall effect of all these decision is optimal. It should be noted that planning under this definition/scenario faces varying forms of uncertainty such as future demands and future resource capacities.

3.1.2 Planning Principles

As outlined in previous chapter, water resources planning is now more broadly based. Major changes in planning have resulted from the inclusion of non-traditional areas of consideration, such as regional, socio-political, environmental issues, that are not quantifiable in the traditional engineering sense. Furthermore, as shown in the literature review, relatively little work has been undertaken to address uncertainties, e.g., budgetary and socio-technical and political factor uncertainties which differ from the traditional engineering considerations of hydrologic uncertainty. Although these non-traditional problems are universal, their impact, magnitude, and priority may be quite different. For example, the problems of budgetary and socio-economic uncertainties are more profound in developing countries, e.g., Indonesia, than in developed countries. On the other hand, environmental concerns have become a major issue in developed countries. Although environmental aspects are not ignored in developing countries, they are not considered as explicitly as in the more economically advanced countries such as the United States (Goodman, 1984).

In addition to the need to recognize the various types of non-traditional uncertainties described above, the objectives of water resources investment also has to comply with the specific characteristics of problems inherent in each region. For example, in the case of developing countries, objectives of planning have to recognize the need to achieve short-term and medium-term economic targets before it is meaningful to introduce long-term goals. As noted by Wiener (1972), "achievement of reasonable nutritional, educational, housing, clothing and leisure levels must precede attempts to set comprehensive and more sophisticated aims." Wiener (1972) then divides objectives into "direct or final objectives" concerned with production of commodities and services, and "indirect" or "instrumental objectives," which are the means and tools that have to be created and employed to reach a direct objective.

Appropriate planning for water resources projects might involve, for example, the explicit consideration of both budgetary and socio- economic and political uncertainties, and the dynamic physical and social responses which occur following major water resources development projects. In this thesis an attempt has been made to recognize and incorporate budgetary, social-technical, economic and political factors uncertainties in the general planning phases but more particularly in the investment planning phase.

3.1.3 Planning Phases

The following general phases are adopted for the planning and management of a major water resources project as cited from American Society of Civil Engineers (ASCE, 1974): 1) *Establishment of goals and objectives*, 2) *Problem identification and analysis*, 3) *Solution identification and impact assessment*, 4) *Formulation of alternatives and analysis*, 5) *Decisions*, 6) *Implementation*, and 7) *Operation and management* (detailed description can be found in Goodman, 1984). The methods of water resources planning which fit within this structure range from fairly simple techniques employing substantial professional judgment to sophisticated mathematical optimization approaches (Goodman, 1984).

The seven phase of planning defined by ASCE can be expanded to accomodate the need to consider budgetary and socio-technical, economic and political uncertainties explicitly in the planning processes.

The following extended planning phases are proposed to enable the planner to handle, more comprehensively and realistically, a complex water resources planning problem, especially for investment planning under uncertain environment.

1. *Establishment of goals and objectives* . Any public investment related to water resources development has to reflect the broad national and regional development objectives in terms of the planning horizon considered:

    - *Long Term Development Objectives.* Every river basin development plan must conform to the objectives of long term plans for national as well as regional development in those areas in where the projects are being developed.
    - *Medium Term Development Objectives.* Every river basin development activity

must conform to the objectives of medium term plans both nationally and regionally. These medium term objectives give specific direction as to regional needs and potential at particular scheduling horizons in the context of national objectives. In interpreting this statement it should be realized that water resources is not an objective in itself, but contributes to the realization of sectoral development objectives.

2. *Preparation.* During the preparation phase data on all relevant aspects of water resources systems are collected and analysed. This phase consists of three activities:

   - *Identification of Problems and Measures.* Identification of water related problems and the most promising measures, at the regional basis, in the context of the achievement of regional and national objectives.
   - *Analysis of Water Demands.* In this activity the transformation is from the level of population and economic activities to quantities of water demanded to fulfill the medium and long term national and regional objectives.
   - *Analysis of Water Supply.* In this activity the natural and man made system, including rainfall-runoff processes, ground water flow, erosion, water quality, flooding and operation of weirs and reservoirs, etc, is analysed.

3. *Identification of Alternative Solutions.* This stage of the planning process involves two steps.

   - *Identification of Measures and Solutions.* An inventory of possible alternative measures and solutions to alleviate the regional and national problems based on the inputs of the previous steps is established. Measures and solutions can include physical or infra-structure projects (reservoirs, canals, etc), operational measures and incentive and institutional oriented measures.
   - *Engineering and Economic Evaluation of Alternatives.* Alternative measures are evaluated to provide a specific design for each possible project.

4. *Selection of Projects for Specified Budget Levels.* The selection of alternative combinations of projects given specified budget levels is undertaken taking into consideration:

- Multiobjective evaluation and ranking of alternative plans based on regional and national needs.
- Multicriteria decision making with specific criteria reflecting characteristics of the problem under consideration. The socio-economic factors causing socio-economic uncertainty are considered as criteria in this phase and incorporated in the selection process. The output of this step is an optimal portfolio of projects, based on the preferred goals and criteria for each possible budget level at each scheduling horizon.

5. *Identification of Budgetary Characteristics.* In this step the various levels and probabilities of possible budget allocation are identified. Socio-economic and political factors govern determination of the likelihood of the occurence of these various level of possible funding. An appropriate collective opinion technique may be used to elicit numerical assessments from the decision makers on these factors. Quantification of these factors enable the problems of budgetary fluctuation to be anticipated and incorporated in decision making processes.

6. *Preliminary Decision.* The preliminary decision process is carried in the following manner.

   The "Alternative Development Plans" are presented to the Decision-Makers to obtain more precise input related to the government policies in terms of economic, socio-political and environmental consideration. In this process the assessment of uncertainty in terms of the degree and implication of that uncertainty must be reported and displayed in a manner that makes clear to the DM the consequences of the selection of each of the alternative plans. Ideally interactions with the DM are undertaken to check the level of satisfaction of preferred goals and criteria and to obtain additional information/inputs related to any changes in preferences and other influential parameters.

7. *Final Decision.* Once the DM's are aware of the implications of each decision and are satisfied with the estimated performance relative to available resources, the final decisions on the project(s) are made with legal authorization.

8. *Implementation.* In this step the budgetary plan necessary to implement the projects in an optimal fashion in accordance with existing or selected strategies for staging of development is formulated.

9. *Monitoring and Management.* This phase is used to observe changes of the influential parameters of project performance identified in the planning process. The results of the monitoring process can be used to review and revise planning decisions in the light of the additional new information and certainty that become available after decisions have been taken.

A schematic of these nine steps of water resources planning and identification of the specific area of this study in such an overall planning context is shown in Figure 3.1. With respect to the classification of planning levels these nine phases of expanded planning can be categorized as follows:

1. Phase II-Preparation, and Phase III-Identification of Alternative Solutions, are categorized as the technical level of planning,

2. Phase IV-Selection of Projects for a Specified Budget Level, Phase V- Identification of Budgetary Characteristics, Phase VIII-Implementation , and Phase IX-Monitoring and Management are categorized as medium level decision making,

3. Phase I-Establishment of Goals and Objectives, Phase VI-Preliminary Decision, and Phase VII-Final Decision are categorized as high level decision making.

3.2 Planning Under Uncertainty

3.2.1 Definition

As identified in the previous chapter, planning of water resources projects involves some types of risk and or uncertainty. Projects are planned to meet future (therefore, uncertain) needs, using water and related land resources which are themselves characterized by uncertainty. Furthermore, since any project is a part of the economic and social environment it is also affected by the many chance factors inherent in that environment. Future projections and

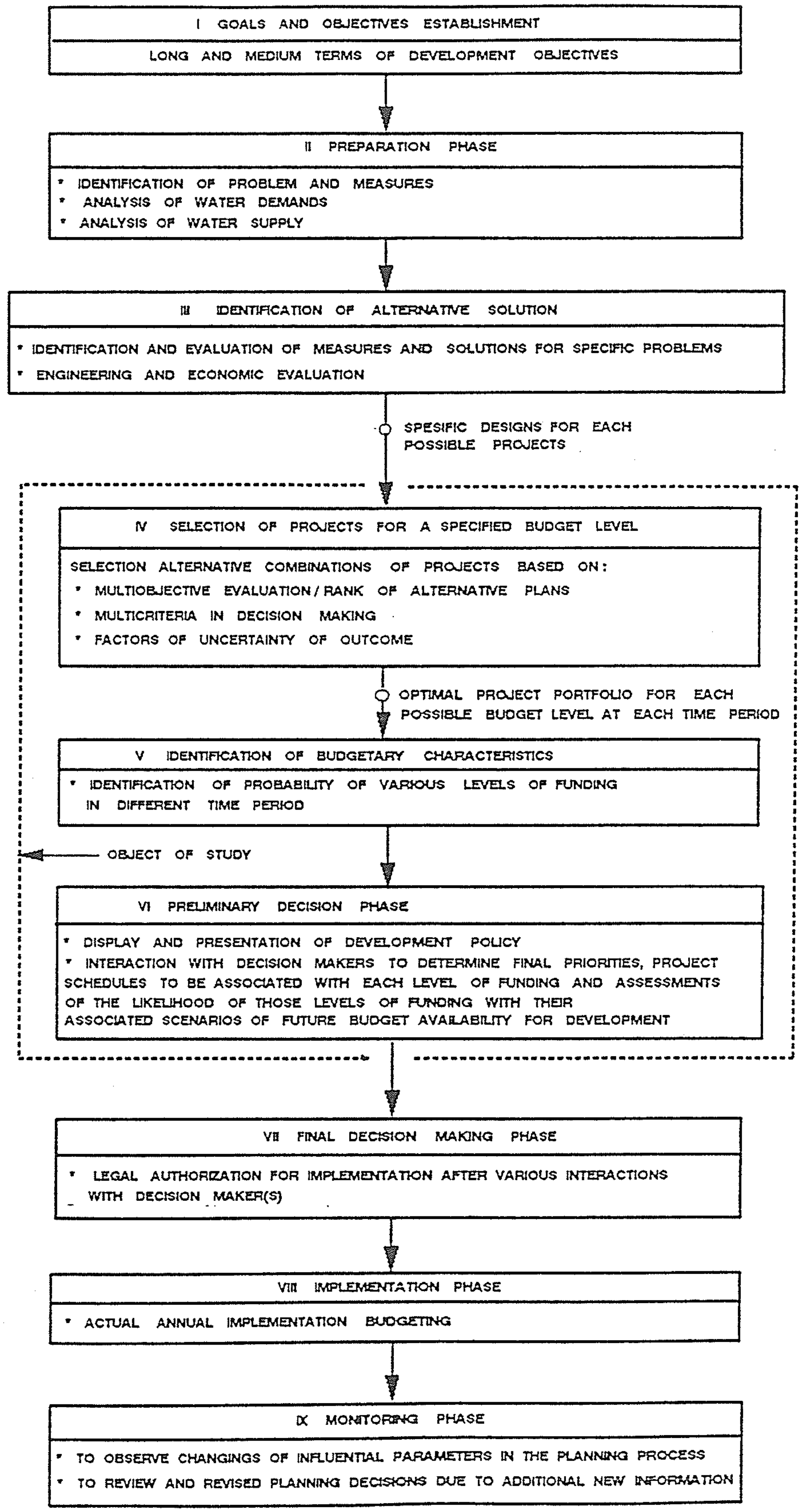


Figure 3.1: Nine-Steps of Water Resources Planning

assessments of these factors, all of which influence the performance of a project, are subject to high chance variations and uncertainties.

Random variables involved in any decision in water resources systems are often related to three terms: risk, reliability and uncertainty. In order to formulate planning models to handle the uncertainty it is necessary to clearly define these terms. In this study, the definition of the first two of these given by Yevjevich(1983) is adopted.

Risk is defined as the exceedance probability, or non-exceedance probability, of a decision value of the critical random variable. However, the economic risk may be also conceived as the product of the above probability and the consequence (value, damage, and loss) due to the occurence of the event.

Reliability (assurance) in design of a project may be defined as the difference between factor of one (implies a condition of full assurance) and the risk probability, or otherwise.

Definitions of *uncertainty* are much less uniform than definitions of risks and reliability. In some of the US governmental documents, e.g., US Water Resources Council (1983), uncertainty is defined in terms of non-quantifiable phenomena, while risk is defined in terms of quantifiable random variables. For example, the projection of population growth may be considered a non-repetitive event, difficult to forecast or quantify, and is therefore part of uncertainty. On the other hand, the annual precipitation of a future year being repetitive can be quantified, so it is part of the risk.

However, the definition of uncertainty above example shows a high arbitrariness (Yevjevich, 1983), as a result of the concepts of "repetitive" and "nonrepetitive" variables or "quantifiable and "non-quantifiable" variables. Yevjevich (1983) subsequently argues that any random variable, derived either from nature or related to human activities, once identified and clearly defined should be subject to some level of quantification by measurements or data collection and that it is therefore difficult to accept a definition of uncertainty which is based upon either repetitiveness or power of quantification. True risk always refers to the unknown probability of occurence of random variables. In this context, Yevjevich concludes that *uncertainty* becomes closely related to the unknown risk, in which case uncertainty should be defined in terms of the lack of knowledge on the risk.

Another definition for uncertainty is given by Rowe (1977) who notes that uncertainties are not only related to random, but also to deterministic features such as the lack of knowledge. Rowe (1977) concludes, that there are three types of uncertainties: a) model uncertainty (descriptive uncertainty); b) parameter uncertainty (estimation or measurement uncertainty); and c) natural uncertainty (climatic changes, economic changes, even social and environmental changes).

3.2.2 Types and Sources of Risk and Uncertainty

A number of types and sources of risks and uncertainties occur in the natural, economic and social environments of water resources projects, especially irrigation projects that generally involve three subsystems. Based on the Chaturvedi (1992) definitions, these subsystems are: the water control subsystem, involving efficient collection and distribution of irrigation water to, and efficient removal of drainage water from, the farms; the agricultural production subsystem, involving the efficient combining of water, seeds, fertilizers, energy, machines, labor, and management for production of food and fiber; and the agricultural marketing subsystem, involving efficient collection and transportation of produced food and fiber to markets and processing. There are basically two types of risks and uncertainties that have the most influence on irrigation projects. These are: physical-environmental uncertainties which mostly affect the first type of subsystem and socio-economic and political uncertainties that mostly affect the second and third types of subsystem, i.e., the agricultural production and marketing subsystems.

In terms of the planning phases described previously, each planning phase of water resources projects, is directly or indirectly affected by these uncertainties. Physical uncertainties such as water supply, floods, natural disasters, geophysical environment and water quality and socio-economic uncertainty such as level of water demand derived, for example, from how much of an irrigation project is being used, may affect the technical level of planning phases. However, almost all types of socio-economic uncertainty such as budgetary fluctuation, benefit overestimation, cost underestimation, public rejection/participation, political obstacles, environmental misjudgement and legal complications effect medium levels of decision making, e.g., Identification of budgetary Characteristic in the planning phases. However, only socio-economic uncertainties such as budgetary fluctuations and socio-political obstacles influence high levels of decision making in the planning phases, e.g, Final decision.

3.2.3 Aggregated and Specific Risks for High Level Decision Making

The high level decision making process, regardless of the type and source of risks and uncertainties, requires a reduced number of aggregated and specific risks. From the point of view of a high level DM, risks are attractive for final decisions if they can be aggregated and evaluated on the basis of benefit and cost terms. Aggregation and evaluation of risks and uncertainties in this way enable all the components of the system to be evaluated on the basis of whether they would perform as planned or designed, and whether the benefits and costs would depart from the predicted values.

As concluded by several researchers, e.g., Lutz and Cowles (1971), Goicoechea et al. (1982), Dandy (1985) and Tung (1992), two sources of risks and uncertainties exist, namely: 1) internal factors such as incomplete knowledge and insufficient information on the system being planned, for example, underestimation of enginering cost because of insufficient information on site geological formations, and 2) external factors beyond the control of the DM or planner, for example, the random nature of natural phenomena, e.g., rainfall, flood, etc.

Based on the above assertion, the uncertainty inherent in the Benefit-Cost analysis procedure is adopted as an aggregated risk in this study. This choice is due to its capacity to aggregate physical and economic uncertainties inherent in the water control subsystem simultaneously as long as their implications can be measured in monetary terms through benefit and cost components. Detailed dicussion of this issues is provided in the next sections.

In addition to the overall aggregated risks and uncertainties described above in certain cases many decision makers also have to consider the specific risks and uncertainties of the most influential parameters inherent in both the agricultural production and marketing subsystems which are critical in the final decision making processes of investment planning. This concern is particularly relevant for the case of developing countries in which water resources investment planning, and hence water resources management as a whole, has emphasized only the engineering and economic factors of the water control subsystem and is generally undertaken by government through a centrally planned and funding policy. Based on the experience from planning, implementation and operation of water resources projects in Indonesia (Sutardi, 1988, Sutardi et al. 1991a and 1991b, and Sutardi and Goulter, 1993) and India (Chaturvedi, 1992), it can be concluded that the success of all water resources management systems relies heavily on the cooperation of water users or people affected by water, e.g., farmers using irrigation, domestic and industrial water users, fishermen, residents of floodplains. The key factors for such success generally involve: 1) social responses following completion of water resources projects in terms of understanding, support, cooperation, and participation of water users in specific objectives of developing and operating projects such as irrigation, water supply, flood control, recreation, etc., and 2) the availability of budget for implementation of water resources projects. Furthermore, articles by Lutz and Cowles (1971) and Hanke and Walker (1974) provide evidence that the first factor also affects water resources projects in developed countries.

Based on the above discussion, the other types of uncertainty inherent in water resources projects namely, uncertainty in the budget available for water resources project in any time period, and social responses following completion of projects, are considered as the specific uncertainties in this thesis.

3.2.4 Quantification of Risks and Uncertainties

The most difficult problem faced by planners wishing to consider uncertainty in a formal or rational sense is the quantification of risks and uncertainties. According to Yevjevich (1983), this problem may be considered accomplished when the appropriate probability distributions are estimated for the key random variables that underlie the risks. However, these estimates are themselves subject to uncertainties in terms of estimation of risk properties. Uncertainty may be considered partially quantified when the confidence limits for any decision-affecting variable value can be estimated.

Actual quantification of risks and uncertainties should include: 1) identification of sources of risks and uncertainties specific to benefit and cost parameters, and 2) derivation of probability distributions of the risk variables by objective probability approaches or by subjective approaches such as the possibility ratings technique.

Two basic approaches used in this thesis for quantification of uncertain parameters are:

- Literature search for selection of probability distribution functions and reliable methods for estimation of parameters of random variables involved. This step implies defining the risks and the confidence limits for specific values of the risk-related random variables as uncertainties in quantitative statements (Taylor et al., 1979).

- Development of new approaches for quantification of specific uncertainties which are not well covered in the literature. In this study, specific approaches for quantification of social responses and quantification of characteristics of budgetary fluctuations, based on a combination of an intuitively-based (subjective) model with a collective opinion technique, fuzzy set theory and a statistical model are developed.

The next three sections will address identification of sources of the aggregated risks reflected in the net present value of benefit (NPVB) and the specific uncertainties, e.g., social factors and budgetary uncertainties that affect water resources projects.

3.3 Aggregated Uncertainty Inherent in NPVB Indicator

The basic characteristics of any project, including water resources projects can be defined as benefit, cost and risk. These characteristics can be conceived as mutually interactive. It is not possible to change any one of the three components significantly without changing the other two. It might, however, be argued that project characteristics other than benefit, cost or risk might be incorporated into one or more of these three basic characteristics by the appropriate methods of analysis.

Economic performances of projects are traditionally evaluated based on deterministic Benefit-Cost analysis procedure. The indicators of economic desirability of a project commonly used are: benefit-cost ratio, net present value, annualized net present value, internal rate of return (IRR), and the project payback period. Theoretical examination of these indicators show clearly that net present value and annualized net present value have the fewest computational and economic pitfalls when evaluation of a project's economic desirability is sought (Eckstein 1958; Au 1988). Based on this assertion, the net present value of benefit is adopted in this thesis as the basic economic indicator.

In addition to the need to determine the most appropriate economic indicator there is also a need that this indicator be sufficiently representative to aggregate various types and sources of uncertainties that might affect water resources projects whether they are physical or non-physical (socio-economic) in nature. In water resources projects the Benefit-Cost analysis procedure is subject to significant uncertainties in quantifying benefits and costs. Extensive research related to how component of benefits and costs are affected by various types of risks and uncertainties can be found in, e.g., Lutz and Cowles (1971), Goicoechea et al. (1982), Dandy (1985) and Tung (1992). It can be concluded from these studies that the impacts of any type and source of uncertainty are actually incorporated in either benefits or costs parameters. Since the net present value of benefit (NPVB) consists of the subtraction of two random variables i.e., benefits minus costs, NPVB is also a random variable. Such assumption (the NPVB criterion as a random variable) enables aggregated uncertainty inherent in each component of benefits and costs to be incorporated in project selection decision making processes.

However, in certain cases it may not be possible to quantify the implications of some risks and uncertainties explicitly in terms of benefit and cost parameters. The specific uncertainties which might fall into this category include social aspect uncertainty and budgetary uncertainty. In such cases multiobjective and multicriteria analysis are required.

The following two sections are devoted to addressing detail those specific uncertainties.

3.4 Social Aspect Uncertainty

In this thesis, uncertainties related to socio-technical and political factors will be addressed with the reference to the nature of the problems involved in water resources development in Indonesia, and therefore may be quite seem as being "problem specific". However, the general factors and even some of the problem characteristics can occur in other areas.

Uncertainties related to social aspects inherent in the agricultural production and marketing subsystems are important and possibly the most difficult factors to recognize in water resources planning. Although the impacts of this type of uncertainty could be reflected in a quantitational economic indicator such as Net Present Value of Benefit (NPVB), there are, however, some strong reasons why, in certain planning environments, social aspects should be considered separately and explicitly. These reasons are:

1. Some of the causes of socio-technical and political factor uncertainty, such as the experience and ability of farmers to exploit new technology such as technical irrigation schemes, cannot be quantified in monetary terms. Their presence cannot, therefore, be detected through the traditional Benefit-Cost analysis.

2. There is a need to develop a quantitative approach to estimate the magnitude of public participation and social response following the completion of water resources projects in order to use this information for investment decision making processes.

Experience with water resources development in Indonesia during the last two decades (Sutardi, 1988) might be used as an illustrative example for the existence and implication of socio-technical and political uncertainties in real life problems.

Irrigation development in Indonesia has traditionally addressed not only objectives related to economic efficiency but also non-economic objectives related to national agricultural policies. "Non-economic" objectives in these development policies include: 1) maintenance of self-sufficiency in rice-production by both intensification of existing production through upgrading of existing rice fields and by extensification of production through development of new rice field areas in less developed regions off Java, and 2) support for the transmigration program and thereby simulation of regional development.

However, inspite of this multiobjective definition of the problem, irrigation projects in Indonesia have generally been selected by procedures dominated by traditional Benefit-Cost types of analyses and have experienced considerable delays in reaching the level of development and benefits anticipated for those projects. In this latter case, the problem seems to be closely related to an inappropriate or incomplete analysis of the socio-technical and political aspects and budgetary constraints. It should be noted, however, that such problems exist everywhere especially in developing countries. Studies carried out by several researcher, government agencies, and donor agencies documented by Bower and Hufschmidt (1984), and Chaturvedi (1992) show the following observations: 1) Water resources management is often defined too narrowly in terms of the range of measures considered for producing the outputs that are desired. For example, a water resources management system may consist primarily of physical facilities, such as dams, canals, power plants, wastewater treatment plants, to the exclusion of many other essential measures, such as economic incentives, regulations, technical assistance, credit, land-use zoning, etc. 2) The planning activity, and therefore water resources management as a whole, is often too narrow in scope in that primary emphasis is placed on the engineering, economic, and financial data and analysis required to obtain approval of the projects. Inadequate attention is given to the direct and indirect environmental qualitity and social end effects of projects. The detailed discussion of the causes and impacts of these complex inter-related socio-technical, economic and political factors as well as budgetary limitations using the Indonesian experiences as an example is as follows:

a) The readiness and ability of farmers in a region in which the current agricultural practice is not related to irrigated rice production to adapt to very rapid irrigation development. Although a time allowance is provided to allow a project to reach its full development stage, almost all of completed projects never reached their maximum potential productivity as predicted in feasibility studies due to the inter-related socio-economic factors as described in points b) and c) below.

b) Rice, which is often refered to "a social commodity," is at a comparative economic disadvantage relative to alternative perennial crops such as coffee, rubber, cocoa, etc. and even inland fisheries. Most farmers facing this situation therefore tend to plant these alternative crops or develop fisheries in place of rice;

c) There is a lack of experience and ability of farmers to exploit newly completed irrigation and to sufficiently use new agricultural inputs for irrigated rice production farming;

d) There is also a lack of agricultural production and marketing facilities and service, such as extension services, training facilities and insufficient supply of agricultural inputs (seed, fertlizer, etc.).

It should be noted that the need to expand irrigation facilities to a newly opened agricultural area which is generally located in an underdeveloped region is due to the necessity to maintain the quantity of the area for irrigated rice fields. In many cases, especially in develop regions, there are tendencies to shift land use from rice production to non-agricultural uses such as urban and industrial area expansions, inland fisheries, highway network expansion, etc. To resolve such unavoidable conflicts of interest one practical alternative of solution is to replace rice production areas in remote underdeveloped regions integrated by means of regional development and transmigration programs. However, this alternative is not without problems. One of the obvious consequences has already been desribed in the above discussion and the others will be addressed in Chapter 6 (Subsection 6.2.1). As the implications of the socio-technical, economic and political interaction aspects, many hundred thousands of hectares of completed irrigation and swamp reclamation, particularly in regions off Java, were not utilised to the optimum level projected by economic analysis for more than five years after completion of the projects (Sutardi, 1988). Based on this fact it can be concluded that investment outcome on water resources projects not only depend upon the reliability of the natural phenomena (rainfall and weather) underlying the water control subsystem, but also on the other inter-related socio-technical, economic and political factors which underlie the agricultural production and marketing subsystems. These facts suggest the need for explicit recognition of both classical economic indicators and socio-technical, economic and political interaction aspects in the procedures used for investment planning of water resources projects in general.

A concern to the need to incorporate social aspects into an operational multiobjective planning model has been pointed out by Loucks (1977) as follows:

> There is a need to learn much more than we know about the dynamic physical and social responses following major water resource development projects. It is in the consideration and modeling of potential social, environmental and economic impacts of such water resource projects that system analysts, working with specialists in other relevant disciplines, can make very important and valuable contributions.

The combination of these observations, e.g., the real life experience with water resource planning problems in Indonesia (Sutardi, 1988, Sutardi et al., 1991a, and Sutardi and Goulter,

1993) and other developing countries (Chaturvedi, 1992) and Loucks's statement (1977) provide evidence for the need to incorporate social aspects into a formal multiobjective planning model.

3.5 Budgetary Uncertainty

As mentioned earlier, there is often a need to recognize the specific uncertainty related to fluctuations of future budget available for investment. Such a budgetary uncertainty exists anywhere affecting not only water resource project investments but also project investments of other sectors whether they be in developed countries or in developing countries. To illustrate the existence of such budgetary uncertainty problems in developed countries, a good example may be the Hybernia project in Newfoundland, Canada (Winnipeg Free Press, 1992). This on-going oil refinery megaproject, which was started three years ago, has been rescheduled due to an unexpected sudden drop in funds available for construction. As a consequence the project completion period has to be extended. Although such budgetary uncertainty problems may exist anywhere, their impact is more exaggerated in developing countries. The ultimate impact of such budgetary uncertainty is the reduction, or in the case of project cancellation the total loss, of anticipated benefits accrued from the affected projects. In developing countries such delays or cancellation may result in severe social disruption.

Planning for development of water resource projects has actually been performed under an environment of budgetary limitations and /or uncertainty for more than four decades. This assertion is supported by the following statement quoted from Eckstein (1958):

> The number of resource development projects which local interest and federal agencies might desire to build in any period will always exceed the number for which funds can be actually be made available. Competing claims for money within the federal budget and the difficulty of increasing the general level of taxation impose a limit on the total funds available for water-resource development. Thus choices among projects are unavoidable. To some extent, politics will determine what projects will be undertaken, but there must also be general standards by which projects can be appraised and compared,

However, in the mid 1970's consideration of budgetary uncertainty was still unsatisfactorily handled as indicated by the statement of Neely and North (1976) that:

> The lack of information on future projects and budgets could present the greatest challenge to an operational programming model.

It may be noted that, up until now, there is still no model/approach available to address budgetary uncertainty problems adequately in water resources planning.

To complete the illustrations of the causes and impacts of budgetary uncertainty to water resource projects in developing countries, it is important to examine the real life problems associated with budgetary uncertainty faced by the planners in pursuing water resources development in Indonesia for the last twenty years.

There are two sources of finance for the Government of Indonesia's (GOI's) development expenditure: i) internal funds which are mostly derived from oil and gas export revenue, and ii) external funds, which are borrowed from different institution and countries. These development funds are then allocated to the twenty six (26) competing sectors for development, of which six sectors (Agriculture-Irrigation, Industry, Mining and Energy, Transportation and Communication, Transmigration and Regional Development, Urban and Rural Development) have historically been allocated most of the development funds. However, the world oil price fluctuations over the last ten years and the changing of priorities of government funding allocation among various competing sectors arising from a number of factors such as, achievement of self-sufficiency in rice productions, and the decreasing contribution of agriculture sector to Indonesia's Gross Domestic Product (GDP) have caused the budget available to be allocated for water resources development to become more uncertain than before. Such budgetary fluctuations and priority changes severely restricted the GOI's ability to continue funding all of its ongoing projects simultaneously. Many hundred of medium projects were therefore rescheduled and some postponed.

The conceptual framework for how the most influential socio-technical, economic and political factors affecting the prediction of the likelihood of future budget availability are incorporated in the proposed approach is described in Chapter 5 Subsection 5.5.2. The implications of the specific budgetary uncertainties that affect water resources projects in Indonesia are described in detail in Chapter 7 Subsection 7.1.1.

Chapter 4

MODELS FOR HANDLING UNCERTAINTY IN INVESTMENT PLANNING

4.1 Existing Measures of Uncertainty in Current Planning Practice

4.1.1 Inclusion of Uncertainty in Benefit-Cost Analysis

Inclusion of uncertainty within benefit-cost analysis in the planning of water resources development has been receiving increasingly greater attention. However, relatively few articles on the subject can be found in the literature, particularly in comparison with the work on inclusion of uncertainty in water resources operation and management. There has been considerable concern as to the importance and relevance of this issue, but very little has actually been done in real terms on the methodology of decision making and its impacts in practice. A review of the regulatory and advisory activities on inclusion of uncertainty in decision making for water resources projects within the USA governmental agencies and councils over the last 30 years supports this statement (Goodman, 1984)

In addressing the problem of incorporating uncertainty into water resource investment decisions, Eckstein (1958) and the U.S. Inter-Agency Committe on Water Resources (1958) suggested general adjustment of influential parameters on Benefit-Cost analyses. Such adjustments are in the form of: a factor added to the interest rate, overestimation of costs, and underestimation of benefits, or limitation of the period of analysis. However, as noted by McKean (1958) and Margolis (1959) these adjustment methods "miss the major problem". Both authors argue that responsible government agencies must select the best possible projects and this choice should be "affected not only by the expected values of the projects but also by the probabilities of a range of benefits and costs, i.e., a measure of variability." A review at the beginning of the 1960's of the literature concerning the incorporation of uncertainty reveals that the problems related to the consideration of uncertainty had been unsatisfactory resolved. The question of uncertainty remains so unclear that Eckstein (1958) admits these difficulties and concludes

> I am sure that enough has been said to indicate that this particular problem is far from a solution. In the meantime, judgment methods must be used, whether verbal or formal, with the identification of the major contingencies and some provision being made against them constituting a minimum program for the design of reasonable decision procedures in the face of uncertainty.

A review of the more recent literature indicates increasing concern and apprehension on how to incorporate the effects of risks and uncertainties into various aspects of decision making in planning and operation (Goodman, 1984). Although authorities, e.g., Hirschman (1967), Linblom (1968), Howe (1971), Mack (1971), Kaynor (1978), U.S. General Accounting Office (1978), are not in agreement on what to do about uncertainty, options under consideration are: reduce it, ignore it, avoid it, or analyze it in mathematical terms for planning purposes. However the U.S. Water Council (1983) provides explicit guidelines on how uncertainty should be handled (for detail refer to Chapter 2 Subsection 2.1.1). This document also lists the following methods for dealing with risk and uncertainty and provides additional guidance on project evaluation: 1) collecting more detailed data to reduce measurement error, 2) using more refined analytical techniques, 3) increasing safety margins in design, 4) selecting measures with better known performance characteristics, 5) reducing the irreversible or irretrievable commitments of resources, and 6) performing a sensitivity analysis of the estimated benefits and costs of alternative plans.

Major (1977) recommends "airing" the problems of uncertainty in an "open" planning process involving governmental and non-governmental organizations and individuals with different points of view. He also points out that general adjustments tend to obscure the differences in uncertainty that characterize different parts of a program or project when they are applied to all projects and programs. Major prefers instead to make explicit assessments of the degrees of uncertainty prevailing for different aspects of programs and projects, and to present these to participants in the political process. For example, the component of a project that would make provision for future recreation demands might be worthwhile, with very little uncertainty about the general level of future demand, whereas the component of a project dedicated to the supply of irrigation water might have very uncertain merit because of the dependence of its success on agricultural support decisions elsewhere in the system or abroad.

The following comments by Wiener (1972) are convincing:

> Attention is drawn to a type of optical illusion to which most of us are prone, namely *underestimating the extent of uncertainty.* When reviewing possible outcomes, we are not usually in a position to list all factors that may modify our future assumptions or to identify all unpredictable future developments; furthermore, we also tend to neglect influence from outside the system that may bear upon outcomes within the system. As a consequence we tend to underestimate the importance of low sensitivity of outcomes and the value of decision or action liquidity.

Other studies have underlined both the importance and difficulties of treating uncertainties inherent in Benefit-Cost analysis procedures and offer some measures to deal with the problems. Such studies include Lutz and Cowles (1971), Mercer and Morgan (1975), Taylor et al. (1979), Haimes (1980), Goicochea et al. (1982), Dandy (1985) and Tung (1992) as discussed in Chapter 2. Almost all of these studies (except Lutz and Cowles, 1971) rely on subjective (expert) estimates to specify the "pessimistic," "most likely" and "optimistic" values of the benefit or cost. Lutz and Cowles (1971), on the other hand, propose a rather unique procedure for incorporating uncertainty in benefit-cost analysis. The technique involves a contingency index to correct any consistent bias of the benefit-cost ratio resulting from overestimation and underestimation of the benefits and costs. The important feature of the Lutz and Cowles (1971) technique relevant to this study is that the statistical parameters for this correction, which are determined based on the past performance of completed projects, could be used as factors of corrections in estimating future performance of similar projects.

The most recent study on probabilistic approaches to B/C analysis has been reported by Tung (1992) who investigated which probability distribution is most appropriate when approximate methods such as FOSM is used to estimate the statistical moments of the net benefit and/or the B/C ratio instead of the exact analytical probability distribution as proposed by Goicoechea et al. (1982a). Tung (1992) concludes that the normal distribution is suitable for modelling the net benefit and lognormal distribution for the B/C ratio. The reasons for such choices are as follows: i) both distributions provide an acceptable accuracy relative to the exact numerical integration, and ii) both distributions require the least computational burden relative to other distribution functions.

Inspite of the considerable work that has been done to incorporate uncertainty in Benefit-Cost analysis, problems of projects selection under uncertain Net Present Value of Benefit (NPVB) and uncertain B/C ratio have not yet been addressed fully. The following Dandy (1985) statement supports this assertion:

> The question of how to choose between a number projects, each with an uncertain benefit-cost ratio, needs to be addressed in future works.

4.1.2 Strengths and Weaknesses of Existing Stochastic Models

The Needs for Stochastic Decision Models

Results of statistical analysis of economic criterion are not significant for decision making within themselves. For example, information about a mean outcome and standard deviation of benefits of a project without some basis for comparison will not generally provide an answer to the question of the economic acceptability of a particular water resources project

(Taylor et al., 1976). However, statistical parameters are useful when a number of projects are compared with one another. One project may have a higher mean outcome than another but it also may have a higher standard deviation indicating a greater amount of risk. The problem then becomes one of policy. Which is more preferable - the lower risk or the higher expected outcome? To solve this dilemma, specific decision rules which reflect society's or the DM's preference on risk i.e., "risk taker" or "risk averter," must be formulated. It should be noted that a distinction should be made in developing decision rules for private and public investment. The latter might involve non-economic objectives in which special treatment is required in evaluating risk of such objectives. For example, preferences toward uncertainty may be elicited from a large number of assessors through political processes. In this case, a collective opinion technique is required. The following discussion is devoted to address the strengths and the weaknesses of the stochastic decision models most relevant to the problems of water resources investment planning in uncertain environment addressed in this study.

Problem Characteristics

In assessing the usefulness of the existing techniques, it is important to recognize some dominant characteristics of the problems at hand and the limitations of the existing techniques. As mentioned earlier, water resources investment planning problems are characterized not only by traditional engineering problems, in which past observations could be used to estimate future events, but also by non-traditional problems such as socio-economic and political factors. In the later case, past observations cannot be used solely to estimate future event. Intuitive approaches in the forms of: subjective inputs, insight, understanding, and ranking of priorities may be required (Drucker, 1973, and Saaty and Vargas, 1991). On the other hand, most existing stochastic techniques rely on a mechanistic model, and hence their applications are limited to those cases where the quantitative estimation of modelling parameters are available.

In response to these limitations, the integration of both mathematical and subjective models is proposed for the purpose of understanding and predicting the behaviour of complex systems inherent in water resources investment planning. Further descriptions for the requirements of the proposed approach is given below.

Evaluation Criteria/Model Requirements

The nature of the uncertain environment underlying water resources investment planning problems under consideration requires that a useful stochastic approach satisfy the following eight criteria:

1. **Sequential Decision Process:** The definition of planning indicates that it is essentially a sequential decision process. Resources are committed to various activities at given points in time in such manner that the overall effect of all decisions is optimum. Therefore, the model should constitute, or reflect, a sequential decision making problem in which the latter decision can be influenced both by earlier decisions and by outcomes of the stochastic parameters whose values only become known to the decision maker after the earlier decisions have been taken;

2. **Recognition of the Causes and Effect of Uncertain Parameters:** The model must provide a means of explicitly recognizing and incorporating socio-economic and political factors that ultimately affect the level of budget availability and the probabilities /possibilities of those levels occuring. The model should also be able to provide a conceptual framework to display how the most influential socio-economic and political factors affect the prediction of the likelihood of future budget availability;

3. **Sensitivity Analysis of Uncertain Parameters:** Since some of the probabilities in 2) above may have to be defined very subjectively, it must be easy to perform a sensitivity analysis of the effects of changes in those possibility ratings;

4. **Capable of Handling Multiobjective-Multicriteria Analysis:** The model should be capable of facilitating the application of a detailed optimisation model within each scheduling horizon (time period) to handle the other types of uncertainty not able to be considered in the stochastic sequential decision making process. This detailed optimisation model should be able to address such multiobjective and multicriteria issues as achievement of socio-economic goals which are not able to be suitably quantified as part of the sequential decision making process itself.

5. **Flexibility:** The model should have flexibility in terms of : 1) providing a guide for extreme situations, e.g., if the actual funding level is significantly greater or less than that anticipated, and 2) a flexibility which allows application of the other frameworks suitable for purposeful systems rather than being limited to mathematical rigor;

6. **Collective Opinion Approach:** The model should capable to incorporate a collective opinion technique to elicit assessments on critical issues from a group of DM, or a large number of assessors through political processes.

7. **Measures for Handling Imprecise Input Data:** The model should be able to handle imprecise (fuzzy) input data, "soft" (qualitative) data, imprecision of target and goal settings, and imprecise specification of preferences which are generally inherent in water resources investment planning.

8. **Computationally Efficient:** The model should be computationally efficient, or at least tractable, in handling real life problems which are usually of large dimension. The model algorithm complexity and the involvement of the DM in the interactive decision-making steps should also be kept at reasonable level to make the model attractive to the DM.

A summary of the evaluations of the existing Stochastic Programming including the proposed model, i.e., SDDP-FCCIGP, with respect to eight requirements/ criteria suitable for the problems under consideration is given in Table 4.1. Among the existing stochastic model being evaluated, the last five models, i.e., Mean-Variance approach, MOTAD, TARGET MOTAD, PROTRADE, and STRANGE, appear to have the most relevant characteristics to the problems examined in this study. Thus a more detailed examination of these approaches follows.

Mean-Variance Approach

This approach was proposed by Markowitz (1959) for portfolio analysis. The study considers maximization of a utility function with respect to two criteria, namely, expected income and its variance. An efficient solution is defined as a feasible solution such there is no other

Table 4.1: Evaluation of Existing Stochastic Programming and Proposed Model for Problem Characteristics Under Consideration

TECHNIQUE	ATTRIBUTES							
	Sequen -tial Deci- sion Making	Recog -nize Uncer -tain Para- meter	Sensi- tivity Anal -ysis	Compu- tation -ally Effi- cient	Multi Objec -tive	Flexi- bility	Collec -tive Opinion Tech- nique	Fuzzi -ness of Inputs Data
1 Chance Constrained	Yes	Yes	No	No	No	No	No	No
2 Two Stage Linear	Yes	Yes	No	No	No	no	No	No
3 Stochastic Linear	Yes	Yes	No	No	No	No	No	No
4 Discrete Stochastic	Yes	Yes	No	No	No	No	No	No
5 Decision Tree	Yes	Yes	No	No	No	No	No	No
6 Stochastic Decision Tree	Yes	Yes	Yes	No	No	No	No	No
7 Decision Making	Yes	Yes	No	No	No	No	No	No
8 Focus Loss Constrained	Yes	Yes	Yes	No	No	No	No	No
9 Mean-Variance approach	No	Yes	Yes	No	No	No	No	No
10 Motad	No	Yes	Yes	No	No	No	No	No
11 Target Motad	No	Yes	Yes	No	No	No	No	No
12 PROTRADE	Yes	Yes	Yes	No	Yes	Yes	No	No
13 STRANGE	Yes	Yes	Yes	No	Yes	Yes	No	No
14 SDP-FCCIGP	Yes	Yes	Yes	Tractable	Yes	Yes	Yes	Yes

Note: Detailed description of each attribute is given in Subsection 4.1.2

feasible solution that can achieve the same or better performance for all objectives. Collection of efficient solutions is defined as an efficient set. One of many approaches to generate such an efficient set in this method is by minimization of the variance while specifying the expected income as a parametric restraint. The approach involves non-linear programming (quadratic programming) and is computationally intensive since it requires consideration of the various combinations of correlation among project investments.

In evaluating the performance of a decision model, it is necessary to evaluate the stochastic efficiency of the results of such model. One set of alternative decision rules to mean-variance analysis advocated in the literature is stochastic dominance. The most general form of s-tochastic dominance makes no assumptions about the form of the probability distribution of returns. It only needs definition of efficient sets under assumptions about the general characteristics of investor's utility functions. There are three progressively stronger assumptions of investor behaviour that are employed in the stochastic dominance literature (Anderson et al., 1977). These assumptions lead directly to first-, second-, and third-order stochastic dominance. First-order stochastic dominance assumes that an investor prefers more to less.

Second-order stochastic dominance assumes that, in addition to investors preferring more to less, they are risk averse. Finally, third-order stochastic dominance adds to the two assumptions of second-order dominance, the assumption that investors have decreasing absolute risk aversion. With respect to this stochastic efficiency criterion, the results derived from this approach are not necessarily second-degree stochastic dominance (SSD). If returns are normally distributed then the solutions of this approach are SSD efficient (Levy and Hanock, 1970). In addition to these limitations, due to a heavy computational burden and serious dimensionality problems this model is also not suitable for handling the sequential problems characteristic of the planning problem.

Minimization of Mean Absolute Deviation (MOTAD)

In this approach Hazell (1971) has shown how the Markowitzean mean-variance approach involving non-linear programming (quadratic programming) can be substituted by minimization of mean absolute deviations about return (MOTAD). This approach enables an ordinary LP model rather than quadratic formulation to be used.

However, as for the mean-variance approach described above, the MOTAD results are not necessarily SSD efficient (Tauer, 1983). Furthermore, since it imposes a computational burden, this linear model is not an efficient approach for handling sequential decision making problems.

TARGET MOTAD

This approach, which was proposed by Tauer (1983), establishes a target level of return T, allowing a deviation Y_R below T for state of the nature of the r^{th} period. Two objectives, maximization of expected gross margin, and minimization of aggregated deviation, are considered. The efficient set is established following a constraint method approaches.

The Target MOTAD model generates a subset of feasible SSD solutions. However, Target MOTAD does not provide means of exploring the dispersion of the random variables explicitly. Furthermore, predetermined target levels, and probability that a state of nature or observation r will occur, may be difficult to specify quantitatively. As with MOTAD approach, this model also suffers from computational burden problems, especially when it dealing with sequential problems.

PROTRADE

In spite of its generality, e.g., it can be applied for linear as well as non-linear constraints, and the general distribution for the random coefficient of the linear objectives, PROTRADE is not free from problems. These problems are partly associated with general conceptual and philosophical issues as well as with some more specific problems of investment planning being examined in this study, such as:

1. Practical construction of the utility function is often based on assumptions which are often not satisfied in practice and thus limit its area of application.

2. The information is reduced to the mean value of the objective function at each step and is not therefore able to take sufficient account of the dispersion of the values which the objective function might take on.

3. The approach also requires intense interaction with the DM and assumes that DM has a broad knowledge of the approach. These requirements may hinder its application to the real world problems, especially in developing contries where lack of DM training in Operations Research may become one of the limiting factors.

4. In terms of interaction with the DM, this approach requires an intensive input from the DM or assessor in response to a complex and extensive questioning procedure. This makes elicitation of subjective input and trade-offs analysis difficult, time consuming, tedious and perhaps lessening the quality of responses given.

STRANGE

The STRANGE approach provides some advantages relative to its basic approach, i.e., STEM (Benayoun et al., 1971) in the following context: 1) it always gives efficient solutions and eliminates ambiguities in the pay-off table by including Despotin's (1984) modification; 2) it takes into account uncertainties in the objective function by defining all scenarios as individual criteria; 3) it eliminates the uncertainty affecting the right-hand-side (RHS) of constraints by using the idea of "stochastic programming" of Kall (1982). This means that a new criterion is created taking into account the sum of penalties incurred for all the constraint violations.

As shown in Table 4.1 STRANGE satisfies the six out of the eight selection criteria listed in Table 4.1 for the problem in question. However, in terms of interaction with the DM, STRANGE has the following limitations :

1. It requires information which is sufficently precise to define different scenarios with associated subjective probabilities. This information is often difficult, if not impossible, to obtain.

2. In relation to the interactive phase, it is particularly suitable for applications in which the language scenario and graphical information are easily accepted by the DM. However, for the problem of water resources planning in which many hundreds of projects must be considered, an interactive phase using graphical information can become impractical and cumbersome for the DM.

3. It introduces the extra criterion of a global measure of the risk of non-feasibility. The concept of dispersion of criteria is given by comparison of the values obtained by extreme scenarios. However, STRANGE does not impose the new compromise to the DM, but instead proposes a number of possibilites. This characteristic makes it unsuitable for the problem being examined because the solution requires an answer to the problems of conflicting goals and competing regional interest rather than a broad set of alternative/possibility policies.

Besides these general conceptual and philosophical problems with the use of STRANGE for the planning problem there are also some more specific problems.

1. At present there is no allowance in the formulation to incorporate (0-1) integer programming to satisfy the requirement of "go or no go" status decision variables to avoid fragmented project completion. Although STRANGE can be modified to accomodate (0-1) variables, inclusion of such integer variables makes interactive phase with the DM using graphical information becomes impractical and cumbersome since the number of integer variables may reach many hundreds.

2. Multi-objective issues in STRANGE are handled by parametric study and interaction with the DM until a satisfactory solution is reached. The need for intense interaction with DM and the requirement that DM has to be familiar with the approach in great detail may hinder its application to the real problems, especially in developing countries in where lack of training of a DM in Operations Research may become a limiting factor. Therefore the multiobjective-multicriteria issues of the problem in consideration appear to be best served when solved by a goal programming (GP) type analysis in which intense interaction with DM may not be required. In the GP approach, interaction with the DM is only required at the initial phase, e.g., in setting goal levels and weighting scales, and in the final phase, when the DM makes a decision e.g., the DM is satisfied and therefore accepts the solution or is not satisfied and reruns the model by changing the influential parameter (Goicoechea et al., 1982b).

Conclusion for Existing Stochastic Models:

It should be noted that in terms of stochastic efficiency criterion, the decision rule of stochastic dominance is not applicable to the last two approaches, i.e., PROTRADE and STRANGE, because in these approaches utility functions or preferences of DM are explicitly stated as decision variables in the model formulation.

In terms of their applicability to the problems of public investment planning under uncertain environment examined in this thesis, the existing stochastic models described above suffer from the following drawbacks:

- They are not suitable for sequential decision processes. From a practical point of view, when considering a development period of moderate length e.g., 8 to 12 years, such a formulation may yield a coefficient matrix of thousands of rows and columns.

- The first three approaches only deal with single objective, and are therefore not suitable for handling the problems of investment planning for public systems which generally are characterized by multiple, and often conflicting, objectives.

- They do not consider the need for handling imprecise (fuzzy) data. In the planning problem some data may not be availabe in precise terms. Such cases may involve non-statistically defined data. Therefore, some consideration should be given to handling these types of data in the planning model.

- They do not provide a means for collective opinion approaches to be incorporated in the decision process. Such approach is required when some assessments should be obtained from a large number of assessor by political processes. However, a suitable collective opinion technique may be incorporated to the last two approaches, i.e., PROTRADE and STRANGE.

Due to these limitations of the existing multiobjective stochastic programming techniques for handling multiobjective sequential decision making under budgetary and socio-technical, economic and political uncertainties, as well as the need to handle imprecision of input data simultaneously and explicitly according to the requirements as described above, a combination of mathematical models and an intuitively-based (subjective) model is required.

The mathematical models are required to model the highly reducible actual systems into mathematical symbolisms and descriptions in order to obtain an optimal solution through formal optimization procedures. On the other hand, subjective models are required to accomodate complex purposeful systems (which is defined by Fiksel (1982) as a system originating from human beings or societies desire) which are irreducible to mechanistic forms of mathematical formulations.

4.1.3 Inclusion of Social Uncertainty in Existing Planning Practice

A water resources project is more than a physical phenomenon; it is an intervention into a social system. The success of a large water resources project often hinges on an effective balance of local costs and distributed benefits (Goodman, 1984). Social assessment techniques are useful in suggesting appropriate trade-offs of these costs and benefits. Social impact assessments have become an integral part of the water resources planning and evaluation in developed countries, e.g., the United States, where the U.S. Water Resources Council (1983) provides a guidelines for consideration of social factors in water resources planning under the name of Other Social Effects (OSE).

Goodman (1984) has documented the following contributions of social impact assessment to the planning process: 1) assistance in handling the difficult methodological problems of assessing benefits and costs which are both monetary and nonmonetary and are thus not directly commensurate, 2) assistance in the identification and estimation of water-based needs and the formulation of alternatives, 3) improved ability to project the acceptability and costs of alternatives, and 4) assistance for public involvement programs. Goodman (1984) also documented application each one of twelve social science techniques to steps of the planning process. Fitzsimmons (1977) discussed the following principal forecasting techniques available for assessment of social factors: trend extrapolation, discussion with expert informants, contingency trees, surveys, Delphi techniques, and scenario generation.

4.2 Proposed Measures for Handling Uncertainty in Investment Planning Practice

4.2.1 Aggregated and Specific Uncertainties

The high level decision making process in water resources investment planning addressed in Chapter 3 Subsection 3.2.3 requires a reduced number of aggregated and specific uncertainties. For the final decisions, the DM needs information regarding the certainty of investment outcome in a single aggregated indicator that is sufficiently representative to measure the economic desirability of an investment. On the other hand, the DM also needs information about the certainty of resources (budget) available to fund these investments. It should be noted however, that in certain cases some water resources projects are also planned to meet non-economic objectives as well. In such cases the DM also requires information related to the factors contributing to the achievement of each objective of these non-economic objectives. To fullfil the DM's need for such information in this final decision stage, two types of uncertainties appear to be worthy of detailed examination :

1. Aggregated Uncertainty

Uncertainties inherent in one of the economic indicators of desirability of a project, i.e., Net Present Value of Benefit (NPVB), are adopted as the aggregated uncertainty in this study (refer to Section 3.3, Chapter 3). The reason for this choice can be explained as follows: i) NPVB has the capacity to aggregate and accomodate various types of uncertainties whether they are physical or non-physical, as long as their impacts can be translated into the benefit-cost framework and measured in monetary terms, and ii) it has the fewest computational and economic pitfalls relative to the other economic indicators such as benefit-cost ratio, internal rate of return and project payback period (Eckstein, 1958; Au, 1988).

2. Specific Uncertainty

There are two sources of this type of uncertainty :

i) Budgetary Uncertainty

As identified in Chapter 3 Section 3.5, uncertainty which affects amount of budget actually available for investment in water resources projects should be recognized and incorporated explicitly in the final decision making process. This type of uncertainty deals with complex inter-related socio-political and economic factors that govern the future availability of budget for development arising from purposeful systems originating from human beings or societies. As pointed out by Fiksel (1982) and Karsten (1990), in any purposeful system, past and repeated observations cannot be solely used to estimate future events due to the unique, irreproducible nature of such systems. To handle the problems of uncertainty in this environment subjective inputs and judgments are required. In this case, the probability reflecting the likelihood of actual funding levels relative to the possible funding levels is determined subjectively based on a combination of an intuitively-based model, subjective inputs, judgments and historical data. A collective opinion technique is required to integrate subjective inputs from an individual or a large number of assessor(s) with external factors governing the future availability of budget for development into scenarios of future budget availability. This time dependent budgetary uncertainty becomes the uncertain parameter in the context of sequential decision making process for investment planning of the water resources projects. The detailed description on how this type of uncertainty is incorporated in the optimization model is given in Chapter 5 Subsection 5.5.2.

ii) Social Aspect Uncertainty

In addition to those uncertainties whose impacts can be measured in monetary terms, the DM also requires information related to the certainty of the socio-technical and political factors which underlie the agricultural production and marketing subsystems. Uncertainties related to such social factors are an important and possibly the most dificult factors to recognize in water resources planning. The baseline social conditions are not static but are dynamic system of interactions, and are likely to differ from region to region in a manner that must be described in some manner. Social assessment assists the planning process to profile this dynamic system, to project future states, to identify and to evaluate the impact of the project. As summarized in Chapter 2 Subsection 2.1.5, a review on the papers related to social issues that appear in the literature (e.g., Dinius, 1972; Gum eet al., 1976; Flug and Ahmed, 1990; Hukkinen, 1991; and Sutardi and Goulter, 1993) suggests it is reasonable to use a weighting and rating scheme to quantify non-quantifiable social factors. Such quantification enables these factors to be combined in harmony with pure economic and physical factors. Furthermore, as pointed out by Ryan (1990), statistical analysis, i.e., regression techniques, can be used to describe the relationship between physical (engineering), economic, and social factors for the purpose of description, prediction, estimation and evaluation of such a cause-effect relationship among these factors. However, as Karsten (1990) points out there is also a need to incorporate the intuitive judgment of DM or analyst in forecasting model including such cause-effect relationship. In pointing this factor, Karsten (1990) also argues that the future state of socio-economy is influenced by qualitative changes, which may not be known in advance, and therefore some intuitive/subjective judgment in combination with the theoretical basis and actual data is needed.

In this thesis, an integration of a point allocation technique and a multiple variable regression model, in the form of a scoring prediction model, is applied to estimate and measure the future influential social responses which contribute to the success of utilization of newly completed water resources projects. In the scoring prediction model, a subjective approach utilizing a point allocation technique is used to evaluate independent variables. The relative importance of independent variables with respect to dependent variable is then determined by multiple regression techniques. The scoring for each candidate project under consideration derived from this model is then incorporated in the multiobjective-multicriteria optimization through selection criteria constraints. The detailed description of the scoring prediction model is presented in Chapter 6 Subsection 6.2.1.

4.2.2 Requirements for the Proposed Model

The definition of planning discussed earlier indicates that it is essentially a sequential decision process in which resources are committed to various activities at a given points in time in such a manner that the overall effect of all decisions is optimal. However, as discussed in Chapter 3 Subsection 3.2.3, activities related to water resources project are subject to four types of uncertainties, namely, uncertainty inherent in the benefits and costs parameters (economic uncertainty), uncertainty in the budget actually available for investment in any time period (budgetary uncertainty), the uncertainty on the social responses which control the rate at which project benefits accrue (social uncertainty), and non-random uncertainty due to imprecision (fuzziness) of input data. In addition of these four uncertainties, like any others public investment, water resources investment is characterized by multiple and often conflicting objectives as well as complex socio-economic and political factors. Such factors are highly irreducible into mathematical symbolisms and descriptions.

Identification of sources of uncertainties and their characteristics as summarized below enables the appropriate model for handling the problems to be identified.

1. Uncertain Outcome

This factor reflects the uncertainty surrounding the benefits, and to a lesser extent the costs, that will be associated with a project. All sources of risks for which the causes and implications can be measured in monetary terms are aggregated into uncertainty inherent in investment outcome which is specified within a Benefit-Cost analysis frameworks. Since they deal with reasonably repetitive events (the outcomes of previous projects) past observations can be used to estimate future events. In this case, statistical approaches may be employed to predict the properties of the uncertain parameters/variables.

2. Budgetary Uncertainty

The type of uncertainty reflects year-to-year budgetary fluctuations originating from complex inter-related local, national, and international socio-economic, and political factors. It deals with non-repetitive events, and therefore past observations cannot be used solely to estimate future events. In this case, a combination of historical data and intuitive approaches or subjective models is required.

3. Uncertain Social Factors

These factors reflect the uncertain social responses which, following completion of water resources projects, control the rate at which project benefits are accrued. This uncertainty deals with inter-related socio-technical, economic and political factors inherent in the agricultural production and marketing subsystems. Some of these features are repetitive and some are non-repetitive in nature.

4. Imprecision of Input Data:

This feature relates to non-random uncertainty due to vagueness originating from imprecision or fuzziness of qualitative data or incomplete knowledge of quantitative data used to define and specify the desired outcomes of the project.

The nature of the uncertain environment underlying water resources investment planning as described above, necessitates that the proposed model consist of the integration of both mathematical and subjective models to enable the actual complex systems to be modelled adequately. The adequacy of the model is highly dependent on the levels of the *reducibility* of the systems. The degree of *reducibility* of a management problem, in this case an investment planning, corresponds to the degree of simplification and explicit description that may be achieved. Purposeful systems such as human beings or societies are generally acknowledged to have low reducibility (Fiksel, 1982). For example, the behaviour of a farmer is less reducible than the behaviour of a pumping machine, since the latter may be easily "reduced" to a mathematical description of certain measurable parameters. As the reducibility of a system decreases, there is an increasing need for intuitive facilities in order to understand and manage that system (Fiksel, 1982).

Based on the level of reducibility of the systems and the compatibility of models for the systems being modelled, the required approaches can be broadly classified as follows:

1. High Reducibility:

The system is "highly reducible" to a mathematical description of certain measurable parameters (decision variables) if the modelling parameters can be estimated quantitatively and the relationships among modelling parameters be described into mathematical formulation through system constraints and objective function. The desirable outcomes of the system represented in this mathematical model is achieved by optimization. Treatment of uncertainty for this situation can be carried out using past or multiple observations which can lead to improved knowledge about chance events, expressed in the form of frequency distribution or objective probabilities.

2. Low Reducibility:

The system has low reducibility, e.g., the system to estimate the likelihood of future government budget availability, if it deals with a complex inter-related socio-economic and political factors, which are characteristic of purposeful systems since such systems originate from society's needs. This condition needs intuitive approaches, subjective inputs, and often employs knowledge or judgments which may be inexact and intuitively derived in order to understand and manage that system. In this situation, past and repeated observations cannot be used to estimate future events due to the unique, irreproducible nature of any purposeful system. In this case, the future is not what it used to be, i.e., the future may not be the same as the past.

Models required for dealing with this system should have capability to integrate analytic and intuitive approaches such as insight, understanding, ranking priorities, and subjective inputs and perceptions. The model and approaches proposed in this thesis attempts to consider these features, by using the Analytic Hierarchy Process which has capabilities to handle such requirements (Saaty, 1977; Saaty, 1982; and Saaty and Vargas, 1991).

4.2.3 Rationale for Model Choices

To date there has been no attempt reported in the literature to simultaneously incorporate several factors of uncertainties as the uncertainty of the investment outcome (aggregated in NPVB term), uncertainty in budgetary (budgetary fluctuations) and uncertainty of social factors in the form of the multiobjective-multicriteria portfolio investment planning model for water resources projects. The rationale for the choices of mathematical and "subjective" models to meet these needs is described as below:

1. Mathematical Models

With respect to the mathematical model requirements for the highly reducible systems under consideration as discussed above, an integrated two-level formulation consisting of dynamic programming and multiobjective-multicriteria programming is proposed. The features of each these two components of the formulation are discussed below.

1. Stochastic Dynamic Programming (SDP).

Dynamic programming is known as a powerful and versatile tool for solving a wide range of sequential problems in water resources (Yakowitz, 1982). This optimization technique is the most suitable approach for the investment planning problems in the face of uncertainty due to its efficiency for sequential decision problems defined over discrete or integral decision sets and its adaptive controlability.

The justification for the use of stochastic dynamic programming over many other mathematical programming techniques such as stochastic programming and stochastic linear programming can be illustrated as follows:

i) Stochastic Programming

The basic stochastic programming problem can be stated by the following linear programming formulation:

Objective function:

$$Max \quad z = \underline{c}\,\underline{x} \tag{4.1}$$

Under the constraints:

$$\underline{A}\,\underline{x} \leq \underline{b} \tag{4.2}$$

$$\underline{x} \geq \underline{0} \tag{4.3}$$

where:

$\underline{c}$ = a row vector of n elements,

$\underline{x}$ = a column vector of n elements,

$\underline{b}$ = a column vector of m elements,

$\underline{A}$= an n x m matrix.

Elements of vectors $\underline{b}$, $\underline{c}$ and matrix $\underline{A}$ can be partly or entirely random variables characterized by their distributions. The task is to determine the distribution of z_{max}. This linear programming problem can be solved for all possible combination of the parameters. However, the great number of possible combinations often prevents the use of this approach. These limitations of the linear formulation may be overcome by the application of stochastic dynamic programmming (Bellman and Dreyfus, 1962).

ii) Stochastic Linear Programming

The problem of programming in the case of uncertain decisions is to define the expected value M from the following linear programming formulation:

$$Min \quad M(\underline{c}\,\underline{x} + \underline{d}\,\underline{y}) \tag{4.4}$$

Subject to the following constraints:

$$\underline{A}\,\underline{x} + \underline{B}\,\underline{y} = \underline{b} \tag{4.5}$$

where:

$\underline{A}$, $\underline{b}$ and $\underline{c}$ are as in Equations (4.1) and (4.2) above,

$\underline{y}$ = a column vector of n elements,

$\underline{d}$ = a row vector of n elements,

$\underline{B}$ = an n x m matrix.

Matrix $\underline{A}$ and vector $\underline{b}$ may contain random elements. The vector variable $\underline{y}$ and expression $\underline{B}\,\underline{y}$ compensate for this random effect and assure that the equality in Equation (4.5) holds. Impacts due to random effects are articulated in the objective function as $\underline{d}\,\underline{y}$. Although "time" may be included in such linear programming formulation, the resulting formulation may yield a coefficient matrix of thousands of rows and columns when considering a scheduling horizon of even moderate length (5-10 years). These difficulties can also be overcome by the application of stochastic dynamic programming (Bellman and Dreyfus , 1962).

2. Fuzzy Chance Constrained Integer Goal Programming (FCCIGP).

The proposed second level optimization, i.e., a FCCIGP model, involves the two general approaches, of Chance-Constrained Programming (CCP) and Fuzzy Integer Goal Programming (FIGP). The justification for the use of both approaches is as follows:

i. Chance-Constrained Programming

Chance-Constrained Programming is a type of stochastic linear programming which allows a small probability that the constraints can be violated. The following formulation is standard for this type of programming:

$$Max \quad f(\underline{c}\,\underline{x}) \tag{4.6}$$

Subject to the following constraint:

$$P(\underline{A}\,\underline{x} \leq \underline{b}) \geq \underline{\alpha} \tag{4.7}$$

Where:

$\underline{A}$, $\underline{b}$ and $\underline{c}$ are as in Equations (4.1) and (4.2)

$\underline{\alpha}$ the column vector of m elements for probability levels $0 \leq \alpha_i \leq 1$.

Although, as shown in Table 4.1, for the complex problem of investment planning under uncertain environment, the use of CCP approach in isolation is considered being unsuitable, the CCP can be applied to handle a portion of those problems, in particular, uncertainty of investment outcome. The justification of this choice is as follows:

a) Data that contribute to the investment outcome uncertainty can be analysed statistically such that the probability distribution of uncertain parameters, and hence the confidence limits of critical levels of these uncertain parameters, can be determined.

b) CCP programming does admit random data variations and permits constraint violations up to specified probability limits.

c) Use of CCP does not increase the model dimension from the size of deterministic formulation (Burn and McBean, 1985).

d) "Deterministic equivalents" in the form of specified convex programming problems for a general class of objectives have been established for the general/standard formulations. These deterministic equivalents include: 1) maximum expected value (E model), 2) minimum variance (V model), and 3) maximum probability (P model).

However, the CCP method also has limitations, including:

1) It is impractical if several stochastic constraints have to be accomodated simultaneously and if the probabilities involved are not easily tractable.

2) There is no explicit consideration made either of penalties or reward involved if the chance contraints are violated or made less restrictive.

3) It suffers from arbitrary choice of probability levels.

In order to alleviate some difficulties associated with the existing CCP, its application in the integrated model proposed in this thesis is combined with Fuzzy Set Theory and Goal Programming (GP). The use of the fuzzy concept enables subjective information and qualitative data to be incorporated in the multiobjective optimization.

ii) Integer Goal Programming (IGP)

Goal programming, and its extension IGP, is adopted as the basis for the second level optimization in this integrated model for the following reasons:

a) It is the most suitable multiobjective technique for the goal (target) oriented planning approach typical of developing countries. More specifically its use enables the relationship between resource capacities and target attainments to be easily and readily observed.

b) It is capable of handling multiple conflicting objectives and multicriteria as well as monetary and non monetary objectives.

c) It is computionally efficient procedure relative to others Multiobjective Programming (MOP) and Multi Atribute Utility Theory (MAUT) especially for large scale problems (Romero, 1991).

c) It has the flexibility that its formulation can be easily extended to accomodate specific character of planning problems such as:

- The probabilistic nature of NPVB criterion can be incorporated in the multiobjective-multicriteria analyses and final decision making by means of chance constraints.
- Imprecise data related to the funding availability and imprecise preference of level of confidence limit can be represented in the model formulation by making use of the Fuzzy Set Theory.

A review of the literature indicates there is no evidence that an integrated formulation of the form of the proposed SDP-FCCIGP has been applied previously in the water resources planning. The detailed rationale for such model choices e.g., SDP and FCCIGP is addressed in Chapters 5 and 6 respectively.

2. Subjective Models

As discussed in the previous section, an integration of mathematical models and subjective models is required to handle the range of characteristics of the problems under consideration. The need to incorporate an intuitive approach into a formal mathematical approach in dealing with intuitive problems has been pointed out by Drucker (1973) as follows:

> *Insight, understanding, ranking of priorities, and a "feel" for the complexity of an area are as important as precise, beautifully elegant mathematical models-and in fact usually infinitely more useful and indeed even more "scientific". They reflect the reality of the manager's universe and of his tasks.*

Subjective model are required specifically to process the combination of subjective information, inputs and perception, with historical data into the information required for the decision making process. The Analytic Hierarchy Process (AHP) and Fuzzy Set Theory have been identified as vechicles for harnessing and codifying the intuition of the planners or the DMs with respect to this type of subjective information within a structured framework (Fiksel, 1982; and Saaty and Vargas, 1991).

In addition to these intuitively-based analytical methods, traditional statistical methods such as the first order and second moment analysis, and multiple regression analysis in combination with the Contingency Index, and the point allocation and unit weighting approaches can be used to process historical data available into useful information, e.g., statistical properties of uncertain parameters used in decision making process.

The rationale for choices for each type of model can be described as follows:

1. The Analytic Hierarchy Process (AHP):

The AHP is a theory for dealing with complex technological, economic, and socio-political problems. Basically, the AHP is a multiobjective multicriteria decision-making approach which employs a pairwise comparison procedure to arrive at a scale of preferences among sets of alternatives (Saaty and Vargas, 1991).

In addition to these capabilities, the AHP actually combines the four existing collective opinion techniques: 1) Delphi method: A panel of experts is interrogated by a sequence of questionaires in which the responses to one questionaire are used to produce the next questionaire, 2) Market research: A systematic, formal, and conscious procedure for evolving and testing hypotheses about real markets, 3) Panel consensus: This technique is based on assumption that several experts can arrive at a better forecast than one person. 4) Visionary forecast: A prediction that uses personal insight, judgment, and when possible, facts about different scenarios of the future. In this case, the assessor could be an individual or a group of assessors.

2. Fuzzy Set Theory:

Fuzzy set theory provides a means of dealing with those situations where subjective judgment or estimation of each individual will play a central and significant role in dealing with the existing ambiguity or uncertainty. As suggested by Zadeh (1978), fuzzy set theory also provides a basis for possibility theory.

3. The Contingency Index:

The Contingency Index approach as suggested by Lutz and Cowles (1971) provides a means of correcting any bias of the benefit-cost ratio resulting from overestimation of benefits and underestimation of costs (The detailed procedure is described fully in Subsection 6.3.1 Chapter 6). The "corrected" benefits and costs figures then provide a better estimate for a future economic performance than subjective estimates by experts which are generally estimated without consideration of correction for any bias.

4. Scoring Prediction Model for Social Responses:

This model combines two approaches, i.e., a subjective approach in the form of point allocation technique and a regression model to estimate and measure levels of non-quantitative social responses in term of the understanding, support, cooperation, and participation of water users which control the rate at which benefits of a project are accrued. The main features of the multiple regression model are: 1) its predictive ability expressed in a causal model, and 2) its ability to provide overall (holistic) evaluation of independent variables simultaneously.

In this thesis, independent variables which cause the behaviour pattern of the dependent variable are evaluated using a point allocation method in an interval scale. Using stepwise analysis, the relative importance of independent variables relative to dependent variable is then estimated via traditional least squares.

Chapter 5

STOCHASTIC DYNAMIC PROGRAMMING (SDP)

5.1 Theoretical Background

5.1.1 Rationale for Model Choice

Since water resources investment planning problems deal with the management of water in a wide range of areas related to the use of natural resources, agriculture, industrial development and the environment in general, they may be categorized as general resource problems. As discussed earlier, over the past 50 years water resources planning methods have evolved from relatively straightforward approaches to complex procedures (Goodman, 1984). The major changes in this process have been the result of the inclusion of non-traditional areas of consideration such as regional, socio-political, environmental objectives, and uncertainty related to budgetary and socio-economic concerns. These issues of uncertainty are different from the traditional engineering concerns about uncertainty, such as hydrologic uncertainty, etc.

Operations research techniques have also been used increasingly to tackle the increased complexity of water resources planning. One of the most attractive methods addressing the complexity of general resource planning and management problems is dynamic programming.

In fact, Esogbue (1989) has noted that Dynamic Programming (DP) has become one of the most popular techniques in the field of water resources systems. The reason for such popularity of DP was attributed to its capability of handling problems of a certain structure and complexity, for example, a complex sequential decision making problem in water resources planning management, for which other approaches and optimization techniques had been found to be ineffective. Esogbue (1989) also stated that DP offers a wider range of the variety of problems able to be addressed.

As described in previous chapters, public investment planning is essentially a sequential decision process in which resources are ideally committed to various activities and objectives at given points in time such that the overall effect of all these decision is optimal (Schlesinger, 1966). However, in reality such decision processes are generally affected by various types of uncertainty such as budgetary fluctuations and uncertain socio-economic and political factors. Dynamic programming is a suitable approach for helping to solve some features of such problems. The suitability of DP for these problems arises from the following specific advantages of the technique.

1. It can handle sequential decision problems more efficiently than other techniques such as linear programming (LP) and two-stage LP, particularly for non-linear and stochastic problems.

2. It provides a means of efficiently solving stochastic resources management problems numerically. The method can be adapted to handle two types of stochastic events (Bellman, 1962): i) *adaptive control processes* in which the probabilities of the stochastic events are themselves uncertain and are revised as an additional information becomes available as the process evolves and, ii) *stochastic control processes* in which the probabilities of stochastic events are known initially and no new information is available as the process evolves. The probabilities that govern the stochastic events in the second type of process can be defined objectively, i.e., based on historical data and statistical analysis, or subjectively, when the probabilities are based on past observations if available, or on well-considered degrees of belief (Kennedy, 1986). This last possibility is relevant to the problems of budgetary uncertainty addressed in this thesis in that

the likelihood of future budget availability level may not be able to be determined statistically due to the uniqueness of each situation.

3. It can be easily integrated with a second level of optimization to handle multiobjective-multicriteria issues within each stage or, in the case examined in this thesis, each scheduling horizon. Although dynamic programming can be formulated in its own right to handle multiobjective problems (Tauxe et al., 1979), the additional criteria and hence additional state variables required for this approach increase the computational burden considerably. To alleviate the well known "curse of dimensionality" problem, some decomposition methods are usually used (Hall et al., 1968). [In this study, the application of the FCCIGP (Fuzzy Chance Constraint Integer Goal Programming) as a second level optimization to handle problems of uncertain outcome and imprecise input data as well as the multiobjective-multicriteria issues inherent in the public investment type of planning examined in this thesis, appears attractive since the procedure has the potential to reduce the computational burden.]

4. It has the flexibility to allow for decision sets consisting of quantitatively different level of decisions. For example, in the case of scheduling problems subject to budget uncertainty, the decision set might be in the form of various possible funding levels relative to the projected budget level (B): a) 90%B; b) 80%B; c) 70%B; etc. This feature is very useful for certain types of planning problems; particularly for staged development planning approaches in which flexibility is required.

One of the many interesting features of DP relevant to the work in this thesis is the similarity in structure of the functional equation formulation for both deterministic and stochastic processes.

5.1.2 Characteristics of Planning Problems and the SDP Approach

In general, a water resources system is planned, designed, built, operated and controlled for the purpose of fulfilling specified current and future demands. However, water resources development activities are subject to uncertainties inherent in both resource availabilities as well as in future demands and returns. By definition, planning itself is the process of forecasting future developments. Therefore, ideally planning activities have to address these uncertainties. As described in Chapter 3 (Subsection 3.1.3), uncertainties related to natural resources and future demands are generally handled in the technical level of planning. On the other hand, uncertainties inherent in economic resources, e.g., the level of future budget availability for investment, are generally handled in the high level decision making process (investment planning).

Planning problems tend to be sequential decision making problems by nature, characterized by a situation in which decisions can be influenced both by earlier decisions and by outcomes of the stochastic parameters whose values only become known to the decision maker after the earlier decisions have been taken. In this thesis, the stochastic parameter addressed in the SDP is the level of budget actually available for investment in each scheduling horizon (stage) t of the long term planning horizon, where $t = 1, ..., S$, and S is the number of scheduling horizons (stages) within a given long term planning horizon. To illustrate the problem of this budgetary uncertainty, consider an investment planning problem in which,

(i) D_t^k, for $k = 1, .., N_{D_t}$, representing various levels of possible funding decisions at the beginning of scheduling horizon (stage) t, where N_{D_t} is the number of levels of D_t, and

(ii) F_t^l, for $l = 1, ..., N_{F_t}$, representing various levels of actual funding received during the scheduling horizon (stage) t, where N_{F_t} is the number of levels of F_t,

are to be investigated to fund a portfolio of multiobjective projects to be implemented during the scheduling horizon t. However, the outcome of these levels of possible funding decisions, denoted above as F_t^l for $l = 1, ..., N_{F_t}$ are, in general, never exactly known in advance and are subject to uncertainties due to fluctuations of levels of budget actually available for investment. Furthermore, it should be noted that the probability distribution $p_k(F_t^l)$, $l = 1, ..., N_{F_t}$, for each level of k for $k = 1, ..., N_{D_t}$ is not known completely since past observations generally cannot be used solely to estimate the likelihood of future events associated with such parameter. As described in Subsection 4.2.1 the uncertainty underlying these budgetary fluctuations originates from a 'purposeful system' which is defined by Fiksel (1982) as a system related to human beings or societies desire. Therefore as suggested by Fiksel (1982) and Karsten (1990) consideration of these uncertainties also needs some form of intuitive (subjective) approach. The procedures allowing such consideration of uncertainty to be incorporated in the transformation probabilities of the proposed SDP model are described in Section 5.6.

The funding decision at each stage or scheduling horizon selected from among the complete range of possible funding decisions D_t^k for $k = 1, ..., N_{D_t}$, is the 'optimal' investment decision/ policy D_t^* with its associated 'optimal' portfolios of multiobjective projects to be implemented with that funding level in the scheduling horizon t. (Note that it is portfolios of projects rather than a portfolio of projects because each possible funding outcome from a decision will have its own portfolio of projects.) The use of the term 'optimal' associated with the most desired investment decisions has two meanings. The first meaning relates to the fact that such investment decisions have to recognize the possibility that actual funding is significantly different, normally less than, from anticipated. This concern is to reduce the possibility of project delays, rescheduling, postponement, and even cancellation due to budgetary fluctuations. The second meaning is related to the need to obtain the multiobjective portfolio of projects that yields the satisficing 'return' with respect to preferred objectives and criteria. As discussed in the previous subsection, a SDP method, which is able to handle both risky (the probabilities of occurrence are universally well defined) and uncertain (the probabilities of occurrence are less universally defined) problems, represents an effective approach for handling sequential decision problems in which 'optimal' investment decisions have to be made in the light of a wide range of unknowns.

Another feature of investment planning, namely, that of flexibility, relates to the fact that the components of the system, e.g., the scale of the system, must be adjusted in accordance with changing conditions. This consideration indicates that flexibility is a capability which can be employed in the planning process to ensure that uncertainties regarding the future can be reasonably anticipated and handled appropriately. Two aspects of flexibility in planning are required to operationalize this 'flexible' plan, i.e., *staged development* and *trade-offs between alternatives*. Staged development addresses such questions as which part of the plan should be implemented immediately, what portions are to be staged for future consideration, and when they might be constructed under various scenarios of future budget availability. Trade-offs between alternatives recognise this budgetary uncertainty in terms of goal achievement vs. confidence limit of preferred goal, shorter vs. longer scheduling horizon, etc. The proposed integration of the SDP and FCCIGP models is considered capable for incorporating these features and is described in detail in Chapters 6 and 7.

5.2 Objective of the SDP Approach

The objective of the proposed SDP investment planning model is the development of an investment planning policy for the decision makers which permits them to define and select the optimal investment planning decision in terms of the level of development or projects to pursue during any time interval under conditions of current and future budgetary fluctuations. The decision policy generated by the model should explicitly recognize the possibility that the actual level of funding received is different from, normally less than, that anticipated or, more precisely, desired for that planning period.

Optimal investment decisions at each scheduling horizon t of the SDP are evaluated on the basis of the expected present value of the return. In the proposed model the return is defined in terms of the expected NPVB (net present value of benefit) of the investment in that scheduling horizon, taking into account confidence limits on that estimate of expected return. Note that evaluation of NPVB in probabilistic terms available through the specification of the confidence limits enables the risk aversion attitude of the DM towards economic outcome to be incorporated explicitly in the decision making process. Thus, any decision in each scheduling horizon or stage will be able to take into account the dispersion of NPVB indicators, e.g., the worst case (the upper confidence limit), the best case (the lower confidence limit) and the most likely (the mean confidence limit). Therefore, the optimal planning/investment decision on each scheduling horizon is based on both the probabilities of actual funding levels for the specified scenarios of future budget availability and consideration of the risk aversion attitude of the DM for economic outome.

The detailed descriptions of the proposed SDP model, the development of the transformation probabilities which describe the likelihood of particular budgetary outcomes and the mathematical formulation for the proposed SDP model are given in the following sections.

5.3 Two-State Stochastic Dynamic Programming

A two-state SDP formulation is proposed to handle the problems in the following manner. The first set of state variables for the DP model for this problem are the levels of project development stated in physical units in terms of hectares of irrigated area already developed at the beginning of each scheduling horizon or stage t and denoted as $L_t^i \; \forall \; i, \; t$, for $i = 1, ..., J_t$, where J_t is the number of discretized levels of development in hectares of irrigated area at the beginning of stage t.

Examination of annual budgetary allocation realization for water resources development during the last 20 years in Indonesia shown in Figure 5.1 indicates that the level of funding allocated in any development scheduling horizon (the five year development plan in the Indonesian case) or stage is affected by the level of funding actually received in the immediately preceding scheduling horizon. One cause of such a relationship is that any unfulfilled demands in the previous scheduling horizon has to be satisfied in the next budgeting year or scheduling horizon. Such relationships may be best described using a probability term based on a Markov concept. In this case, the probability of receiving a particular level of funding in one scheduling horizon depends on how 'good' the funding was in the previous scheduling horizon. To address this issue, an additional state variable representing the level of funding actually received in the immediately preceding scheduling horizon $t-1$ is required. This variable is denoted as PF_t^m and represents the m^{th} possible level of funding received in the scheduling horizon previous to scheduling horizon (stage) t and $m = 1, ..., N_{PF_{t,i}}$, where $N_{PF_{t,i}}$, is the number of levels of funding received during the previous scheduling horizon $t-1$. The 'state' of the system at the beginning (or end) of each scheduling horizon t is now defined in terms of both the current level of development $L_t^i \; \forall \; i, \; t$ and the level of funding received during previous scheduling horizon $PF_t^m \; \forall \; m$ and can be denoted by $L_t^{i,m} \; \forall \; i, \; m, \; t$.

There are similarities in *attributes* between this stochastic investment planning model under budgetary uncertainty and the well known stochastic dynamic programming for reservoir

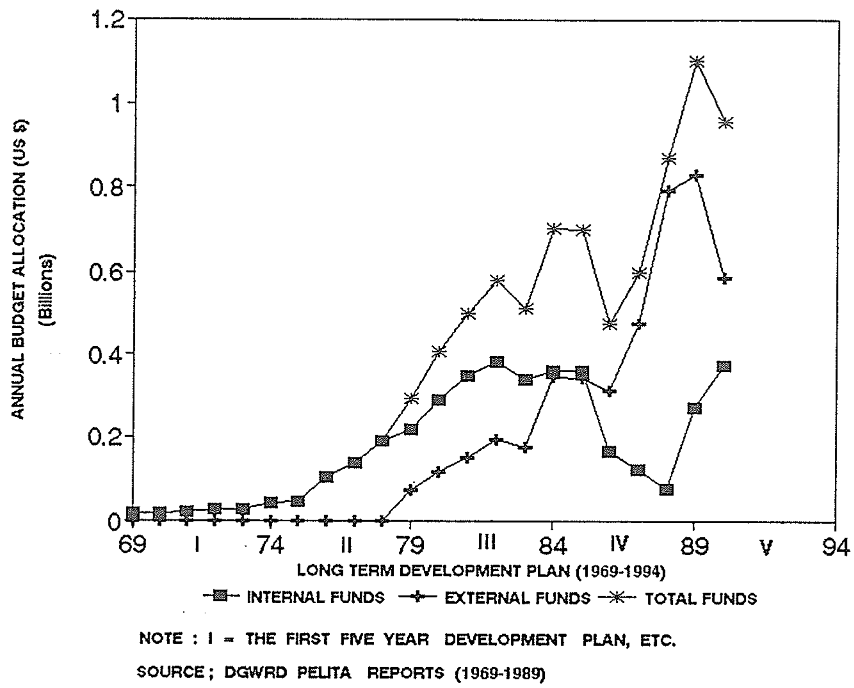


Figure 5.1: Annual Budget Allocation for Water Resources Development in Indonesia for the Last Twenty Years

operation under uncertainty in the inflow developed by Loucks et al. (1981). For this reason the proposed investment planning model will be described initially with reference to that reservoir model. In the proposed SDP investment planning model one state variable L_t^i is directly comparable to reservoir storage in the reservoir operation model. The other state variable of level of funding received in the previous scheduling horizon PF_t^m is analogous to the state variable of flow observed in the previous stage in the reservoir operation model of Loucks et al. (1981) and as such is based upon a 'Lag-one' Markov concept. Similarly, the impact of levels of funding provided in the previous stage on probabilities of funding levels in the current stage is conceptually similar to the relationship between reservoir inflows in two successive stages. The release decision given the current reservoir storage and inflow in the previous stage in the reservoir model also has a direct corollary in the investment planning model. In the investment planning model the decision is what level of development to pursue, i.e., level of funding $D_{t,i,m}^*$ to plan for in each current scheduling horizon t, given the current or existing state of development L_t^i and the observed or actual level of funding in the previous scheduling horizon PF_t^m.

One very important characteristic by which the planning formulation differs from the reservoir operation model lies in attaining what is known as the steady state condition. The reservoir model is almost always able to determine a steady state policy for releases when the model is run for a sufficiently large number of years. This steady state policy reflects the cyclic nature of annual inflows. However, no such cyclic condition exists in the investment planning case where probabilities of the occurence of each level of possible funding are likely to be unique to each project and to change with time in a non-cyclic fashion. It is not therefore possible to undertake repeated observations to establish the values of the probabilities. In this case, the likelihood of each possible level of funding in each scheduling horizon within a planning horizon is a unique event, unlikely, if not impossible, even for the same projects, to occur again with the same funding opportunities. In fact, the uncertainties in the funding allocation process even make the completion date uncertain. The investment planning formulation must attempt to account for this depth of uncertainty.

The decisions to be made in the SDP planning model are what level of investment (consisting of a portfolio of the projects to be implemented in the period being reviewed) to plan for in each scheduling horizon or stage t given the existing level of development of the projects L_t^i, the level of previous funding PF_t^m, the range of possible funding decisions to consider (D_t^k for $k = 1, ..., N_{D_t}$), the range of actual funding outcome (F_t^l for $l = 1, ..., N_{F_t}$) and the probabilities denoted as $p_k(F_t^l)$ of getting the various F_t^l given a range of D_t^k. Note that the probabilities $p_k(F_t^l)$ of getting the various F_t in any scheduling horizon depend upon one or all of L_t^i, PF_t^m, and D_t^k. For completeness of analysis the model will be developed for probabilities which depend on all three factors. However, if it is felt that for particular planning problems the probabilities do not depend on all three parameters the model is easily modified. In fact all that is required is a reduction in the number of parameters (and subscripts) needed to define the probabilities with a corresponding decrease in computational requirements.

The decision, (or more specifically in the stochastic case, the outcome) of the decision results in transformation of the two state variables. The transformation function (f_t) is in the form of $L_{t+1}^j = f_t\{L_t^i, D_t^k, F_t^l\}$ for all t, i, k. This transformation function shows that the level of development (L_{t+1}^{j}) specified in terms of hectares irrigation area developed at the end of scheduling horizon t is the result of the k^{th} level of possible funding decision planned for sceduling horizon t, D_t^k, the l^{th} actual funding received in the same scheduling horizon t, (F_t^l) when level of development at the beginning of scheduling horizon is at the i^{th} state or level. Note that the level of funding in the previous scheduling horizon (stage) is defined by: $PF_t^m = F_{t-1}^l$ which states that the level of previous funding at stage t is actually the same as the level of actual funding received in the previous scheduling horizon $t-1$ (it is assummed that $PF_1^m \; \forall \; m$ is knowing at the beginning of planning horizon when the planning activity is undertaken. This knowing level of previous funding is the amount of funding received in scheduling horizon just prior to the time for which the activity being examined by the planning process will begin.)

The results of the set of possible funding levels to plan for scheduling horizon t are specified in two terms; the economic return expressed in Net Present Value of Benefit (NPVB) and the incremental level of development associated with the generation of that NPVB, expressed in hectares of Irrigation Area Developed (IAD). The economic return under this transformation function in terms of NPVB is then denoted as $V_t^{k,l}$ which describes that incremental NPVB accruing at the end of scheduling horizon t as a result of the k^{th} level of possible funding decision D_t^k and the l^{th} level of funding actually being received during the scheduling horizon t for $k = 1, ..., N_{D_{t,i,m}}$ and $l = 1, ..., N_{F_{t,i,m}}$, where $N_{D_{t,i,m}}$ is the number of possible levels of funding decision at the beginning of scheduling horizon t for each state combination $L_t^{i,m}$, and $N_{F_{t,i,m}}$ is the number of levels of actual funding able to be received during the scheduling horizon t when the current level of development is at the state combination $L_t^{i,m}$.

The return, (in terms of irrigation area developed), is denoted by $AD_t^{k,l}$ which describes the irrigation area developed at the end of the scheduling horizon t as a result of the k^{th} level of possible funding decision D_t^k and the l^{th} level of funding actually being received during the scheduling horizon t. The expected value of the NPVB for a given funding/investment decision D_t^k is determined by multiplying the $V_t^{k,l}$ arising from each of the outcomes F_t^l of the decision D_t^k by the probabilities $p_k(F_t^l)$ of that F_t^l occuring, given that the decision was D_t^k and the current state of the system was in the state combination $L_t^{i,m}$. A graphical depiction of the SDP formulation for investment planning problem under the conditions described above is given in Figure 5.2.

5.4 Inclusion of Uncertainty in the SDP Model

It was asserted previously in this thesis that budgetary uncertainty is one of the most influential uncertainties in the public investment planning and that the most efficient method to handle the problems associated with this type of uncertainty is a SDP approach. The previous section described a two state SDP formulation capable of handling a particular type of budgetary uncertainty associated with water resources investment planning. The following discussion describes how the probability reflecting budgetary uncertainty is actually incorporated in the SDP formulation.

As noted previously the problems associated with the type of budgetary uncertainty being examined in this thesis are mainly related to period-to-period budgetary fluctuations caused by socio-economic and political factors. Two sources of budgetary uncertainty were identified: 1) budgetary fluctuation arising from uncertain economic cycles, and 2) budgetary limitations due to changes of priority in public funding allocation arising from socio-political factors. A combination of a subjective model and an appropriate collective opinion technique method is proposed to quantify qualitative information of socio-economic and political factors into a set of probabilities such that these qualitative factors are able to be incorporated appropriately into the transformation probabilities required in the SDP.

A number of issues have to be addressed or recognized in determining the transformation probabilities. As described previously, the levels of development actually occuring in a particular scheduling horizon (stage) are related to the level of the funding decisions and the probability of occurence of each of these possible funding decisions. Consider the case that the level of development or the possible funding decision D_t^k selected (planned for) is $ 8 million and the actual level of funding (F_t^l) received is only $ 5 million. Under this scenario only a portion of the project will be completed at the end of the period in question. Benefits derived from the project in this situation may be nil or at best only a portion of what the development was intended to achieve. Moreover, the actual level of development completed at the end of period, and the net benefit accruing from it, is likely to be less 5/8 of the total

$L_{t+1} = f_t(L_t^i, D_t^k, F_t^l)$=Level of development specified in terms of hectares irrigation area at the end of scheduling horizon t as the result of the k^{th} level of possible funding decision planned D_t^k at the beginning of scheduling horizon t, the l^{th} level of actual funding received during the scheduling horizon when the current level of development at the beginning of scheduling horizon t is L_t^i

=state transformation function

k $=1, \ldots, N_{D_{t,i,m}}$,

l $=1, \ldots, N_{F_{t,i,m}}$,

$N_{D_{t,i,m}}$ = number of levels of possible funding decision to plan for each state combination $L_t^{i,m}$ at the beginning of scheduling horizon t,

$N_{F_{t,i,m}}$ = number of levels of actual funding received during scheduling horizon t when the current state of development is at the state combination $L_t^{i,m}$,

t $= 1, \ldots, S$

S = number of scheduling horizons or stages in a given planning horizon.

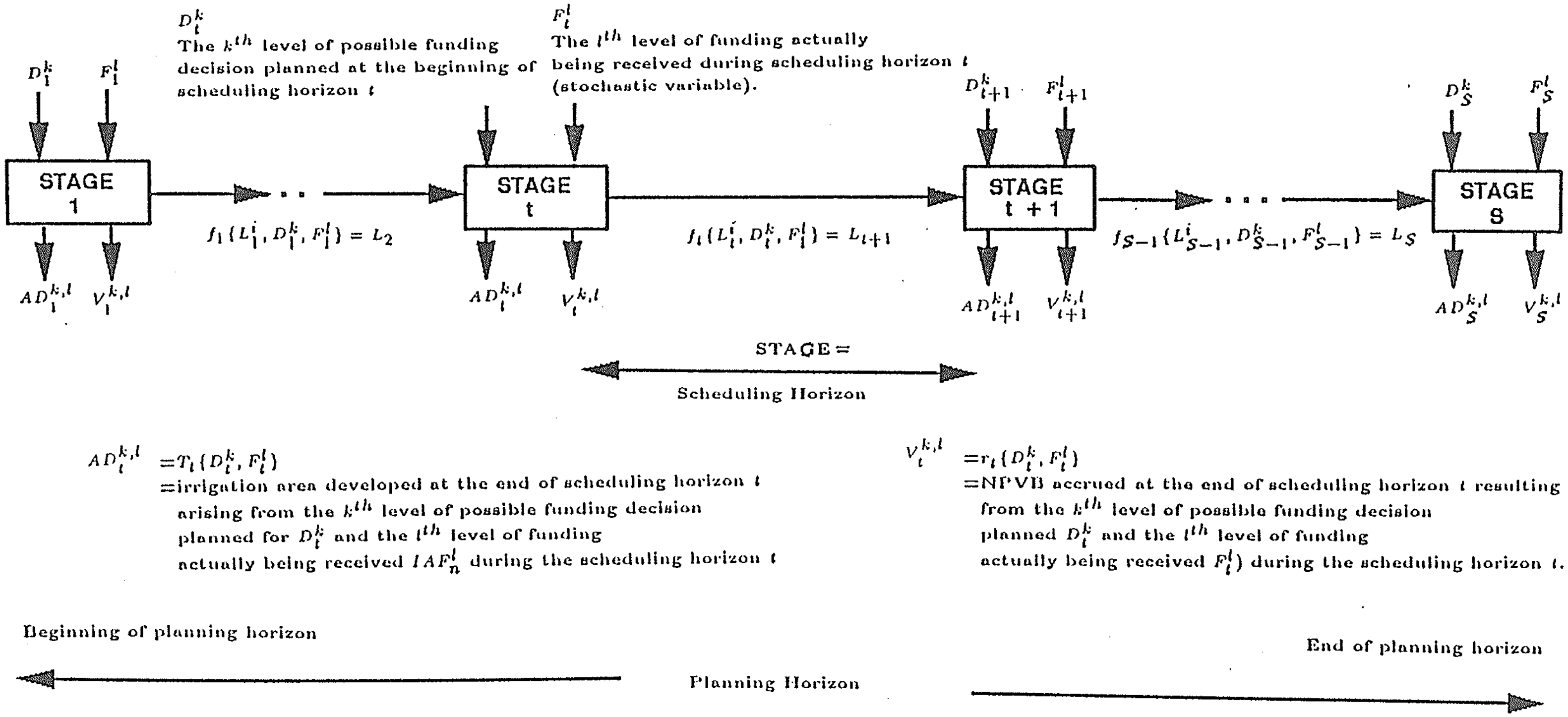


Figure 5.2: Schematic of the SDP Formulation for Investment Planning

expected where 5/8 is the ratio of 5 million/8 million of actual funding received relative to that expected or planned for. This deviation from the ratio of 5/8 is due to an inability to complete works already started due to lack of funds and because of the extra costs for design modification and any other activities required for adjustment of preparation works. On the other hand, if the original decision was to plan for a level of funding of \$ 5 million with the associated portfolio of projects, and the same \$ 5 million was received the project would have achieved the full complement of benefits commensurate with its completion.

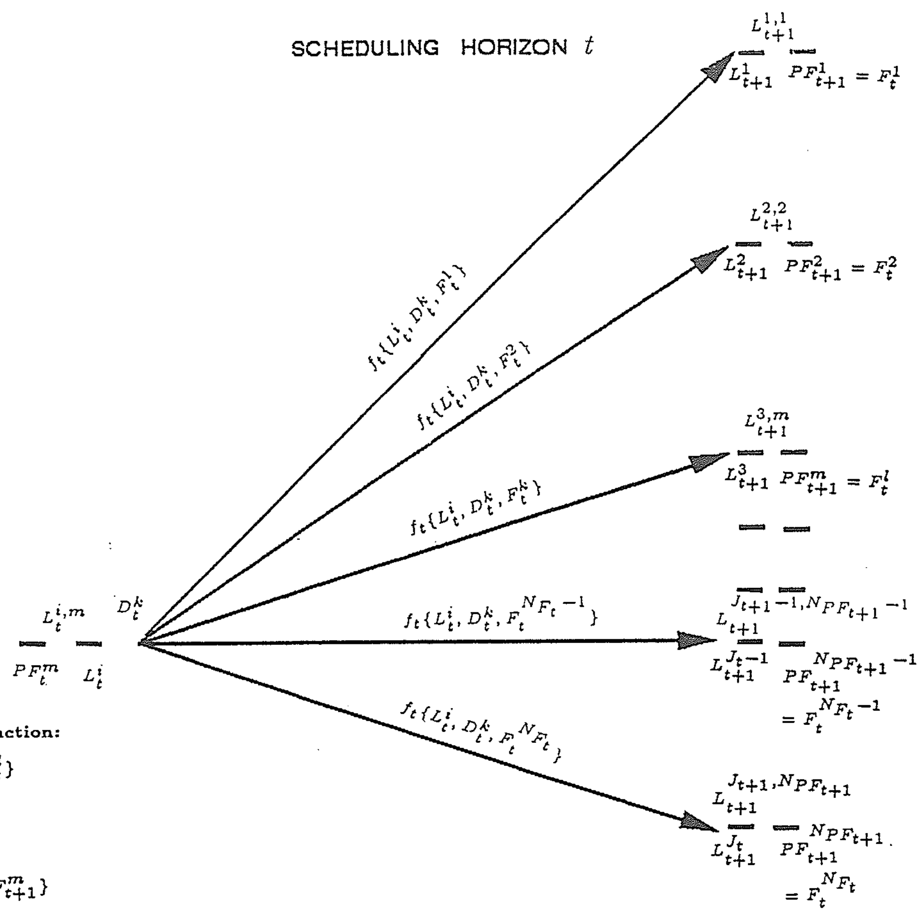
To incorporate the above problem, i.e., potential discrepancies between D_t^k and F_t^l, into the overall model, two approaches are applied:

1. Assignment of probability reflecting the likelihood of the actual level funding received relative to the level of possible funding planned as described in the previous section, i.e., $p_k(F_t^l)$. This probability is applied explicitly in the SDP model to govern the determination of expected return.

2. Introduction of a kind of penalty in the form of the cost 'escalation' coefficients in percentages of the original cost to penalize the discrepancies between the level of actual funding realization and the level of possible funding decisions. For example, the closer the l^{th} actual funding F_t^l is to the k^{th} funding decision D_t^k the smaller the penalty. When $l = k$ then the cost escalation coefficient is zero. These cost escalation coefficients are applied explicitly in a second level Fuzzy Chance Constrained Integer Goal Programming (FCCIGP) optimization model in which the return, specified in terms of Net Present Value of Benefit and amount of land developed for each level of possible funding decision and funding outcome is determined.

The probability of getting a particular funding allocation in any scheduling horizon is obviously a factor in the decision as to the level of development to be chosen. Under these circumstances, if the relevant probabilities of various levels of possible funding, and the implication of receiving funding levels differ from those associated with the planned course of action can be estimated, the problem becomes the SDP problem described above. The state-stage transformations under such relationship are shown in Figure 5.3.

The outcome of the decision at the end of scheduling horizon t has two consequences.



Legend :

State Transformation Function:

$$L_{t+1}^j = f_t\{L_t^i, D_t^k, F_t^l\} = L_t^i + AD_t^{k,l}$$

$$PF_{t+1}^m = F_t^l$$

$$L_{t+1}^{j,m} = f_t\{L_t^i, D_t^k, PF_{t+1}^m\}$$

- k = index corresponding to one of levels of the possible funding decision at the beginning of the scheduling horizon t taking integer values $1, 2, ..., N_{D_{t,i,m}}$,
- l = index corresponding to one of levels of the actual funding received during the scheduling horizon t taking integer values $1, 2, ..., N_{F_{t,i,m}}$,
- m = index corresponding to one of levels of the funding received during previous scheduling horizon $t-1$ taking integer values $1, 2, ..., N_{PF_{t,i}}$,
- $N_{D_{t,i,m}}$ = number of levels of the possible funding decision for each possible state combination $L_t^{i,m}$ at the beginning of scheduling horizon t,
- $N_{F_{t,i,m}}$ = number of levels of actual funding received during the scheduling horizon t when the current level of development is at the state combination $L_t^{i,m}$,
- $N_{PF_{t,i}}$ = number of levels of actual funding received during the previous scheduling horizon $t-1$ when the current level of development is at the state L_t^i,
- L_t^i = i^{th} level of development stated in hectares of irrigated areas developed at the beginning of stage t,
- $L_t^{i,m}$ = state combination of the level of development L_t^i and the level of funding received at the previous stage $t-1$, PF_t^m,
- i = index corresponding to one of level of development (states), taking integer values, $1,...,J_t$,
- J_t = number of levels of discretized level of development (states) at the beginning of scheduling horizon t specified in terms of hectares of irrigated area developed,
- D_t^k = k^{th} level of possible funding decision planned at the beginning of scheduling horizon t,
- F_t^l = l^{th} level of actual funding received during the scheduling horizon t,
- $AD_t^{k,l}$ = Irrigation Area Developed in hectares at the end of scheduling horizon t arising from the k^{th} level of possible funding D_t and the l^{th} level of actual funding F_t.

Figure 5.3: Depiction of the Two-State Transformations of the SDP for Investment Planning

Firstly, it results in transformation in the states of the system from scheduling horizon t to the next scheduling horizon $t+1$. The transformation functions for this problem as given in Equations (5.1) and (5.2) respectively below, show how the level of development L_t^i at the beginning of period t, are changed to the appropriate level of development L_{t+1}^j at the end of stage t (beginning of stage $t+1$), by the funding decision D_t denoted by k and the actual funding received F_t denoted by l taking into account the incremental irrigation area developed generated by the actual funding actually received in that period.

$$\begin{aligned} L_{t+1}^j &= f_t\{L_t^i, D_t^k, F_t^l\} \quad \forall \quad i,\ k,\ l,\ t \\ &= L_t^i + AD_t^{k,l} \quad \forall \quad i,\ k,\ l,\ t \end{aligned} \tag{5.1}$$

It is easy to see that at the beginning of stage $t+1$ (end of stage t) the actual outcome of funding F_t^l for a given l is PF_{t+1}^m. Therefore, this relationship can be written as

$$PF_{t+1}^m = F_t^l \quad \forall\, l,\ m,\ t \tag{5.2}$$

Using the earlier definition of state variables Equation (5.1) can be re-written as

$$L_{t+1}^{j,m} = f_t\{L_t^i, D_t^k, PF_{t+1}^m\} \quad \forall\, i,\ j,\ m,\ k,\ t \tag{5.3}$$

where, $t = 1, ..., S$, $i = 1, ..., J_t$, $j = 1, ..., J_{t+1}$, $m = 1, ..., N_{PF_{t,i}}$ where $N_{PF_{t,i}}$ is the number of levels of PF_t^m when the current level of development is at the state L_t^i.

Secondly, the results of each combination of the k^{th} level of investment/ funding decision $D_{t,i,m}^k$ and the l^{th} level of actual funding received $F_{t,i,m}^l$, are specified in terms of the NPVB (V) and irrigated area developed (AD). These two stage returns are written

$$V_t^{k,l} = r_t\{D_t^k, F_t^l\} \tag{5.4}$$

where the economic return, denoted as $V_t^{k,l}$, describes the incremental NPVB accrued at the end of stage t as a result of the k^{th} level of possible funding decision D_t^k and the l^{th} level of funding actually being received F_t^l during the stage t and

$$AD_t^{k,l} = T_t\{D_t^k, F_t^l\} \tag{5.5}$$

5.4.1 Expected Stage Return

As described in previous section the role of the 'probability of transformation' representing the likelihood of occurence of each level of the actual funding $p_k(F_t^l)\ \forall\ l,\ k,\ t$ is to 'weight' the outcome of stage return to get the expected return. The probability must therefore be explicitly incorporated in the determination of expected stage return by multiplying the economic stage return associated with each possible actual funding outcome by the probability of that outcome occurring. Since the objective function for the investment planning problem investigated in this thesis is the maximization of expected (expected defined in a range of senses described later in the thesis) present value of economic stage returns in terms of the NPVB criterion with the associated confidence limit (β), the recursive equation for the SDP problem can be stated as follows:

$$R_t = \text{Max} \sum_{D_t \in N_{t,i,m}} p_k(F_t^l)([V_t^{k,l}]^\beta + \alpha\ R_{t+1}) \tag{5.6}$$

subject to:

$$\sum_{l=1}^{N_{F_{t,i,m}}} p_k(F_t^l) = 1 \quad \forall\ k,\ t. \tag{5.7}$$

$$R(S+1, L_{S+1}^i, F_{S+1}^l) = 0.0 \quad \forall\ i,\ l \tag{5.8}$$

where:

S = number of scheduling horizons (stages) within a given planning horizon,

t = index corresponding to one of the scheduling horizons (stages), taking integer values $1, .., S$,

i = index corresponding to one of the level of developments (states), taking integer values $1, ..., J_t$,

J_t = number of levels of discretized level of developments (states) at the beginning of scheduling horizon t specified in term of hectares of irrigation areas,

R_t = optimal stage return at the end of scheduling horizon t expressed as the expected net present value of benefit,

D_t^k = levels of possible funding decision planned at the beginning of scheduling horizon t,

F_t = levels of actual funding received during the scheduling horizon (stage) t,

PF_t = levels of actual funding received at the previous stage $t-1$,

L_t = levels of discretized level of development (state) specified in hectares of irrigated area developed at the beginning of stage t,

L_t^i = i^{th} level of development (state) at the beginning of scheduling horizon t,

$N_{PF_{t,i}}$ = number of levels of actual funding received during the previous stage $t-1$ when current level of development is at the state L_t^i,

m = index corresponding to one of the levels of actual funding received in the previous stage $(t-1)$, taking integer values $1,...,N_{PF_{t,i}}$,

$L_t^{i,m}$ = state combination of the i^{th} current level of development and the m^{th} level of previous funding at the beginning of stage t,

$N_{D_{t,i,m}}$ = number of levels of possible funding decision at the beginning of scheduling horizon t for each state combination $L_t^{i,m}$

$N_{F_{t,i,m}}$ = number of levels of actual funding received during stage t when the current level of development is at the state combination $L_t^{i,m}$,

k = index corresponding to one of the levels of possible funding decision D_t, taking integer values $1,...,N_{D_{t,i,m}}$,

l = index corresponding to one of the levels of actual funding received F_t, taking integer values $1,...,N_{F_{t,i,m}}$,

$D^*_{t,i,m}$ = optimal funding decision at each stage t for each combination of level of development L_t^i and level of previous funding PF_t^m where $t = 1,...,S$; $i = 1,...,J_t$; and $m = 1,...,N_{PF_{t,i}}$,

$N_{t,i,m}$ = index of a set of the number of levels of possible funding decision at each stage t for each combination of level of development L_t^i and level of previous funding PF_t^m, where $t = 1,...,S$; $i = 1,...,J_t$; and $m = 1,...,N_{PF_{t,i}}$,

$p_k(F_t^l)$ = transformation probabilities which describe the likelihood of the occurence of the l^{th} level of actual funding received F_t^l relative to a range of levels of possible funding decision D_t^k,

$(V)_t^{k,l}$ = Net Present Value of Benefit accrued at the end of scheduling horizon t resulting from the k^{th} level of possible funding D_t^k and the l^{th} level of actual funding F_t^l,

α = discount factor associated with the duration of scheduling horizon t,

β = level of confidence limit on Net Present Value of Benefit (NPVB) with the associated membership grade based on information provided by FCCIGP model.

The detailed description of the relationship between the objective function of the SDP and the determination of the optimal funding decision within the integrated model FCCIGP-SDP is given in the next section.

5.5 Optimal Total Return for the SDP Planning Model

The objective function of the complete SDP model itself is maximization of the total or sum of expected present value of total economic return over all stages (scheduling horizons).

The economic return at each stage of the complete SDP component is obtained from the expected economic return of a range of levels of actual funding outcomes F_t^l. These economic returns are defined in terms of the NPVB for each funding decisions and are determined or provided by a second level optimization, i.e., the FCCIGP model with the associated confidence limits and membership grade of this confidence limit. Based on the possible funding decisions and outcomes, the portfolio of projects selected for a particular funding outcome are also scheduled by the FCCIGP according to goals and criteria preferences. [The process by which this scheduling is undertaken by the FCCIGP is described in Chapter 6.]

An assumption in the FCCIGP that the NPVB is a random variables enable the objective function to be evaluated in probabilistic terms. Furthermore, through the use of confidence limits on the value of the NPVB, the worst and best cases of the NPVB value and probability of those and certain other conditions occurring can be considered directly.

The optimal total return for the SDP in terms of maximisation of the sum of the expected present value of stage return using the notation of scenario-based transformation probabilities given in Equation (5.17) (the detailed descriptions for obtaining such transformation probabilities are given in the next two sections) for the last stage of the planning horizon can be stated as:

$$TR_S = \text{MAX} \sum_{t=1}^{S} \sum_{D^*_{t,i,m} \in N_{t,i,m}} \left(p(F^l_{t,i,m,k})^\gamma \right) \ \alpha \ \left[(V)^{k,l}_t \right]^\beta \tag{5.9}$$

subject to:

$$\sum_{l=1}^{N_{F_{t,i,m}}} p(F^l_{t,i,m,k})^\gamma = 1 \quad \forall \, t, \ i, \ m, \ k. \tag{5.10}$$

The corresponding recursive equation for all other stages can be written as:

$$R_t = \text{Max} \sum_{D^*_{t,i,m} \in N_{t,i,m}} (p(F^l_{t,i,m,k})^\gamma) \left(\left[V^{k,l}_t \right]^\beta + \alpha \, R_{t+1} \right) \tag{5.11}$$

subject to:

$$R \left(S + 1, L^i_{S+1}, F^l_{S+1} \right) = 0.0 \quad \forall \, i \, , l \tag{5.12}$$

$$\sum_{l=1}^{N_{F_{t,i,m}}} p(F^l_{t,i,m,k})^\gamma = 1 \quad \forall \, t, \ i, \ m, \ k. \tag{5.13}$$

Where:

TR_S = optimal total return at the last stage of the planning horizon expressed as the expected net present value of benefit,
= expected total benefit of optimal policy,

$p(F^l_{t,i,m,k})^\gamma$ = transformation probabilities which describes the likelihood of the occurence of a range of levels of actual funding F_t relative to a range of levels of possible funding decision D_t defined as a function of stage t, a level of development L^i_t, a level of previous funding PF^m_t, and level of possible funding decision D^k_t, for all t, i, m, k, l and scenario of future budget γ (the detailed procedures for obtaining this transformation probabilities are given in the Section 5.6 [Equation (5.17)]),

γ = index corresponding to one of the three scenarios of future budget availability, i.e., Limited, Non-Limited, and Undetermined Budget

$\left[V^{k,l}_t \right]^\beta$ = Net Present Value of Benefit accrued at the end of scheduling horizon t resulting from each combination of the k^{th} level of possible funding decision D^k_t and the l^{th} level of actual funding F^l_t

generated by the optimal project portfolio selected
by FCCIGP taking into account the specified confidence limit on the
NPVB criterion β with the associated membership grade.

The other terms are the same as defined in the previous Subsection.

Recursive solution of Equation (5.11) results in the determination of R_t and the optimal funding decision $D^*_{t,i,m}$ for $t = 1, ..., S$, $i = 1, ..., J_t$, and $m = 1, ..., N_{PF_{t,i}}$.

5.6 Uncertain Parameters

5.6.1 Quantification of Uncertain Parameters

As noted earlier one of the uncertain parameters considered in the proposed SDP model concerns budget availability. Since objective, or observed, probabilities of such budget availability are very difficult to determine in this case, subjective assessment is employed to quantify budgetary uncertainty. Formal justification of this procedure can be found in Ferrell (1972) who discusses three types of subjective input in decision making: 1) creative inputs occuring principally in the choice or invention of models to represent physical reality or in the invention of alternative actions for the set of means from which choice is to be made, 2) valuational inputs involving scaling of preferences or measurement of utilities, and 3) judgmental inputs involving experience and engineering judgments.

Procedures to incorporate "subjective" inputs into an intuitively-based model are outlined as follows:

1. **Quantification of Dispersion of Uncertain Parameters:** The upper and lower bounds of uncertain parameters are determined on the basis of historical data, relevant influential factors, and prediction of future demands.

2. **Subjective Probabilities Assignments:** Subjective probabilities are assigned to each level of the uncertain parameters to reflect the DM's, or the planner's, assessment of the likelihood of these uncertain parameters. These subjective probabilities may be generated using two subjective models: 1) combination of a historical scenario based

model with the Direct Assessment of Taylor (1984), and 2) combination of a historical scenario based model with a collective opinion technique, i.e., the Analytic Hierarchy Process of Saaty (1977, 1982, and 1991).

3. **Rating the Possibility of Scenarios of Future Budget Availability:** A collective opinion technique, in this case the Analytic Hierarchy Process of Saaty (1977, 1982, and 1991) is used to rate the possibility/likelihood of each scenario of future budget availability by integrating subjective inputs from assessor(s) with external factors governing the future availability of budget.

The first procedure, i.e., quantification of uncertain parameters is described in detail below. The second and third procedures are described in the next section under the heading of Transformation Probabilities.

Quantification of Dispersion of Uncertain Parameters

In this procedure the uncertainty in parameters, in terms of their magnitude and dispersion as well as their likelihood, have to be defined. The processes to quantify uncertain parameters inherent in the type of budgetary uncertainty addressed in this thesis are as follows:

- Upper and lower bounds of the range of possible levels of funding D_t are defined.

  The upper bound of possible funding normally reflects the funds necessary to satisfy the projected demand on scheduling horizon t.

  The lower bound reflects the minimum level of projected possible funding that might occur during that scheduling horizon.

  Note, that for computational simplicity there is a one to one relationship between a range of levels of possible funding decision D_t and a range of levels of actual funding received F_t. Therefore, quantification of the range of D_t will also cover quantification of the range of F_t.

- Having determined the possible range (difference between the upper and lower bounds) of possible/planned and actual funding level, the next step is to divide these ranges into subranges, denoted by D_t^k for $k = 1, ..., N_{D_{t,i,m}}$ and F_t^l for $l = 1, ..., N_{F_{t,i,m}}$ respectively. It should be noted that indices k, l and m correspond to the various funding option levels relative to (in percentage) the upper bound of budget projected in the scheduling horizon t, BT_t (e.g., $100\%BT_t$, $85\%BT_t$, $70\%BT_t$, $55\%BT_t$, and $40\%BT_t$).

Probabilities reflecting the decision maker's or expert's assessment of the relative likelihood of each level of actual funding $F_t^l\ \forall\ l$ relative to a fixed value of D_t^k for $k = 1, ..., N_{D_{t,i,m}}$ can then be assigned to each subrange based on the available historical data of actual funding received relative to the projected levels (The detailed procedures for obtaining these probabilities based on subjective models are given in the next section.)

It should be noted, however, that it may not be possible to determine the subranges noted above precisely because of limited information. To handle this imprecision in setting levels of possible funding in each scheduling horizon Fuzzy Set Theory using the concept of tolerance (Zimmermann, 1988) can be applied in the second level optimization for each scheduling horizon of the SDP approach. The procedures whereby such fuzzy consideration can be included in the model are described in Chapter 6.

5.7 The Transformation Probabilities

Before describing the theoretical background of subjective probability assessment and the development of the transformation probabilities matrix for the SDP, the most relevant theory for such transformation, e.g., "lag-one" Markov requirements, is briefly reviewed.

A general stochastic process involves a sequence of random variables $H_1, H_2, ..., H_n$. The probability that the n^{th} random variable, H_n, takes the value h_n may depend on the values taken by all the previous random variables, so that in general the conditional probability can be stated as follows (Hastings, 1973):

$$Prob(H_n = h_n | H_1 = h_1, ..., H_{n-1} = h_{n-1}) \tag{5.14}$$

However, a model which assumes that the current value of a variable depends on many previous outcomes is difficult to handle computationally (Hastings, 1973). To alleviate such difficulty and to establish an adequate and computationally feasible model the subclass of stochastic processes called "Lag-one" Markov process is considered. In this type of Markov process the probability that the random variable H_n takes the value h_n depends only on the the immediately preceeding outcome h_{n-1}, i.e.,

$$\begin{aligned} Prob(H_n &= h_n | H_1 = h_1, ..., H_{n-1} = h_{n-1}) \\ &= Prob(H_n = h_n | H_{n-1} = h_{n-1}) \end{aligned} \tag{5.15}$$

As described previously, for the problem of budgetary uncertainty examined in this proposed SDP model, it is assummed that the level of funding in a particular stage is affected by the level of funding in previous stage. [Recall that a state variable reflecting the actual level of funding received in the previous time interval was added to the SDP.] This variable is the one to which the Lag-one Markov process theory is applied, i.e., the probability of receiving a particular level of funding in one scheduling horizon is dependent on the level of funding actually received in the previous scheduling horizon.

5.7.1 Theoretical Background to Determination of The Transformation Probabilities

As mentioned earlier, the type of uncertainty associated with the transformation probabilities of the proposed SDP for a public investment planning model differs from the traditional uncertainty in engineering problems in which "the objective probabilities" may be derived based on past observations. For example, for an event which has taken place in the past, and for which past outcomes can be used to predict the likelihood of future outcomes, e.g., rainfall or streamflows, a probability distribution based on past observations may be reasonably derived by assuming the cyclic nature of the processes. On the other hand, for the case of budgetary uncertainty, the causal factors of uncertain future budget availability for investment are the often specify inter-related socio-economic and political factors that exist in such systems. As noted previously, in this type of system repeated observations are not possible, due to the unique, irreproducible nature this system (Fiksel, 1982) and therefore it may not be possible to generate "the objective probabilities". Although pertinent information such as a 'basic rate' may able to be extracted from historical data of the past actual funding/investment allocations, there is no cyclic condition in the investment planning model.

Since "objective probabilities" in the sense of relative frequency of the past observations cannot be used to estimate the likelihood of future outcomes, another term for interpretation of probability theory, i.e., "subjective probability", will be employed in determining transformation probabilities $p_k(F_t^l)$ in the proposed SDP model. According to Taylor (1984), subjective probability pertains to events which can be thought of in probabilistic terms, but not in terms of relative frequency. Taylor (1984) also notes that subjective probabilities permit personal feelings and judgments to be quantified as degrees of belief. Subjective probabilities can therefore be based on all information available to the DM or the planner in terms of subjective inputs including experience, judgment, and intuition. Subjective probabilities, then, are applicable to events which have not been, or may not be, tested by the performance of a large number of trials or observations (Taylor, 1984).

As noted by Taylor (1984), general probability assessment deals with two activities: i) judging the *likelihood* of events, which is based on how humans predict the probability of an event occurring and, ii) judging the *causes* of events, which is concerned with how people specify the reasons for occurence of events, i.e., attribute causes for events.

Two broad classifications of the measurement of subjective probabilities are also noted by Taylor (1984), namely: 1) **Direct assessment**; in which the strength of a decision maker's belief concerning various events may be determined by direct questioning. For example, the assessor can be asked to give probabilities for a series of events in numbers ranging from 0 to 1, and 2) **Indirect assessment**; involves inferring the DM's degree of belief from behaviour in choosing between two or more alternatives. For examples, degrees of belief are inferred from behaviour in making choices among betting odds, lotteries, insurance premiums, etc., rather than directly asking a DM for an assessment.

5.7.2 Development of the Transformation Probabilities

The structure of the transformation probabilities matrix on each state combination of current level of development and level of previous funding called **the tranformation probability submatrix** will contain $N_{D_{t,i,m}}$ rows and $N_{F_{t,i,m}}$ columns for all i and m, where $N_{D_{t,i,m}}$ is the number of levels of possible funding decision planned for each state combination $L_t^{i,m}$ $\forall$ i, m at stage t, and $N_{F_{t,i,m}}$ is the number of levels of actual funding received during scheduling horizon t when the current level of development is at the state combination $L_t^{i,m}$ $\forall$ i, m. The total numbers of such sub-matrices in each sceduling horizon (stage) t will be J_t x $N_{PF_{t,i}}$, with J_t being the number of discretized states specified in hectares of irrigated area developed at the beginning of scheduling horizon t, and $N_{PF_{t,i}}$ the number of levels of actual funding received during the previous stage $t-1$ when the current level of development is in the state L_t^i $\forall$ t, i. Each element of this sub-matrix represents the probability of the l^{th} level of the actual funding occurring given the k^{th} level of possible funding decision. An example of a transformation probability matrix for $t = 2$, i, $N_{D_{t,i,m}}$, $N_{F_{t,i,m}}$ and $N_{PF_{t,i}}$ is shown in Table 5.1. The complete set of probabilities for all scenarios of future budget availability (described in the next Sub-section) is given in Tables A.15, A.16, and A.17 in Appendix.

Subjective Model for Generating Transformation Probabilities

To handle the specific characteristics of the problems of budgetary uncertainty investigated in this thesis, a subjective model which combines information extracted from historical data as a basic rate , a functional relationship between inter-related parameters, and a set of the definition of scenarios of future budget availability for investment is proposed to estimate the likelihood or probability of the occurence of each level of actual funding received.

For the problem to which the model developed in this thesis is applied for demonstration purposes (see Chapter 7) namely water resources planning in Indonesia, the pertinent information regarding the actual funding allocation for water resources development in Indonesia during the last 17 years is used as the base rate or framework in developing subjective probabilities of funding levels in the future (see Tables 7.1 and 7.3). This information provides characteristics of the past government funding allocation priorities and policies. These data also describe the past likelihood of actual funding relative to the levels previously anticipated. Although future events are unlikely to correspond to these historical conditions, the information extracted from these past observations can be used to estimate general characteristics that may be useful in projecting future government investment allocation. Such characteristics may be in the form of a functional relationship among the inter-related parameters within the SDP model, e.g., t, L_t, D_t, PF_t, and F_t , that govern the distribution of the transformation probabilities. In addition to this relationship, some additional subjective inputs reflecting the DM's or the planner's assessment of the likelihood of future government

Table 5.1: Example of The Functional Relationship for Transformation Probabilities

$p_k(F^l_t) = \mathcal{F}(t, L^i_t, PF^m_t, D^k_t) \Rightarrow p(F^l_{t,i,m,k}) = \mathcal{F}(t, L^i_t, PF^m_t, D^k_t)$

For: $t = 2$; $i = 1,2$; $m = 1,..,N_{PF_{2,i}}$ for $N_{PF_{2,i}} = 5$; $k = 1,...,N_{D_{2,i,m}}$ for $N_{D_{2,i,m}} = 5$; and $l = 1,..,N_{F_{2,i,m}}$ for $N_{F_{2,i,m}} = 5$

$L^{i,m}_2$ $(i=1)$						$L^{i,m}_2$ $(i=2)$					
	$l = 1, ..., N_{F_{1,i,m}}=5$						$l = 1, ..., N_{F_{2,i,m}}=5$				
$p(F^l_{t,i,m,k})$	$l=1$	$l=2$	$l=3$	$l=4$	$l=5$	$p(F^l_{t,i,m,k})$	$l=1$	$l=2$	$l=3$	$l=4$	$l=5$
$p(F^l_{2,1,1,1})=$	0.01	0.01	0.15	0.33	0.50	$p(F^l_{2,2,1,1})=$	0.01	0.01	0.15	0.34	0.49
$p(F^l_{2,1,1,2})=$	0.01	0.01	0.15	0.34	0.49	$p(F^l_{2,2,1,2})=$	0.01	0.01	0.15	0.35	0.48
$p(F^l_{2,1,1,3})=$	0.01	0.01	0.15	0.35	0.48	$p(F^l_{2,2,1,3})=$	0.01	0.01	0.15	0.36	0.47
$p(F^l_{2,1,1,4})=$	0.01	0.01	0.15	0.36	0.47	$p(F^l_{2,2,1,4})=$	0.01	0.01	0.15	0.37	0.46
$p(F^l_{2,1,1,5})=$	0.01	0.01	0.15	0.37	0.46	$p(F^l_{2,2,1,5})=$	0.01	0.01	0.15	0.38	0.45
$p(F^l_{2,1,2,1})=$	0.01	0.01	0.15	0.34	0.49	$p(F^l_{2,2,2,1})=$	0.01	0.01	0.15	0.35	0.48
$p(F^l_{2,1,2,2})=$	0.01	0.01	0.15	0.35	0.48	$p(F^l_{2,2,2,2})=$	0.01	0.01	0.15	0.36	0.47
$p(F^l_{2,1,2,3})=$	0.01	0.01	0.15	0.36	0.47	$p(F^l_{2,2,2,3})=$	0.01	0.01	0.15	0.37	0.46
$p(F^l_{2,1,2,4})=$	0.01	0.01	0.15	0.37	0.46	$p(F^l_{2,2,2,4})=$	0.01	0.01	0.15	0.38	0.45
$p(F^l_{2,1,2,5})=$	0.01	0.01	0.15	0.38	0.45	$p(F^l_{2,2,2,5})=$	0.01	0.01	0.15	0.39	0.44
$p(F^l_{2,1,3,1})=$	0.01	0.01	0.15	0.35	0.48	$p(F^l_{2,2,3,1})=$	0.01	0.01	0.15	0.36	0.47
$p(F^l_{2,1,3,2})=$	0.01	0.01	0.15	0.36	0.47	$p(F^l_{2,2,3,2})=$	0.01	0.01	0.15	0.37	0.46
$p(F^l_{2,1,3,3})=$	0.01	0.01	0.15	0.37	0.46	$p(F^l_{2,2,3,3})=$	0.01	0.01	0.15	0.38	0.45
$p(F^l_{2,1,3,4})=$	0.01	0.01	0.15	0.38	0.45	$p(F^l_{2,2,3,4})=$	0.01	0.01	0.15	0.39	0.44
$p(F^l_{2,1,3,5})=$	0.01	0.01	0.15	0.39	0.44	$p(F^l_{2,2,3,5})=$	0.01	0.01	0.15	0.40	0.43
$p(F^l_{2,1,4,1})=$	0.01	0.01	0.15	0.36	0.47	$p(F^l_{2,2,4,1})=$	0.01	0.01	0.15	0.37	0.46
$p(F^l_{2,1,4,2})=$	0.01	0.01	0.15	0.37	0.46	$p(F^l_{2,2,4,2})=$	0.01	0.01	0.15	0.38	0.45
$p(F^l_{2,1,4,3})=$	0.01	0.01	0.15	0.38	0.45	$p(F^l_{2,2,4,3})=$	0.01	0.01	0.15	0.39	0.44
$p(F^l_{2,1,4,4})=$	0.01	0.01	0.15	0.39	0.44	$p(F^l_{2,2,4,4})=$	0.01	0.01	0.15	0.40	0.43
$p(F^l_{2,1,4,5})=$	0.01	0.01	0.15	0.40	0.43	$p(F^l_{2,2,4,5})=$	0.01	0.01	0.15	0.41	0.42
$p(F^l_{2,1,5,1})=$	0.01	0.01	0.15	0.37	0.46	$p(F^l_{2,2,5,1})=$	0.01	0.01	0.15	0.38	0.45
$p(F^l_{2,1,5,2})=$	0.01	0.01	0.15	0.38	0.45	$p(F^l_{2,2,5,2})=$	0.01	0.01	0.15	0.39	0.44
$p(F^l_{2,1,5,3})=$	0.01	0.01	0.15	0.39	0.44	$p(F^l_{2,2,5,3})=$	0.01	0.01	0.15	0.40	0.43
$p(F^l_{2,1,5,4})=$	0.01	0.01	0.15	0.40	0.43	$p(F^l_{2,2,5,4})=$	0.01	0.01	0.15	0.41	0.42
$p(F^l_{2,1,5,5})=$	0.01	0.01	0.15	0.41	0.42	$p(F^l_{2,2,4,5})=$	0.01	0.01	0.15	0.42	0.41

Note: Index l's are in the order of decreasing level of actual funding, $l = 1 > l = 2$, $l = 2 > l = 3$, etc.

budget allocation is needed.

Two approaches are adopted to elicit such subjective inputs from an assessor or a group of assessors. The first approach is Direct Assessment (Taylor, 1984). In this case the approach is called "Subjective Model with Direct Assessment". The second approach is the Analytic Hierarchy Process (AHP) (Saaty, 1977, 1982, and 1991). Consistent with the terminology used for the first approach the second approach is called 'Subjective Model with AHP'.

The detailed descriptions of the components of this subjective model, i.e., the functional relationship between inter-related components and the definition of future budget availability, are given in the following subsections.

5.7.3 Functional Relationship Between Inter-related Parameters

The transformation from the state combination (existing level of development and level of funding provided in the previous scheduling horizon) in one scheduling horizon (stage) to a new state combination in the next scheduling horizon (stage) is related to the prior estimates of actual funding levels which may be anticipated, through the associated probabilities, and the likelihood of these funding levels relative to the levels of possible funding decision. These transformation probabilities are defined as a function of the scheduling horizon or stage t, the state or the level of development L_t, the level of previous funding PF_t, the level of the possible decision D_t, and the level of actual funding F_t, received as expressed in a functional form by

$$p_k(F_t^l)^\gamma = \mathcal{F}(t, L_t^i, PF_t^m, D_t^k)^\gamma \tag{5.16}$$

where γ denotes the budget scenario for which the probabilities are defined. Taking into account the functional relationships described above, the general form of the transformation probabilities can be re-written as:

$$p_k\left(F_{(t,L_t^i,PF_t^m,D_t^k)}\right)^\gamma = p(F_{t,i,m,k}^l)^\gamma \tag{5.17}$$

Examples of the characteristics of this functional relationship were extracted from the information and experience of the investment study of irrigation projects in Indonesia during the last twenty years (BCEOM, 1989)]. Such characteristics can be delineated as:

- The higher the actual existing level of development, (L_t^i) the lower the probability of obtaining a higher level of possible funding. Conversely, the lower the level of L_t^i, the greater the probability of obtaining higher levels of possible funding. This observation matches the situation in Indonesia where, if the level of development is at a lower level, the demand for rice will force decision makers to allocate more funds to water resource projects associated with increasing rice production.

- The lower the level of previous funding m, the greater the probability of obtaining higher levels of current funding. This estimate also conforms to the Indonesian situation in that lower levels of previous funding generally correspond to lower levels of development and therefore require the same policy adjustment discussed for lower levels of development above.

- The lower the level of possible funding decision k, i.e., the smaller the level to anticipated or planned budget, the greater the probability of getting the lower levels of possible funding. Therefore, the chance (probability) of getting lower levels of allocation with a lower budget level decision will always remain greater than the probability of getting the higher levels of funding.

An example of a set of transformation probabilities fulfilling these procedures for a given value of t, i, $N_{D_{t,i,m}}$, $N_{F_{t,i,m}}$, and $N_{PF_{t,i}}$ is presented in Table 5.1. Other types of this functional relationship for various scenarios of future budget availability are discussed in the next section.

5.7.4 Definition of Scenario of Future Budget Availability

A preliminary application of the basic SDP (Sutardi et al., 1991b) indicated that the results of the model depend critically, and not unexpectedly, on the subjective probabilities and therefore on how these subjective probabilities are generated. The issues behind this assessment of subjective probabilities can be demonstrated by the experience in water resources budgeting in Indonesia which suggests that three distinct situations of budget allocation can be identified and categorized as follows:

- The decision maker (DM) or the planner knows that there is a higher chance of obtaining a higher level of development funds over the planning horizon relative to what previously have been received.
- The DM or the planner knows that the likelihood of future development funds allocation will be at a lower level relative to the level actually required.
- The DM or the planner does not know exactly the likelihood of the level of future development funds allocation. However, he or she knows that it is unlikely that the future allocation development funds will be at either of the two extreme levels, i.e., the highest and the lowest levels.

The above observations provide a basis for constructing a definition of 'scenario of future budget availability' which underlies the proposed scenario-based prediction approach by requiring examination of events that might influence the future and parametrizing the principal components of the system (Saaty and Vargas, 1991).

The general approach for prediction of the future government funding allocation must be based on the characteristics of past government funding priorities and policies and incorporate the DM's or the planner's assessment of the likelihood of future government budget allocations. Such approach may in the form of "if-then" scenarios that reflect future government budget availability situations. This approach implies that *if* budget availability situation is such, *then* the probability assignments will be a specified set of values.

The possibilities of future budget availability for investment, have to be reflected in the generation of probability assessment of the transformation probabilities. The following scenario-based probability assignments are proposed to handle the budgetary fluctuations expected to occur in these scenarios. The three scenarios described below represent the most commonly encountered future budget availability estimation.

Scenario I. Limited Budget

When the current level of development is at a higher level, higher probabilities are assigned to the lower levels of actual funding. When the current level of development is at medium levels, higher probabilities are assigned to the lower to medium levels of actual funding. When the current level of development is at the lower levels, higher probabilities are assigned to

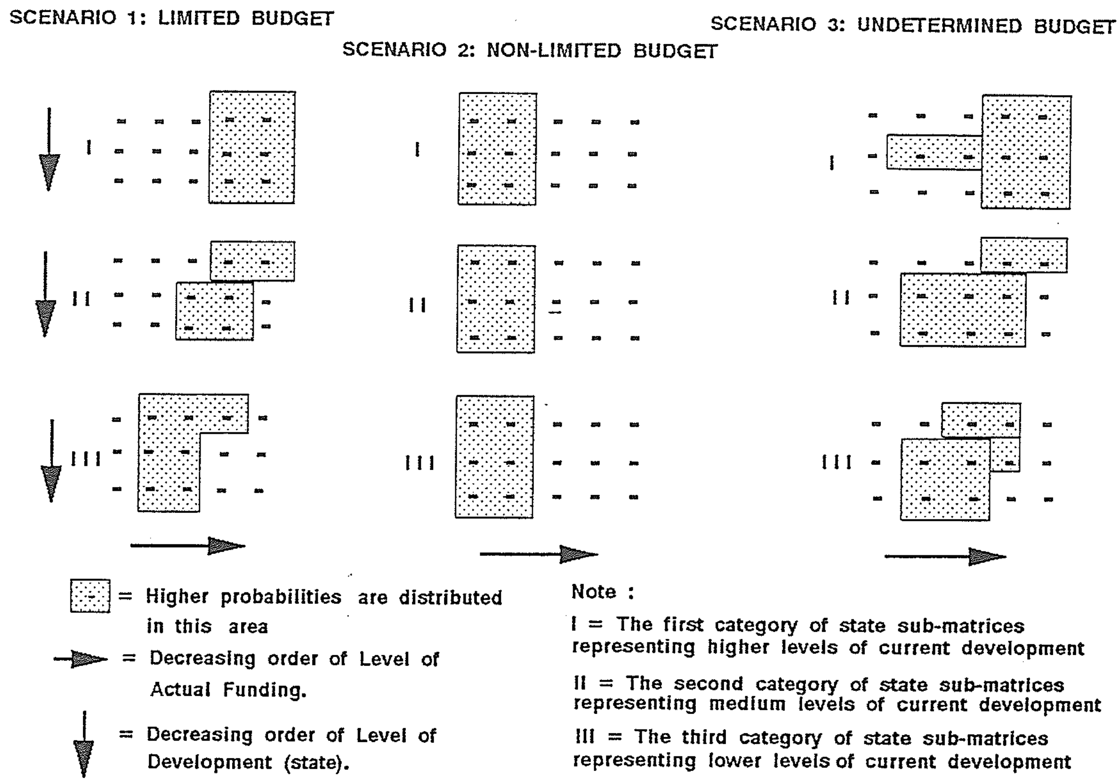


Figure 5.4: Schematic of Subjective Probabilities Assignments According to a Three Scenarios Future Budget Availability

the higher levels of funding. This type of probability assignment, which is shown in Figure 5.4 Scenario 1, reflects the situation where: i) the likelihood of obtaining a high level of development funds is low, and ii) when the existing level of development is already at a high level, so that the chance of getting a higher level of funding is low. On the other hand, the lower existing levels of development suggest a greater possibility of obtaining higher levels of funding in a future time period.

Scenario II. Non-Limited Budget

In this case regardless of the current level of development, higher probabilities are assigned to the higher levels of actual funding. This type of assignment, which is shown in Figure 5.4 Scenario 2, reflects the situation where the possibility of obtaining a higher level of development funds is uniformly high and the funding decided upon or anticipated is the most likely outcome. In other words, whatever decision taken, the most likely available funding is the level anticipated or planned for.

Scenario III. Undetermined Budget

When the current levels of development are high, higher probabilities are assigned to the medium and the lower levels of actual funding. As the levels of development decrease, i.e., when levels of development are at medium and lower levels, higher probabilities are assigned evenly to the medium levels of actual funding. This type of assignment, which is shown in Figure 5.4 Scenario 3, reflects the situation that the likelihood of the available funds is somewhere in between the two extreme conditions, i.e., between the highest and the lowest level.

It is not known which of the three scenarios will prevail, and thereby govern the future budget availability for investment. To address this question, a suitable collective opinion technique , e.g., the Analytic Hierarchy Process (AHP) (Saaty and Vargas, 1991) must be applied to combine the range of external factors governing the future budget availability with subjective inputs such as the priorities of these factors as determined from a DM or a group of DM. These priorities would be specified in terms of a numerical rating representing the likelihood of each scenario. The application of the AHP method for the possibility rating of such scenarios is given in Subsection 5.7.6.

5.7.5 Combined Subjective Model and Direct Assessment

This model consists of: 1) a functional relationship between the inter-related parameters of the scheduling horizon (stage) t, the level of development L_t, the level of previous funding PF_t, the level of possible funding decisions D_t, and the level of actual funding F_t, to describe the likelihood or probability of the occurrence of each level of actual funding received; 2) a set of scenarios of future budget availability for investment, expressed for demonstration purposes in this case, by Limited, Non-limited, and Undetermined Budgets; and 3) historical data providing pertinent information which is used as a basic rate in developing the transformation probabilities (see Tables 7.3).

The Direct Assessment method is applied to elicit subjective inputs from the assessor by asking the assessor a numerical probability assessment ranging from 0 to 1 reflecting the likelihood of each level of actual funding. The main advantage of this approach is that it is able to address a large number of combinations of level of development L_t^k and level of previous funding PF_t^m, since there is no limitation of the use of scale in the numerical assessment. (The problem of scale is discussed in more detail in relation to the Analytical Hierarchy Process.) However, this approach is not free of problems, i.e., it is difficult to preserve logical consistency in the judgments.

Examples of the transformation probabilities developed based on this combined subjective model and Direct Assessment for the three cases of scenario of future budget availability for given values of t, i, $N_{D_{t,i,m}}$, $N_{F_{t,i,m}}$, and $N_{PF_{t,i}}$ are shown in Table 5.2.

5.7.6 Subjective Model with the Analytic Hierarchy Process (AHP)

The same subjective model used in the previous section, i.e., the combination of a functional relationship between inter-related parameters, a set of scenarios of future budget availability for investment, and historical data as a basic rate (Table 7.3) is still employed in this approach. However in this case, the Direct Assessment component is replaced by the Analytic Hierarchy Process (AHP) which elicits qualitative pairwise comparison judgments between each level of the actual funding. These qualitative judgments are then transformed into numerical scales using the pairwise comparison scale recommended by Saaty (1977) as shown in Table 5.3. The main advantage of this approach is that it provides a means of checking the consistency of judgments. A minor difficulty with this approach is the restriction of having to use the 9 scales of comparison of Saaty. This range of scale may not be sufficient to cover a large number of combinations of L_t^i and PF_t^m. A slight modification in interpreting and enlarging (by interpolation) of the scale may therefore be required.

The AHP method is used in this model to elicit a pairwise qualitative judgment for each level of actual funding decision from an individual assessor or a group of assessors. The eigenvalue method is then applied to transform these qualitative judgments into numerical probability ratings of the likelihood of each level of actual funding outcome.

Table 5.2: Comparison of Transformation Probabilities Generated by the Direct Assessment and the AHP Method for the Three Scenarios of Future Budget Availability

$(p_k(F_t^l))^\gamma = \mathcal{F}(t, L_t^i, PF_t^m, D_t^k) \Rightarrow p(F^l_{t,i,m,k})^\gamma = \mathcal{F}(t, L_t^i, PF_t^m, D_t^k)$

For: $t = 2$; $i = 1$; $m = 1, .., N_{PF_{2,i}}$ for $N_{PF_{2,i}} = 1$; $k = 1, ..., N_{D_{2,i,m}}$ for $N_{D_{2,i,m}} = 5$; and $l = 1, ..., N_{F_{2,i,m}}$ for $N_{F_{2,i,m}} = 5$

Direct Assessment						Analytic Hierarchy Process (AHP)					
γ=Limited Budget Scenario						γ=Limited Budget Scenario					
	$l = 1, ..., N_{F_{2,i,m}} = 5$						$l = 1, ..., N_{F_{2,i,m}} = 5$				
$p(F^l_{t,i,m,k})$	$l=1$	$l=2$	$l=3$	$l=4$	$l=5$	$p(F^l_{t,i,m,k})$	$l=1$	$l=2$	$l=3$	$l=4$	$l=5$
$p(F^l_{2,1,1,1})=$	0.010	0.010	0.150	0.330	0.500	$p(F^l_{2,1,1,1})=$	0.003	0,013	0.128	0.298	0.558
$p(F^l_{2,1,1,2})=$	0.010	0.010	0.150	0.340	0.490	$p(F^l_{2,1,1,2})=$	0.003	0.014	0.132	0.307	0.544
$p(F^l_{2,1,1,3})=$	0.010	0.010	0.150	0.350	0.480	$p(F^l_{2,1,1,3})=$	0.003	0.014	0.139	0.327	0.517
$p(F^l_{2,1,1,4})=$	0.010	0.010	0.150	0.360	0.470	$p(F^l_{2,1,1,4})=$	0.002	0.014	0.141	0.327	0.516
$p(F^l_{2,1,1,5})=$	0.010	0.010	0.150	0.350	0.480	$p(F^l_{2,1,1,5})=$	0.002	0.015	0.145	0.337	0.501
γ=Non-limited Budget Scenario						γ= Non-limited Budget Scenario					
	$l = 1, ..., N_{F_{2,i,m}} = 5$						$l = 1, ..., N_{F_{2,i,m}} = 5$				
$p(F^l_{t,i,m,k})$	$l=1$	$l=2$	$l=3$	$l=4$	$l=5$	$p(F^l_{t,i,m,k})$	$l=1$	$l=2$	$l=3$	$l=4$	$l=5$
$p(F^l_{2,1,1,1})=$	0.450	0.250	0.150	0.100	0.050	$p(F^l_{2,1,1,1})=$	0.489	0.244	0.122	0.082	0.063
$p(F^l_{2,1,1,2})=$	0.460	0.240	0.150	0.100	0.050	$p(F^l_{2,1,1,2})=$	0.493	0.246	0.117	0.082	0.062
$p(F^l_{2,1,1,3})=$	0.470	0.230	0.150	0.100	0.050	$p(F^l_{2,1,1,3})=$	0.499	0.249	0.113	0.078	0.061
$p(F^l_{2,1,1,4})=$	0.480	0.220	0.150	0.100	0.050	$p(F^l_{2,1,1,4})=$	0.500	0.260	0.109	0.073	0.058
$p(F^l_{2,1,1,5})=$	0.490	0.210	0.150	0.100	0.050	$p(F^l_{2,1,1,5})=$	0.512	0.256	0.102	0.073	0.057
γ=Undetermined Budget Scenario						γ= Undetermined Budget Scenario					
	$l = 1, ..., N_{F_{2,i,m}} = 5$						$l = 1, ..., N_{F_{2,i,m}} = 5$				
$p(F^l_{t,i,m,k})$	$l=1$	$l=2$	$l=3$	$l=4$	$l=5$	$p(F^l_{t,i,m,k})$	$l=1$	$l=2$	$l=3$	$l=4$	$l=5$
$p(F^l_{2,1,1,1})=$	0.010	0.010	0.150	0.330	0.500	$p(F^l_{2,1,1,1})=$	0.002	0.083	0.361	0.361	0.193
$p(F^l_{2,1,1,2})=$	0.010	0.200	0.250	0.200	0.340	$p(F^l_{2,1,1,2})=$	0.002	0.092	0.363	0.363	0.180
$p(F^l_{2,1,1,3})=$	0.010	0.200	0.250	0.200	0.340	$p(F^l_{2,1,1,3})=$	0.002	0.102	0.364	0.364	0.168
$p(F^l_{2,1,1,4})=$	0.010	0.200	0.250	0.200	0.340	$p(F^l_{2,1,1,4})=$	0.002	0.111	0.365	0.365	0.157
$p(F^l_{2,1,1,5})=$	0.010	0.010	0.150	0.370	0.460	$p(F^l_{2,1,1,5})=$	0.002	0.122	0.366	0.366	0.144

Note:Index $l's$ are in the order of decreasing level of actual funding, $l = 1 > l = 2$; $l = 2 > l = 3$, etc.

Table 5.3: The Pairwise Comparison Scale for Generating Transformation Probabilities

Value	Definition*	Explanation
1	Equally likely	Two elements equally importance
3	Moderate likelihood of one over the other	Experience and judgment slightly favour one over another
5	Strong likelihood of one over the other	Experience and judgment strongly favour one over another
7	Very strong likelihood of one over the other	An element is very strongly favour one over another
9	Extreme likelihood of one over the other	The evident extremly favour one over another
2, 4, 6, 8	Intermediate values between adjacent judgments	Compromise is needed between two judgments

*) The terminology modified to have meaning in terms of probabilities.

The important features of the AHP method with respect to its ability to generate probabilities from subjective assesment can be described as follows (Zahedi, 1986; Saaty and Vargas, 1991):

1. It can accomodate qualitative preference judgments, rather than numerical values, for pairwise comparison of the likelihoods of actual funding allocation levels.

2. It is a formal mechanism for pairwise comparison, and has the advantage that it is easier to form pairwise judgments between two particular objects than to construct an entire ordering among all the objects simultaneously.

3. It provides a means of identifying any inconsistencies and intransitivities associated with the subjective assessments elicited from the DM.

4. It is a collective opinion technique for eliciting both individual and group judgments. In the latter case, when there is disaggreement the *geometric mean* approach is preferred to combine group judgments (Saaty and Vargas, 1991).

Following a brief review of an eigenvalue method as proposed by Saaty (1977) and Yager (1979), two applications of the procedure for generation of subjective assessments for transformation probabilities matrices and for estimation of the likelihood or the possibility rating for future budget availability being addressed in this thesis are examined.

Theory

In certain types of stochastic decision making, one task faced by the modeller is the extraction from a decision maker of his or her subjective evaluations for a set of discrete, finite, mutually exclusive, and exhaustive events. Consider a decision problem in which a set of such events, $A_1, A_2, \ldots, A_s$ are examined and it is desired to obtain the set of probabilities $P_1, P_2, \ldots, P_s$ associated with each event such that $\sum_{g=1}^{s} P_g = 1$. Furthermore, assume that the decision maker's subjective consideration is used in determining the values of the probabilities P_g.

Once these probabilities have been obtained a matrix W consisting of the ratio of these probabilities, can be formulated, i.e.,:

$$W = \begin{bmatrix} P_1/P_1 & P_1/P_2 & P_1/P_3 \ldots P_1/P_s \\ P_2/P_1 & P_2/P_2 & P_2/P_3 \ldots P_2/P_s \\ \vdots & \vdots & \vdots \\ P_s/P_1 & P_s/P_2 & P_s/P_3 \ldots P_s/P_s \end{bmatrix} \tag{5.18}$$

It should be noted that W has the following properties:

$$W_{go} = P_g/P_o, \tag{5.19}$$

$$W_{gg} = 1, \tag{5.20}$$

$$W_{go} = 1/W_{go} = P_o/P_g. \tag{5.21}$$

The above properties are called the consistency of W. Now consider the product of W and the vector $\hat{X}$ consisting of the probabilities:

$$\hat{X} = \begin{bmatrix} P_1 \\ P_2 \\ . \\ P_s \end{bmatrix} \tag{5.22}$$

$$\begin{bmatrix} P_1/P_1 & P_1/P_2 & \dots & P_1/P_s \\ . & . & \dots & . \\ . & . & \dots & . \\ . & . & \dots & . \\ . & . & \dots & . \\ P_s/P_1 & P_s/P_2 & \dots & P_s/P_s \end{bmatrix} \begin{bmatrix} P_1 \\ P_2 \\ . \\ . \\ . \\ P_s \end{bmatrix} = \begin{bmatrix} sP_1 \\ sP_2 \\ sP_3 \\ . \\ . \\ sP_s \end{bmatrix} = s \begin{bmatrix} P_1 \\ P_2 \\ . \\ . \\ . \\ P_s \end{bmatrix} = s\hat{X} \tag{5.23}$$

s is therefore an eigenvalue of W (λ), that is, s satisfies the equation:

$$W\,\hat{X} = s\,\hat{X} \tag{5.24}$$

or

$$\hat{X}\,(W - \lambda\, I) = 0 \tag{5.25}$$

and $\hat{X}$ is an eigenvector associated with that eigenvalue. Saaty (1977) has shown that W has $s-1$ eigenvalues which are zero and the remaining eigenvalue, λ_{max} is s.

The real problem is, however, that the $P_g's$ are unknown and must somehow be extracted from the DM. The problem of extraction of subjective probabilities is one fraught with many dangers (Brown et al., 1974 and Taylor, 1984) some of which were discussed in the previous subsection. Although the DM may try to process all his/her subjective feelings onto a hard scale the process is usually quite difficult, particularly when s gets large. However, as Saaty (1977) and Yager (1979) have argued, it is easier for the DM to compare events two at a time and thereby avoid "Bellman's curse of dimensionality" (Yager, 1979). Saaty (1977) similarly states, that it is psychologically easier for most individuals to form pairwise judgments between two particular objects than to construct an entire ordering among the s objects.

Method

The DM is first asked to give his or her subjective evaluation of whether event A_g or A_o is more likely to occur, i.e., which has a higher probability of occurence. The DM is then asked to express the ratio of the probability of the more likely event over the probability of the less likely. Assuming A_g is preferred to A_o the probability is called the likelihood of A_g over A_o. Saaty (1977) proposed a scoring frame with which to evaluate this question and suggests an integer scale of 1-9, in which the values can be interpreted as shown in Table 5.3.

A matrix B of dimension s x s, can now be constructed in the following manner. The DM compares A_g and A_o along the scale shown in Table 5.3, and selects a value depending upon the degree of preference. Without loss of generality, it is assumed that A_g is preferred to A_o. The number generated is then assigned to b_{go} representing the extent of the preference for A_g relative to A_o, while b_{og} becomes $1/b_{go}$. The procedure is continued in this manner for all pairs. Note that $b_{gg} = 1$. The matrix B composed of the elements b_{go} reflects the DM's subjective evaluation of the probabilities of the various events and is in such a form as to be the DM's approximation of the theoretical matrix W. Since B is an approximation of W, the desired final probabilities can be obtained by finding the largest eigenvalue of B, namely λ_{max} and then finding the unit eigenvector $\hat{X} = (\hat{X}_1, \hat{X}_2, \ldots, \hat{X}_s)$ associated with λ_{max}. The unit eigenvector is that whose sum of elements is one. The $\hat{X}_1, \hat{X}_2, \ldots, \hat{X}_s$ are then the realization of the DM's subjective probabilities as represented by matrix B.

Consistency of the Probabilities

It should be noted that the crucial feature which leads to the good results obtained from this method is the special structure of W. This special structure is $w_{go}/w_{oq} = w_{gq}$ and is due to the fact that $w_{go} = P_g/P_o, w_{oq} = P_o/P_q$, and therefore $(P_g/P_o)P_o/P_q = P_g/P_q = w_{gq}$. This property is called the consistency property of W.

In constructing the empirical matrix, B, in the manner described, the consistency is not ensured. Matrices constructed by pair-wise comparisons are seldom if ever perfectly consistent (Yager, 1979). Furthermore in many instances they are intransitive. Saaty (1977) has shown that the value of λ_{max} is a good measure of consistency of B. If the DM was perfectly consistent then $\lambda_{max} = s$. The more λ_{max} diverges from s the greater the inconsistency occuring in the construction of B. It has been suggested that a Consistency Index (CI), where $CI = (\lambda - s)/(s - 1)$, be used as a measure of deviation from consistency. The term Consistency Ratio (CR), where $CR = CI/CI^*$ can then be used to measure the divergence of the calculated CI relative to an upper limit (CI^*) of CI. This upper limit CI^* is generated by assuming that all the entries of the matrices used in calculation are randomly generated, i.e., they show the worst consistency scenario for particular matrix size. The closer CR (which takes a value between 0 and 1) is to zero, the greater the degree of consistency of the matrix B. Saaty (1977) indicates that CR should be around 10 percent or less, to be acceptable. Therefore, if the largest eigenvalue of B is close to s, it is reasonable to believe that the matrix forms a fairly reasonable basis for contructing the weights. If λ_{max} diverges significantly from s or B has some obvious inconsistency and intransitivities, the DM can be presented with this information and asked to re-consider his or her preference selections to try to form a more consistent matrix.

Procedure for Generation of the Transformation Probabilities Using the AHP Method

In this model, for given (fixed) values of t, i, $N_{D_{t,i,m}}$, $N_{F_{t,i,m}}$ and $N_{PF_{t,i,m}}$ the DMs/assessors have to decide upon the likelihood of various levels of actual funding F_t^l given a specified budget scenario and a range of possible funding decisions D_t^k to select from for all $l = 1, ..., N_{F_{t,i,m}}$ and $k = 1, ..., N_{D_{t,i,m}}$. To accomplish such assessment, the DMs/assessors have the option of expressing preferences between the two as equally likely, moderate likely, strong likely, and absolute likely to occur, which would be translated into pairwise weights of 1, 3, 4, 5, 7 and 9, respectively, with 2, 4, 6, and 8 as intermediate values (see the Saaty scale in Table 5.3).

The actual generation of the transformation probability sub-matrix $p(F_{t,i,m,k}^l)^\gamma$ with $N_{D_{t,i,m}}$ rows and $N_{F_{t,i,m}}$ columns starts with making qualitative pairwise comparisons of each level l of F_t^l for a given level k of D_t^k for $l = 1, ..., N_{F_{t,i,m}}$ and $k = 1, ..., N_{D_{t,i,m}}$using Saaty's scale. As described previously, three factors govern the assessments of such pairwise comparisons, namely the scenarios of future budget availability (see Figure 5.4), the historical data, and the relationship among inter-related parameters t, L_t^i, PF_t^m, D_t^k in the SDP. Having obtained the composite weight for each level of l using the eigenvalue method described above (Equation (5.25)), the next step is calculate the consistency ratio CR for such an assessment. Once the CR falls within an acceptable limit the composite weights become the entries for the k^{th} row of the transformation probability sub-matrix $p(F_{t,i,m,k}^l)^\gamma$. This procedure is repeated for all different values of t, i, m, k.

Consider the following example to demonstrate use of the procedure. For a fixed t, i, m, with $N_{F_{t,i,m}} = 3 = N_{D_{t,i,m}}$, and for γ= "Undetermined Budget" scenario (i.e., the actual budget will lie somewhere in between the maximum and minimum level), let the qualitative assessments for the D_t^1 be:

Actual funding level 2: F_t^2 is moderately more likely to occur than F_t^1.

Actual funding level 3: F_t^3 is slightly more likely to occur than F_t^1.

Actual funding level 2: F_t^2 is moderately more likely to occur than F_t^3.

The rest of assessments are reciprocals, e.g., F_t^1 over F_t^2 is reciprocal of F_t^2 over F_t^1.

After translating these pairwise qualitative assessments into numerical numbers, the matrix B of the pairwise comparison would be

$$B = \begin{array}{c} \\ F_t^1 \\ F_t^2 \\ F_t^3 \end{array} \begin{array}{c} \begin{array}{ccc} F_t^1 & F_t^2 & F_t^3 \end{array} \\ \begin{bmatrix} 1 & 1/3 & 1/2 \\ 3 & 1 & 3 \\ 2 & 1/3 & 1 \end{bmatrix} \end{array}$$

Applying the procedures for evaluating the maximum eigenvalue (Equation (5.25)) and the associated unit eigenvectors, results in

$$\lambda_{max} = 3.05; \quad W = \begin{bmatrix} 0.16 \\ 0.59 \\ 0.25 \end{bmatrix}$$

Therefore,

$$P(F_{t,i,m,1}^1) = 0.16 \quad P(F_{t,i,m,1}^2) = 0.59 \quad P(F_{t,i,m,1}^3) = 0.25$$

would be an assessment of the subjective probabilities of the "Undetermined Budget" scenario for $N_{F_{t,i,m}} = 3$. The corresponding Consistency Index $(CI) = 0.025$ and while the Consistency Ratio CR $(CR = CI/CI^*)$ where CI^* is the consistency index for a completely random process (For $N_{F_{t,i,m}} = 3$, $CI^* = 0.58$) is 0.034 which is less than 0.10 indicating good consistency (Saaty, 1977, 1982).

Examples of transformation probabilities generated by the subjective model with the AHP method for the three scenarios of future budget availability discussed earlier are given in Table 5.2.

5.7.7 Possibility Ratings of the Scenarios of Future Budget Availability by the AHP Method

Four steps of analytic thought underlie the use of the AHP in estimating the rate/scale of the likelihood of each of the three scenarios of future budget availability, namely:

i) Constructing the decision/rating hierarchy by breaking down the rating problem into a hierarchy of inter-related decision/rating elements,

ii) Collecting input data through elicitation of subjective input from DM(s) or assessor(s) by pairwise comparisons of rating/elements,

iii) Estimating the relative weights of rating elements using the eigenvalue method including checking of logical consistency of those subjective judgments/inputs,

iv) Aggregating the relative weights of rating/decision elements to arrive at a set of ratings for the scenario of future budget availability.

These principles may be best described using a simple problem as an example on how the four steps described above are performed. Consider the following example of a simple decision problem of 'Sectoral Budgetary Allocation' in a developing country such as Indonesia. The first step of applying the AHP is to define the relevant factors for this problem, for example, the set of alternative sectors to be considered , and the most appropriate criteria for a sectoral budget allocation. These factors may be structured into a hierarchy of levels of factors as shown in Figure 5.5. In Figure 5.5 the letter 'L' followed by a numerical denotes the hierarchical level. The highest level (L_1) represents the overall objective of sectoral budget allocation. The intermediate level (L_2) is comprised of the four criteria for sectoral budgetary allocation, namely: *economic, political, social,* and *environmental*. The lowest level (L_3) are the alternative and competing sectors for investment. The factors in this level contribute to the overall focus of the problem through their impact on the intermediate level. In this example problem, three competing sectors for investment were considered, namely, Agriculture, Transportation, and Industry.

The second step is to establish a numerical priority among alternatives by comparing the elements in one level against all others in the same level in terms of how they contribute to

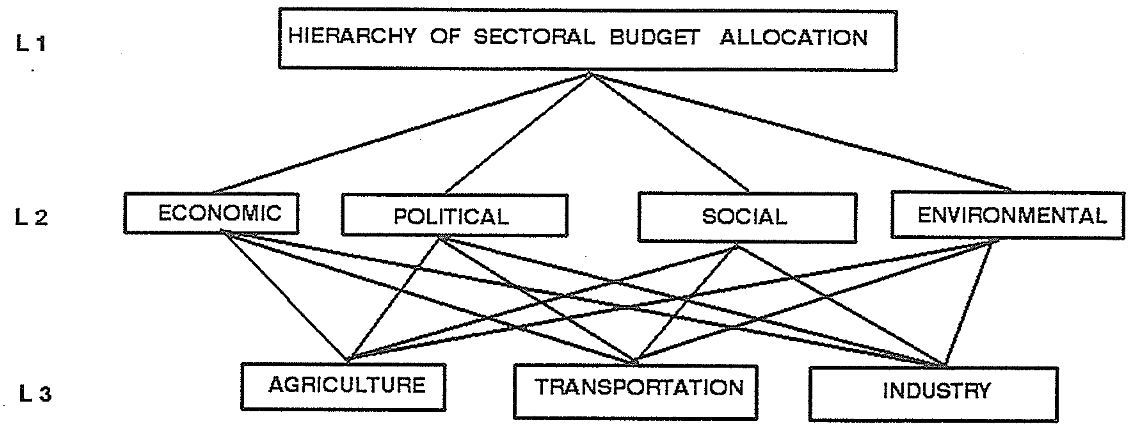


Figure 5.5: Hierarchy of Sectoral Budget Allocation for Demonstration of AHP Method for Possibility Ratings of Sectoral Budget Allocation

Table 5.4: Comparison of Criteria for Demonstration of AHP Method for Possibility Ratings of Sectoral Budget Allocation for the Example Problem in Figure 5.5

	Econ.	Pol.	Soc.	Env.	Priorities
Economic	1	2	3	3	0.45
Political	1/2	1	2	2	0.26
Social	1/3	1/2	1	1/2	0.12
Environmental	1/3	1/2	2	1	0.17

the elements on the preceding (upper) level. For example, in this example each component of L_2 is compared with all other elements in L_2 according to how much they contribute to overall problem stated at L_1 using the comparison scale described previously in Table 5.3. If the *economic aspect* of the sector is moderately more important than its *social aspect* a scale of '3' might be placed in the row-*economic*, column-*social* entry. Similarly, if the *economic aspect* is judged to be only slightly more important than the *political aspect* , a scale of '2' might be placed in the row-*economic*, column-*political* entry. A similar process takes place for the other entries, except for the inverse relation, e.g., comparing *social* against *economic*. In this entry a reciprocal scale is used. The results of this comparison for the Indonesian demonstration case are shown in Table 5.4.

A similar process is applied for factors in the lower level. In this case, each sector at L_3 is compared with the other sectors in the same level according to the L_2 *economic, political,*

Table 5.5: Comparisons of Alternatives with Respect to Criteria for Demonstration of AHP Method for Possibility Ratings of Sectoral Budget Allocation for the Example Problem in Figure 5.5

Economic	Agr.	Tran.	Ind.	Priorities	Political	Agr.	Tran.	Ind.	Priorities
Agr.	1	1	1/3	0.21	Agr.	1	1/2	1/2	0.20
Tran.	1	1	1/2	0.24	Tran.	2	1	1	0.40
Ind.	3	2	1	0.54	Ind.	2	1	1	0.40

Social	Agr.	Tran.	Ind.	Priorities	Environmental	Agr.	Tran.	Ind.	Priorities
Agr.	1	3	5	0.65	Agr.	1	3	7	0.67
Tran.	1/3	1	2	0.23	Tran.	1/3	1	3	0.24
Ind.	1/5	1/2	1	0.12	Ind.	1/7	1/3	1	0.09

social, and *environmental* factors as shown in Table 5.5 which gives the complete results of the analysis.

The third step of the procedure is estimate the relative weight/importance of each rating element using the eigenvalue method (Saaty, 1977, 1980). Once the matrices in each level are completed, the relative importance of the elements in that level is given by the eigenvector of the matrix judgments obtained using Equation (5.25) described previously. These priorities are shown in the right side of each matrix. Note that since the components of each eigenvector sum to unity, the priority of each factor can be expressed in a percentage.

In addition to that result, the logical consistency of comparison judgments performed in the step 2 can be checked using the consistency ratio CR suggested by Saaty (1977, 1980) described in Subsection 5.6.6. The consistency ratio for the 4x4 matrix in Table 5.4 is 0.020, and is 0.012, 0.00, 0.002, and 0.004 for the Economic, Political, Social and Environmental matrices respectively in Table 5.5. Note that in all cases the consistency ratio is less than 10% indicating good consistency in the example responses.

The fourth step is to aggregate the relative weights/priorities of each element. The composite priorities of the sectors with respect to all the criteria are obtained by multiplying the priorities of the sectors under each criterion by the priority of the criterion and adding across criteria. The results of such an analysis for the example problem are given in Table 5.6, which shows that the Industry sector has the highest priority.

Table 5.6: Composite Priorities for Demonstration of AHP Method for Possibility Ratings of Sectoral Budget Allocation for the Example Problem in Figure 5.5

	Economic (.45)	Political (.26)	Social (.12)	Environmental (.17)	Composite Priorities
Agriculture	0.21	0.20	0.65	0.67	0.34
Transportation	0.24	0.40	0.23	0.24	0.28
Industry	0.54	0.40	0.12	0.09	0.38

The relevant factors, subfactors, hierarchy, and the results of performing the four steps of the AHP method for determination of the possibility ratings of scenario of future budget availability for investment are given in Chapter 7 Sub-section 7.2.1 and Table A.18 in Appendix respectively.

Chapter 6

MULTIOBJECTIVE AND MULTICRITERIA OPTIMIZATION

6.1 Multicriteria Aspect Related to Water Resources Planning Problems

6.1.1 Selection Criteria

Uncertainties related to socio-economic issues are an important and possibly the most difficult factor to recognize in water resources planning. As pointed out by several researchers (Loucks, 1977; Bower and Hufschmidt, 1984; Chaturvedi, 1992; and Sutardi and Goulter, 1993) there is a need to give an adequate attention in water resources planning activities, especially in investment planning, to recognize and provide a means of measuring social end effects of projects. Most planning and decision making activities emphasize the engineering and economic aspects of projects. Many water resources management agencies often fail to seek and obtain the understanding, support, and participation of the people affected when they are planning, designing , building, operating, and maintaining water resources systems

(Chaturvedi, 1992). This deficiency in management is often reflected in failure to achieve the anticipated outputs of projects, increased costs in design and construction of project elements, rapid deterioration of project facilities caused by inadequate maintenance, and increased adverse environmental and social effects of projects (Chaturvedi, 1992). In this study, uncertainties related to socio-technical and political factors contributing to the success of such projects in terms of their rate of utilization and productivity are recognized and their possible inclusion into a portfolio model for selecting a project eligible for implementation are examined. The means by which these factors are considered now, and by which they will be addressed in the proposed research, are strongly related to the nature of the problems involved in water resources development and can therefore be quite "problem specific." The focus of the discussion in this thesis and the examples used to demonstrate the issues is the water resources planning and more specifically irrigated development planning in Indonesia

In order to minimize the degree of socio-economic uncertainty and to avoid the excessive time lags between project completion and full utilization such as those currently being observed in Indonesia, criteria used for project selection should incorporate the socio-technical and political issues related to both the agricultural production and marketing subsystems identified by Sutardi and Goulter (1993). These criteria include such factors as the readiness of farmers to fully utilize newly developed agricultural areas, the experience and ability of farmers to exploit new technology such as technical irrigation schemes, and the extent of existing rice fields in the new irrigation schemes, etc. These criteria can then be combined with criteria related to the physical potential that are used to define technical and environmental eligibility of the potential projects.

A procedure based on quantitative measures of 'social suitability' which are then combined, through a system of weights and/or regression analyses, with the pure physical potential factors is proposed to consider the major social and traditional physical factors contributing to project success. In this study the specific socio-technical, economic, and political factors which underlie the irrigation agriculture systems, i.e., the water control subsystem, and the agricultural production and marketing subsystems, are recognized and incorporated as selection criteria in the decision making processes of project selection for implementation. In line with the development objectives of irrigation projects in Indonesia mentioned in

Chapter 3, three general selection criteria related to technical (physical potential), environmental, social, and economic aspects (discussed separately under the heading of probabilistic economic analysis) issues are proposed. These three aspects have to be satisfied, or at least achieved to some extent, in order for a project to be eligible for implementation.

6.1.1.1 Physical Potential and Environmental Aspects

Technical Criteria

1) Water Availability and Quality at Water Source:

A measure of dependable flow, defined as a "minimum" discharge in the river during the dry season, is used as the basis of water availability. This approach is especially applicable for those irrigation areas where the water source is a run-of-the-river diversion system. A dependable discharge of 70% exceedence (70% of the time the discharge is exceeded) is used as the minimum discharge during the dry season in order to irrigate the second crop. For the first crop, which usually occurs in the rainy season, water availability is not a major constraint since the water is only needed as a supplementary irrigation supply. The same minimum discharge for the dry season is therefore applicable for the rainy season.

Water quality aspects are somewhat less complex mathematically with water quality simply having to satisfy specified criteria for agricultural uses.

2) Soil Fertility:

Soil fertility is a critical criterion for ensuring that net farm income for a small land holder (rice farmer) in a project area is sufficient to support a family unit (In the Indonesian context a small land owner is defined as one owns two or less hectares of land.) Two measures are used to specify soil fertility, or more precisely, soil productivity in a particular area:

- productivity level of rice crops in existing fields in the proposed or surrounding area; and
- the existence of relatively infertile peat/sandy soil. These types of soils should be limited to 15% of the total area to be developed.

Environmental Criteria:

3) Topographic Conditions:

In order for a project to be eligible the topography of the project area has to be dominated by flat areas with at least 60% of the project area being in this category. Gently sloping and undulating areas are limited to 25% and 15% of the total area respectively. This criterion ensures that irrigation facilities should only be built on mainly flat areas to minimize disturbance on relatively vulnerable steep terrains. This concern is to preserve watershed ecology of catchment areas.

4) Present and Future Land Use (Land Use Zoning):

There are two concerns related to this criterion. In terms of present land use the more rice fields already in existence in the region, the more preferable is the project. On the other hand the existence of perenial crops such as coffee, cloves etc. in the area should be at a minimum. A value of 15% of the total area has been proposed as the maximum allowable for land already used for perenial crops if the region is to be eligible for development. The same maximum limit for forest losses (15%) is also imposed. This criterion is intended to preserve the existence of the very limited tropical forests and to maintain the watershed ecology balance of catchment areas.

In terms of future land use, zoning is needed to ensure that the areas proposed for irrigation development are assigned as agricultural areas in a regional master plan. This approach with its implicit restrictions provide a means to avoid conflicts of interest if land resources become scarce in the future.

5) Drainage Conditions:

This criterion is to ensure that the cost of drainage and flood protection works is kept to a minimum (the cost of drainage should be less or equal than 15% of the total construction cost). If this criterion is not considered , the project may become dominated by drainage issues thereby requiring it to be treated as a swamp reclamation project rather than an irrigation development project. This criterion also attempts to minimize disturbance of swampy areas in order to preserve the existence of wet land eco-systems.

Social Criteria:

6) Land Distribution:

Land distribution, or more specifically the non-uniform distribution of land ownership, was found to be a significant factor in delays in the utilisation of a number of newly completed schemes located off Java (Sutardi, 1988). It is therefore proposed that project selection criteria recognise that the more evenly the land is distributed to the existing small land holder/ farmers in the area, the more preferable the project. Even distribution of land can be achieved by uniform distribution of land during the introduction of farmers through the transmigration/resettlement program.

7) Site Location:

This criterion is to restrict the distance of the project site from existing supply and market settlements. Fulfillment of this criterion minimises post harvesting processing and transportation costs and thereby stimulates overall development of the agricultural economic base.

6.1.1.2 Social Aspects

Note that the following discussion of social aspects is related to conditions in Indonesia and is therefore only valid for Indonesia. However, the general approach and even some of the characteristics are valid for application to other areas. The important feature is how such factors can be handled explicitly in the optimization framework in particular and in the planning process in general.

Socio-Political Support for Transmigration and Regional Development

Compared to those projects devoted to the single goal of maximizing net benefit, irrigation projects associated with the transmigration (migration within islands of Indonesia to relieve uneven population density) program in Indonesia have not performed well on the basis of classical Benefit-Cost economic indicators. Transmigration programs are implemented for irrigation projects located in remote areas. It is expensive to transport equipment to and to build adequate facilities in these remote regions. Similarly there are also costs associated with providing community facilities and land development for transmigrants.

Quantifying the contributions of irrigation projects to the transmigration and regional development goal can be undertaken as follows. In transmigration projects one hectare of land is distributed to each family for food crop production. The number of transmigrant families that receive one hectare of irrigated rice field from a particular irrigation project will also have an employment impact in the surrounding area as production from the farms generates secondary agro-business. The greater the agricultural production the greater the secondary benefits. A reasonable surrogate for the aggregate of these primary and secondary benefits is the number of transmigrants who directly receive irrigated rice fields.

6.1.1.3 Agricultural Production and Marketing Factors Related to Farmer Readiness Criteria

Several factors, for example, understanding, support, participation, and readiness of farmers for using and exploiting newly completed irrigation facilities which underlie the agricultural production and marketing subsystems, were found to be a major determinant in the rate of the utilisation and productivity of completed schemes. Based on Indonesian irrigation development experiences (Sutardi, 1988; Sutardi et al., 1991a; and Sutardi and Goulter, 1993) these factors can be more explicitly defined in terms of the following eight sub-criteria:

1) Utilisation of existing irrigation schemes:

The higher the level of utilisation of existing irrigation schemes in a particular area, or surrounding such area, the more ready are the farmers in that area to utilise the new scheme. If the existing rate of utilisation is very low, it is generally inappropriate, at least for the time being, to build another new scheme.

2) Productivity of the farmers in existing rice fields:

If farmers in existing rice fields are productive, the farmers who take up the newly developed rice fields are also likely to be productive.

3) The rate of use of the new technologic inputs:

The greater the current use of new technologies, the more willing are the farmers to use even more advanced technology and the "Full Development" condition of new scheme is reached more rapidly.

4) Irrigation efficiency in existing schemes in or near the project:

The higher the existing irrigation efficiency, the more familiar the farmers are with technical irrigation schemes. It is therefore easier for these farmers to exploit fully the new technologies in the newly developed irrigation systems. This criterion is required since the performance in existing schemes and hence ability of the farmers to exploit new irrigation facilities will differ from region to region.

5) Agricultural support services:

Agricultural support, in terms of the agricultural services, markets, access roads and institutional (extension services) support currently available in or surrounding the project area are important to project success. Experience in Indonesia has shown that the more complete these services are initially, the faster the "Full Development" condition of the proposed new scheme is reached.

6) Operation and maintenance:

Farmer groups are responsible for operation and maintenance of irrigation facilities at the tertiary level of water delivery. The better the operation and maintenance activities carried out by farmers groups already in surrounding areas, or already within the proposed development area, the greater the likelihood that the same conditions will occur for the new scheme.

7) Numbers of farmers in the potential areas:

The sufficient number of farmers in the potential projects area is required to ensure that the projected rate of utilization of the potential project can be achieved. If there is a lack of farmers in the potential areas the additional farmer can be brought in these areas through the transmigration /resettlement program.

8) Land ownership certification:

Land ownership certification is required to ensure an adequate and even distribution of land in the potential areas. This condition is appropriate for encouraging an individual farmer to exploit his or her newly irrigated land since land ownership certificate can be used as a guarantee for land development loan and hence accelerate the rate of overall utilization of newly completed irrigation facilities.

Inclusion of the above factors is intended to improve the traditional Benefit-Cost analysis dominated procedures currently being applied in the following manner:

1) Formal inclusion of non-economic criteria, such as socio-political support for transmigration and regional development, for selection of irrigation projects enables projects dominated by non-economic concerns to "compete" more effectively for selection with those projects which are dominated by favourable benefit cost conditions but which do not match the non-economic goals.

2) Explicit consideration of social aspects of irrigation project development enable the planner to identify those projects that have favourable scores in the Benefit-Cost analysis, but whose predicted scores for social responses following the completion of irrigation scheme

are low.

3) It provides a means to explicitly and quantitatively measure the magnitude of support and participation expected to be obtained from farmers using irrigation facilities.

The following subsection addresses the development of the scoring prediction model for the above selection criteria.

6.1.2 Scoring Prediction Model for Selection Criteria

As discussed in Chapter 4 Subsection 4.1.3 there are a number of approaches , e.g., point allocation and unit weighting which are suitable for quantifying 'unquantifiable' social factors associated in the selection criteria so that these factors can be incorporated quantitatively in the investment decision making. The following approaches are considered appropriate for a scoring prediction model to quantify those selection criteria (Mann et al., 1987; Flug and Ahmed, 1990; Sutardi et al., 1991a; Hukkinen, 1991; Murdock et al., 1991; and Sutardi and Goulter, 1993).

1) **Point allocation and unit weighting.**

The point allocation method is simple. In this method the DM or the planner is asked to distribute a fixed number of points (100 in this study) among the various attributes or sub-criteria so as to reflect their relative importance. Following this scoring procedure, a unit weighting method, in which the independent variables are first standardized to exhibit equal mean and variance and are then added together into a composite score, is applied.

The selection criteria in terms of technical or social factors are applied in the project selection process by determining the values for each parameter for a particular project and then comparing those values to an ideal value or standard. The joint or combined evalution of all sub-criteria is performed by assigning to each parameter a weight reflecting the relative importance of the associated sub-criteria. Note that use of an ideal standard is required for each sub-criteria to ensure that, if the ideal standard is surpassed, a contribution greater than 100% is not included in the weighted score. An example of the use of this process using realistic values for each criteria for the case study in Indonesia is shown in Table 6.1 for Physical Potential and Environmental criteria and Table 6.2 for Agricultural Production and Marketing support criteria.

Table 6.1: Example of Scoring List for Physical Potential and Environmental Criteria

Factors	Lower Bound	Upper Bound	Weight (%)	Total Weight(%)	Notes
			Technical Criteria		
1 Water Availability				40	A dependable discharge at 70% exceedence is used as the minimum discharge during dry season second crop.
a Dependable discharge Q_{70}, for every 1000 ha	1.6 (m^3/sec)		35		
b Water Quality	good		5		
2 Land Fertility				15	Reflected in the present productivity of project area to ensure that net farm income is sufficient to support family living.
a Peat/sandy soil ($\leq$15% of total area)	0	15%	9		
b Land productivity (rice ton/ha)	4 ton/ha		6		
			Environmental Criteria		
3 Topography condition (% of total area)				10	The flatter the area, the less expensive it is to develop the land (rice field). These criteria ensure a minimal disturbance on very steep terrain by specifying maximum allowable loss.
a Flat area ($\geq$ 60%)	60%		5		
b Gentle slope ($\leq$ 25%)	0	25%	3		
c Undulating ($\leq$ 15%)	0	15%	2		
4 Land use (% total area)				15	The more perennial crops already existing, the less preferable is the area. Conversely the more rice fields in existence the more preferable. These criteria preserve the existence of tropical forests by specifying maximum allowable loss.
a Rice field ($\geq$ 50%)	50%		7		
b Upland ($\leq$ 20%)	0	20%	3		
c Perenial Crops ($\leq$ 15%)	0	15%	3		
d Forest/shurbs ($\leq$ 15%)	0	15%	2		
5 Drainage condition				10	The cheaper the cost of drainage the more suitable the watershed
a Inundation area	0	20%	5		
b Period of inundation	0	3 days	2		
c Natural drainage	good		1		These criteria preserve the existence of wet land eco-systems by specifying maximum allowable loss.
d Drainage facilities ($\leq$ 15%total cost)	0	15%	2		
			Social Criteria		
6 Land Distribution Distributed evenly (1-2 ha/family)	65%	100%		5	The more equally distributed the land ownership the more preferable is the project.
7 Site location Access road ($\leq$ 20 km in length)	0	20 km		5	The closer the site to existing support infrastucture the more suitable it is.
Total weight (%)				100	

Source: Sutardi et al. (1991)

Table 6.2: Example of Scoring List for Agricultural Production and Marketing Criteria

Factors	Lower Bound	Upper Bound	Weight (%)	Total Weight(%)	Notes
1 Utilization of Existing schemes in the surrounding area	75% of irrigable area			15	The higher the level of utilization of existing irrigation scheme, the more ready is the farmers.
2 Productivity of Existing Rice Field	4 ton/ha			15	The greater the productivity of the farmer in existing rice field, the greater the likelihood of productivity in the new scheme.
3 Use of new inputs				15	The greater the current use, the more willing are the the farmers to take on new approaches.
a. High Yield Variety use	80%	100%	5		
b. Fertilizer use	450 kg/ha		5		
c. Insecticide use	0	6l/ha	2		
d. Cultivation practice	good		3		
4 Agricultural Support				15	The more complete these type of service the faster the "Full Development".
a. Input Supply	good		7		
b. Market	available		5		
c. Access road	good		3		
5 Irrigation Efficiency (on existing scheme)	70%	100%		10	The higher the existing irrigation efficiency, the more familiar are the farmers with technical irrigation schemes.
6 Operation and Maintenance at Tertiary Level	good			10	The better the Operation and Maintenace the greater the likelihood that the same condition will also occur.
7 Number of Farmers in the potential areas	300 persons per 1000 Ha	1000 persons per 1000 Ha		10	The sufficient number of farmers in the potential areas is required to accelerate their rate of utilization.
8 Land Ownership certification	35%	100%		5	Land Ownership certification ensure an adequate and even land distribution in the potential areas.
Total weight (%)				100	

Source: Sutardi et al. (1991)

2) **Multiple Variable Regression Analysis**

In the apparent absence of better approaches for predicting the future performance of potential projects in terms of those selection criteria described previously a scoring prediction model consisting independent variables reflecting each component of such selection criteria is proposed. A multiple variable regression model based on the previous performance of the completed water resources projects is generally sufficient to accomplish such purpose (Mann et al., 1987, and Murdock et al., 1991). (Refer to Chapter 2, Subsection 2.1.5 and Chapter 4, Subsection 4.2.3). Such prediction models have the potential to predict the future performance of the projects under consideration as long as these projects have similarities in terms of their social characteristics to those projects that have been used to develop the prediction model.

To achieve this consistency, completed water resources projects (irrigation projects) must be 'regionalized' with respect to their social conditions. In the Indonesian case study, types of regions for which the regression models might be developed are:

- Regions in Java: this sector represents the most developed region and the farmers most experienced in using irrigation facilities in the country.
- Regions off Java: this sector is very diverse and therefore the regions within the category must be further categorized in:

  developed regions: representing adequacy of agricultural support services, relative to regions in Java, but with less experienced farmers.

  under developed regions: representing inadequate agricultural support service, relative to regions in Java, with farmers inexperienced in using irrigation facilities.

On the basis of the above assumptions two multiple variable regression models related to the Physical Potential and Environmental criteria (refer to Table 6.1) and the Agricultural Production and Marketing criteria (refer to Table 6.2) on the completed irrigation projects are developed. These two complete/full regression model/scoring prediction models are described as follows.

a) Scoring prediction model for the Physical Potential and Environmental (PPE) criteria:

The scoring of PPE criteria of project j is determined by the following model:

$$E(PPE_j) = \zeta_0 + \zeta_1 U_{1j} + \zeta_2 U_{2j} + \zeta_3 U_{3j} + \zeta_4 U_{4j} + \zeta_5 U_{5j} + \zeta_6 U_{6j} + \zeta_7 U_{7j} + \varepsilon \qquad (6.1)$$

where:

$\zeta_{0,..,7}$ = regression parameters based on the completed irrigation projects,

ε = error term of regression model,

$U_{1j,..,7j}$ = independent variables (defined in terms of % relative to the ideal condition within a prespecified lower and upper bounds) representing the scores of project j for the constituent criteria of: 1) water availability, 2) land fertility, 3) topography, 4) landuse, 5) drainage, 6) site location, and 7) land distribution respectively,

j = $1, ..., M_t$, M_t= number of potential projects at stage t.

b) Scoring prediction model for the Agricultural Production and Marketing factors related to the Farmer Readiness (FRD) criteria:

The scoring of FRD criteria of project j is determined by the model:

$$E(FRD_j) = \eta_0 + \eta_1 V_{1j} + \eta_2 V_{2j} + \eta_3 V_{3j} + \eta_4 V_{4j} + ... + \eta_8 V_{8j} + \varepsilon \qquad (6.2)$$

where:

$\eta_{0,..,8}$ = regression parameters based on the completed irrigation projects,

ε = error term of regression model,

$V_{1j,..,8j}$ = independent variables defined in terms of % relative to the ideal condition within a prespecified lower and upper bounds representing the scores of project j for the constituent criteria of: 1) utilization of existing scheme, 2) productivity of existing schemes, 3) the use of new inputs, 5) agricultural support service, 6) irrigation efficiency on existing scheme, 7) operation and maintenance, and 8) land ownership sertification respectively.

It should be noted that the two regression models described above represent a complete model consisting of a relatively large number of independent variables that might be anticipated as potential candidates for predicting the values of Physical Potential and Environmental (PPE) and Farmer Readiness (FRD) criteria respectively. The forward or backward stepwise regression procedure (Neter et al., 1983) may be used to select which independent variables are significant for predicting PPE and FRD for a particular situation.

Scoring Procedure

The application of the scoring prediction model are summarized as follows:

Step 1: Identification of relevant variables contributing to the selection criteria scoring prediction model.

Step 2: Data collection for relevant criteria obtained from the completed projects.

Step 3: Regionalization of the completed projects with respect to their social profiles, e.g., developed and underdeveloped regions. If the number of completed projects in each category is sufficient to perform statistical analysis then the scoring prediction regression model (Step 4) is applied. If this is not the case, the point allocation and unit weighting model is appropriate.

Step 4: Development of the scoring prediction regression model with respect to regional characteristics to predict the future performance of the projects.

Step 5: Once all projects characteristics relevant to each selection criterion have been scored, i.e., quantified in numerical terms by the scoring prediction regression model such they can be assigned as coefficients and right hand sides for the constraint, the selection criteria constraints can be formulated.

Step 6: Scoring criteria based optimization is then performed using the modified Partitioning Algorithm (described in Subsection 6.3.3) in which potential projects are able to be scheduled according to criteria preferences of the DM in a hierarchial manner in light of the funding constraint.

A diagram showing the application of the above procedure or the point allocation and unit weighting procedures as appropriate is presented in Figure 6.1.

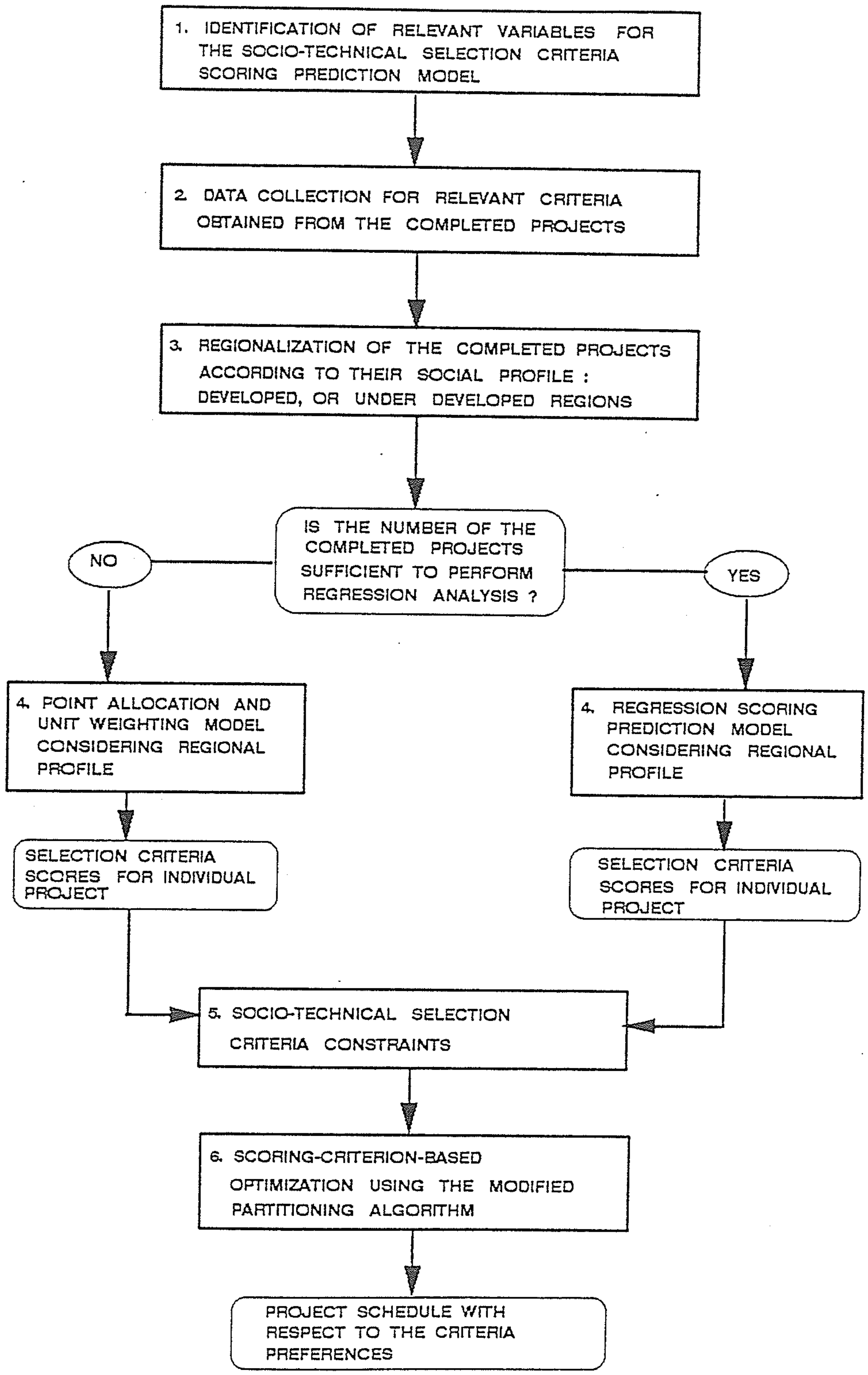


Figure 6.1: Diagram for Development of Socio-Technical Selection Criteria

6.2 Multiobjective Analysis

Traditional Benefit-Cost (B/C) analysis can be used as a screening tool in project selection decision processes. However, its use is effectively limited to the analysis of objectives in which all benefits and costs are easily quantified in monetary terms. The wide range of objectives to be incorporated in the proposed portfolio model necessitate a multiobjective approach in which trade-offs between the various objectives can be observed explicitly.

The major question inherent in multiobjective problems is what goals or objectives should be achieved at the expense of others. In the proposed planning model weighting schemes (Charnes and Cooper, 1977) are used as means of articulating the priority of preferences of the DM.

In the case of water resources planning in Indonesia the establishment of priorities to achieve the three GOI objectives of Support for Self-Sufficiency in Rice Production, Economic Efficiency, and Support for Transmigration Program must reflect the relative importance of each objective and, to some extent, the plans of the GOI for particular types of projects in particular areas. The following combinations of goal and criteria preferences which are articulated in terms of overall priority settings were selected to show the multiobjective-multicriteria nature of the problems and the role of selection criteria in reducing the degree of socio-technical uncertainties in the Indonesian context.

Case A: Priority on Economic Efficiency

In this case, economic efficiency criterion and physical potential and environmental aspects are given the first and second priorities respectively. This type of priority setting is intended to screen irrigation projects which are candidates for inclusion in the rice intensification program. Most of the activities chosen under this priority setting are devoted to rehabilitation of existing irrigation schemes the majority of which are located in developed regions on or off Java where a relatively small investment will gain considerable economic return. In this case, Net Present Value of Benefit (NPVB) is used as a parameter to measure goal achievement.

Case B: Priority on Support of Self-Sufficiency in Rice Production

In this case, technical criteria for project suitability such as water availability and other physical potential are given higher weights than any of the social and economic aspects. However, economic efficiency is also still given a higher weight (priority) than the social aspect of selection. Economic efficiency tends not to be a major consideration in this case as long as the physical potential and environmental aspects fulfill the requirements. In this case, Irrigation Area Developed (IAD) is used as the parameter to measure goal achievement. The IAD target itself is governed by the rate of population growth and the rate of the loss of irrigated rice field (converted to non-rice usage) in Java which has to be replaced.

Case C: Priority on Socio-Political Based Transmigration Programs.

In this case the socio-political aspect criteria are given a higher weight than economic efficiency. However, the physical potential and environmental criteria are still given the highest weight in order to ensure the candidate watersheds are technically and environmentally eligible for inclusion in the irrigation projects. This type of priority setting is intended to screen irrigation projects that are considered suitable to support transmigration and regional development in underdeveloped regions off Java. This condition is to some extent screened a priori in that most areas in developed regions of the country are already fully utilized. Irrigation projects associated with transmigration programs are characterised by the fact that most will be located in remote and underdeveloped areas in which extra costs are needed for access roads, community facilities and land development for transmigrants. These extra costs normally make the investment unattractive for a solely economic viewpoint. Not unexpectedly, compared to those projects devoted to the single goal of maximizing net benefit, irrigation projects associated with transmigration programs have not performed well on the basis of classical Benefit-Cost economic indicators.

It is very useful to be able to express transmigration support in quantitative terms. In this case the number of families supported at a particular transmigration area is used as a parameter to measure the goal achievement for the Transmigration Support (TS) objective.

Case D: Priority on Selection Criteria of Physical Potential, Extent of Existing Rice Field and Agricultural Production and Marketing Simultaneously.

In this case the DM's objective is to select only the projects that are both technically and socially suitable with respect to the criteria of Physical Potential and Environmental (PPE), Extent of Existing Rice Fields (ERF) , and Agricultural Production and Marketing factors related to Farmer Readiness (FRD) simultaneously. This priority setting is intended to support a DM's policy of achieving the maximum attainable overall ideal condition for irrigation development and therefore reducing the degree of socio-economic uncertainty.

Case E: Priority only on Physical Potential and Environmental (PPE) Selection Criteria.

This priority setting is intended to articulate a situation in which the physical potential and environmental aspects of the watershed under consideration become the major concern regardless of achievement of the other goals and criteria. This scenario supports a policy of maximizing the quantity of irrigable areas. In this case Physical Potential and Environmental criteria, stated in terms of percentage relative to the ideal condition, are used as the parameter for measuring the level of satisfaction of this selection criterion.

Case F: Priority only on Extent of Existing Rice Field (ERF) Selection Criteria.

In this case the DM's objective is to select only those projects which minimize land development costs, and is especially relevant for situations when the funds for land development are the major constraint and the rate of utilization of completed schemes is the major issue. This concern also reflects the need to minimize the degree of uncertainty inherent in a complex land development problems.

Case G: Priority only on Agricultural Production and Marketing Factors related to Farmer Readiness (FRD) Criteria.

In this case the DM's objective is to select only "quick yielding" projects in which the level of social response in terms of the readiness of farmers to exploit new irrigation facilities, and the level of factors supporting agricultural production and marketing subsystems, are high. Such concern is directed to minimizing the degree of uncertainty inherent in the complex social factors related to success of water resources projects. This preference is relevant for situations when the rate of the utilization of completed irrigation schemes and rice crop intensification are the major policies.

Case H: Same priority on NPVB and Irrigation Area Developed Goals.

In this case the DM's objective is to satisfy both achievement of Net Present Value of Benefit (NPVB) and Irrigation Area Developed (IAD) goals simultaneously. This preference is relevant for situations where a compromise solution is sought between these goals, i.e., the solution is to satisfy, or to be as close as possible to, the prespecified targets of both NPVB and IAD goals simultaneously. NPVB and Irrigation Area Developed, stated in monetary terms and hectares of completed irrigation schemes respectively, are used as parameters to measure goal achievements.

Case I: Same priority on NPVB and Transmigration Support Goals.

This case is similar to Case H except the goals that have to be satisfied simultaneously are NPVB and Transmigration Support. NPVB and Transmigration Support, stated in monetary terms and number of transmigration families directly supported by the proposed irrigation project respectively, are used as parameters to measure goal achievements.

6.3 Goal Programming Approach

The Goal Programming (GP) procedure was selected for this problem for the reasons given in Chapter 4 Subsection 4.2.3. The discussion in the following three sections is related to the IGP model itself, aspects of the integer formulation, the scoring criterion based optimization used within GP framework and the generation of efficient solutions from the integrated systems.

6.3.1 Generation of Efficient Solutions from the GP Model

The concept of Pareto optimality, initially introduced by Pareto (1896) within a framework of welfare economics, plays a crucial role for the various approaches developed within the MCDM (Refer to Chapter 2 for subsection related to multiobjective planning and investment). A solution to a multicriteria problem is said to be *Pareto optimal* if there is no other solution which is at least as good according to all criteria and strictly better according to at least one criterion. A Pareto optimal solution is not dominated by any other solution, and is therefore, also called a nondominated or noninferior solution and would be chosen by any 'rational' decion maker. Within GP, Paretian efficiency (Pareto optimal) is also necessary condition for a GP solution to satisfy in order for it to represent an appropriate solution for given problem (Romero, 1991).

As pointed out previously by Zeleny [(1973), (1981)] and Cohon and Marks (1975) a possible disadvantage of a GP formulation problem is that the solutions provided by these kind of models can be nonefficient, i.e., the solutions provided via GP are not necessarily

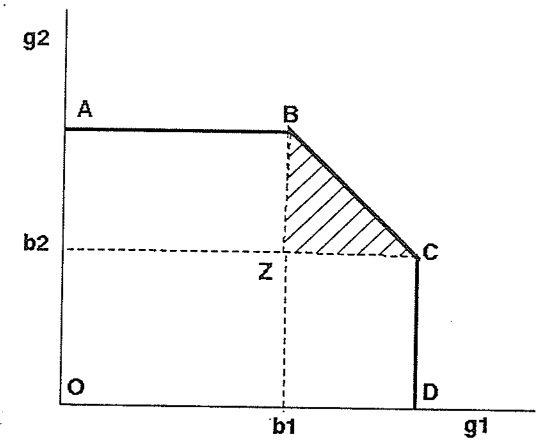


Figure 6.2: Non-efficient GP Solutions

Pareto optimal. Figure 6.2 illustrates this possible disadvantage wherein the space of the goals, the feasible set is represented by the domain $OABCD$. Let the target values of the two goals be b_1 and b_2, respectively. If the intention of the DM is to achieve at least these two target values then point Z represents an optimal GP solution as the negative deviational variables associated with both goals are zero at this point. However, this solution is nonefficient in the Paretian sense because it is dominated by other feasible solutions, i.e., by all the points in the triangle ZBC (with the exception of point Z) (Romero, 1991). In addition to this potential drawback, problems can be encountered in GP in setting an appropriate weighting scheme.

From a practical viewpoint both potential drawbacks can be mitigated by a proper setting of the targets level b_1 and b_2, i.e., by initially setting these targets as high as possible then conducting a parametric analysis of the aspiration levels assumed in the model and by applying a set of weights that minimizes the distance between each solution and the *ideal solution* (Zeleny, 1982) whose co-ordinates are given by the optimum values of the various objectives of the DM. In such a procedure, each solution is calibrated with respect to the ideal solution and an interactive process with the DM is implemented to check his/her satisfaction relative to the ideal solution. Figure 6.3 shows an example of graphical representation of multiobjective analysis of two incommensurate objectives employing such an approach. This

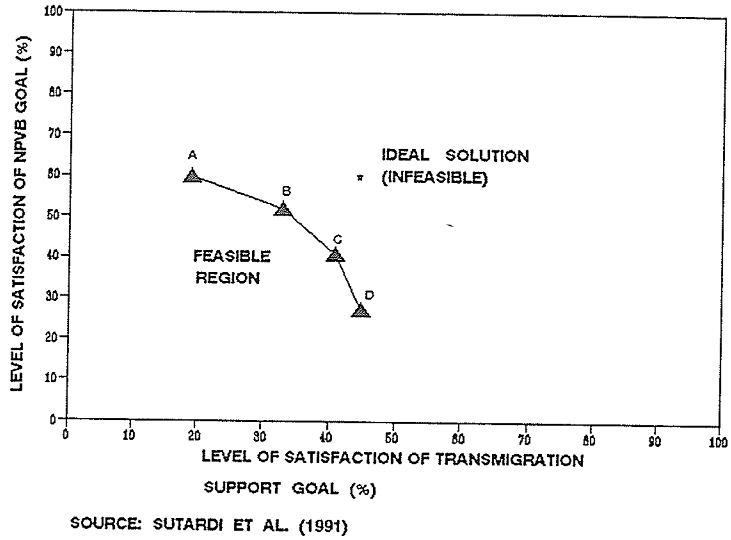


Figure 6.3: Example Graphical Representation of Multiobjective Analysis for a Project with Transmigration Implications

approach has been implemented without too much additional effort and difficulties relative to the other MCDM methods and reported by Sutardi et al. (1990, 1991a, 1992a, and 1992b).

Moreover, as Romero (1991) argues, GP was not invented for the purpose of obtaining nondominated solutions but was developed as a method for finding satisficing solutions in a Simonian sense, i.e., the DM does not try to maximize anything but rather tries to achieve a set of goals as closely as possible with respect to a set of targets for complex real world problems. Furthermore, methods recently reported in the literature for use of GP avoid this problem without too much difficulty, thus further increasing the soundness of the GP approach.

The following discussion outlines a general framework for solving GP models in order to avoid the problem of inferior solutions discussed earlier. This framework combines the method suggested by Hannan (1980) (1985), Masud and Hwang (1981) and Romero (1991):

Step 1. Test of Efficiency in Goal Programming (Hannan; 1980, 1985)

Solve the initial Weighted Goal Program (WGP) or Lexiographic Goal Program (LGP) problem.

(a) If there are no alternative optimal solutions for the WGP model or for the last problem of the sequence of LGP problems in the lexicographic case, then the process ends. The GP solution is the only efficient solution and can thus be chosen. To test the existence of alternative optimal solutions it is sufficient to check if there is a nonbasic variable in the optimal solution which has a value of zero and for which the value of the corresponding reduced cost is also zero.

(b) If there are alternative optimal solutions, then go to Step 2.

Step 2. Generation of GP-Efficient Solutions (Hannan; 1980, 1985)

(a) If the DM is interested only in one optimal solution by necessity it must also be a GP-efficient solution. Go to Step 3

(b) If the DM is interested in exploring the set of optimal and GP -efficient solutions, then go to Step 4

Step 3. Generation of one optimal and GP-efficient (Masud and Hwang, 1981)

Maximize the sum of the 'opposite' deviational variables (under and over-achievement) without increasing the values obtained for the previously minimized deviational variables. The solution obtained to this new problem is efficient and can thus be chosen. It should be noted that the solution obtained in Step 1 is efficient only if it is the same as the solution generated in this step.

Step 4. Generation of a Set of GP-Efficient Solutions (Hannan, 1980; Romero, 1991)

Modify the GP model into a multiobjective problem (MOP) model using Hannan's procedure appropriately modified by Romero (1991). Hannan (1980) proves that if all the goals are bounded, a set of GP-efficient solutions can be obtained by solving an auxiliary MOP problem with the following structure. In this case, the objective functions of the MOP model are the goals of the GP model. When the DM wishes to achieve at least the target value of a particular objective then the corresponding objective is maximized; on the contrary if the DM wishes not to surpass the target then corresponding objective is minimized or the objective goes to zero subject to the constraints on the fundamental level of performance. The feasible set of the MOP model to achieve the desired fundamental level of peformance is formed by the original constraints of the GP model augmented with a set of constraints to ensure that the level of achievement of the goal is at least as good as the level obtained by the previously solved WGP or LGP problem.

Applying the above procedure results in the following MOP problem:

$$\text{Eff}Z(\bar{x}) = [Z_1(\bar{x}), Z_2(\bar{x}), \ldots, Z_k(\bar{x})] \tag{6.3}$$

where

$$Z_k(\bar{x}) = f_k(\bar{x}) \tag{6.4}$$

subject to

$$f_k(\bar{x}) = b_k - (d_k^-)^* + (d_k^+)^* \tag{6.5}$$

$$\bar{x} \,\varepsilon\, \mathbf{F} \tag{6.6}$$

where Eff is the search for the efficient solution, $Z_k(\bar{x})$ is a decisional variable space, $f_k(\bar{x})$ is a mathematical function of the set of decision variables $\bar{x}$, $(d_k^-)^*$ and $(d_k^+)^*$ are the optimum values of deviational variables when the initial WGP or LGP was solved, and $\mathbf{F}$ is a feasible set. A diagram showing the mechanism and main steps of this procedure is presented in Figure 6.4. From the nature of GP formulation as described above, it can be observed that GP method offers a great degree of flexibility suitable for solving the real world decision making with these characteristics:

1. There is always a feasible solution.
   In practical sense this feature means that a good planner never has to give up and accept "no feasible solution".

2. There are no truly alternate optima.
   This feature means that a typical DM will never be indifferent between two proposed courses of action. There are always sufficient criteria to distinguish some course of action as being better than all others.

6.3.2 Integer Goal Programming

The extension of GP to make use of integer programming (IP) has been suggested by Weingartner (1967), Neely et al. (1976) and Clark et al. (1984) for the capital budgeting problem.

The main reasons for this emphasis on the use of IP in the capital budgeting setting are as follows:

1. Difficulties imposed by the acceptance of partial projects in LP are eliminated, since IP requires that projects either be completely accepted or rejected. Therefore the model can satisfy the requirement of "go-no go" status that is a crucial issue in a portfolio model.

2. The three types of project dependencies/interrelationships, e.g., mutually exclusive, prerequisite, and complementary, can be handled in a straightforward manner. The definition and means of handling each of these three conditions are discussed below.

Mutually exclusive projects are defined as a set of projects wherein the acceptance of one project in the set prevents the simultaneous acceptance of any other project in the set. The existence of such a set projects is incorporated in an IP model by the following constraint:

$$\sum_{j \in J} X_j \leq 1 \tag{6.7}$$

where J= set of mutually exclusive projects under consideration

Note that the constraint states that *at most* one project from set J can be accepted; this means that the DM can choose not to accept any project from set J. On the other hand, if it is necessary to select one project from the set, Expression (6.7) would appear as a strict equality, i.e.,

$$\sum_{j \in J} X_j = 1 \tag{6.8}$$

Prerequisite (or contingent) projects are two or more projects wherein the acceptance of one project necessitates the prior acceptance of some other project(s). For example, if project A cannot be accepted unless project Z is accepted, project Z is said to be a prerequisite project for acceptance of project A; alternatively, acceptance of project A can be said to be contingent upon the acceptance of project Z. The representation of this contingency relationship in IP is:

$$X_A \leq X_Z \tag{6.9}$$

where X_A and X_Z are decision variables denoting projects A and Z. Note in Expression (6.9) that if project A is accepted (i.e., X_A=1), then, necessarily, project Z must be accepted also. However, project Z can be accepted on its own and project A rejected.

If two projects must both be accepted then either they are classed as a single project or for the case of the two projects A and Z above

$$X_A = X_Z \tag{6.10}$$

Complementary projects, wherein the acceptance of one project enhances the cash flows of one or more other projects. This synergistic effect is reflected in an IP formulation by using the strategy proposed by Clark et al. (1984).

- **Step 1:** Define a decision variable which represents the acceptance of the complementary project (The complementary project of two projects is that which improves the performance of the first or primary project).

- **Step 2:** Incorporate the decision variable for the complementary project into the objective function and all relevant constraints. The coefficients for this decision variable in the objective function and the constraints will be defined by the specific features of the problem being examined, e.g., the magnitude of the cost savings and/or other benefits associated with the acceptance of the combined projects.

- **Step 3:** Define a constraint similar to Expression (6.7) for mutually exclusive projects that prevents the acceptance of the complementary project without the primary project being selected.

Consider an example formulation for consideration of a complementary project. Let the two complementary projects be X_a and X_b. Any one of these project can be selected in isolation. However, if both are accepted simultaneously, the cost will be reduced by, for example, 15% and the benefits will be increased by, 20%. Thus a composite project, X_{ab} would be constructed with a cost equal to 85% of the cost of projects X_a plus X_b and a benefit equal to 120% of the benefit of projects X_a plus X_b. To prevent acceptance of both projects X_a and X_b as well as project X_{ab} the following constraints is required.

$$X_a + X_b + X_{ab} \leq 1$$

Inspite of the advantages described above, two significant shortcomings of the IP method must be addressed. The solution time of IP formulations vary irregularly. As pointed out by Pettway (1973) the form of an IP formulation has a significant impact on the time it takes to solve the problem. Smaller problems (in terms of number of constraints and number of decision variables) may, in fact, take longer to solve than larger problems. Furthermore, very minor changes in the problem can significantly increase solution times.

The second shortcoming of IP formulation as noted by Baumol and Gomory (1960) is the difficulty in interpreting the shadow prices in IP. In comparison with the solution generated by LP models, solutions provided by IP formulations suffer from the lack of meaningful shadow prices. Many of the integer based constraints on IP problems that are not binding on the optimal integer solution will be assigned shadow prices of zero, which indicates that these resources are "free goods." In reality, this is not true since the objective function would clearly decrease if the availability of such resources were decreased in the integer steps implicit in the possible values of the constraint right-hand-side.

However, recent developments in computer hardware and new efficient software packages for handling IP formulation has considerably decreased the computational time required for solving IP formulation. For example, no more than 20 minutes is required for solving real-world problems of project scheduling problems consisting of 100 constraints and 200 integer decision variables using LINDO 386 microcomputer version (Schrage, 1991) which employs the Branch and Bound technique (Sutardi et al., 1992a and 1992b).

Furthermore, the benefits gained in using an IP formulation with respect to its ability to include the various types of constraints for project interrelationships and to avoid selection of fragmented projects are far much more useful than information that cannot be extracted from shadow prices of IP formulation for the portfolio model (Sutardi et al.; 1990, 1991a, 1992a, and 1992b). Therefore, it is worth moving to IP formulation regardless the difference in solution time.

6.3.3 Scoring Criterion Based Optimization

As mentioned earlier some constraints associated in the proposed IGP (Integer Goal Programming) based-portfolio model consist of a set of selection criteria constraints in which components of the constraints are in the form of scores measured on an interval scale between 0 and 100 (in percentage) relative to the ideal condition. In its earlier form of a scoring-criterion-based optimization, the model tends to discriminate against the projects which have a higher cost even though they have a higher criterion score (Sutardi et al., 1992a). This tendency occurs because the model tries to minimize underachievement of the sum of scores from targeted goals of individual projects subject to budgetary binding constraint rather than selecting the individual projects that have higher scores in a hierarchial manner.

The purpose of selection criteria is to determine ranking of the projects eligible for implementation when selection criteria are simultaneously or individually preferred regardless of the cost of individual projects under consideration. Optimization procedures using these criteria must therefore comply with such requirements. For the type of problem being addressed in this thesis the projects whose scores are higher have to be selected subject to budgetary constraints, before the projects with a lower score are even considered. For handling such problems in the IGP-based portfolio model, a modified version of the Partitioning Algorithm proposed by Arthur and Ravindran (1980) is proposed.

The reason for the choice of this Partitioning Algorithm lies both in the strength of the algorithm itself and in the ease by which the procedure can be implemented in any available commercial optimisation software package. The strength of the algorithm lies in its ability to take advantage of the definition of ordinal preemptive factors in the objective function inherent in most IGP formulations by using partitioning and elimination procedures. In the algorithm, the linear IGP problem is considered as a series of dependent, ordinally ranked LP problems. The ordinal ranking is accomplished through the use of preemptive priority levels which imply that higher order goals must be optimized before lower order goals are even considered. This procedure is imbeded in the IGP-based portfolio model using the strategy outlined below:

- **Step 1:** Decompose the selection criteria constraints into several subconstraints reflecting a range of levels of the desired ranges of score on each criterion. For example, subconstraint level 1 consists of those projects whose criteria scores are greater than 80% ($Sc > 80\%$). Similarly subconstraint level 2 consist of projects for which $65\% \leq Sc \leq 80\%$ and subconstraint level 3 consists of projects for which $40\% \leq Sc \leq 65\%$ and so on. This decomposition enables the projects categorized in the level 1 be optimized before the projects grouped in level 2 are even considered.

- **Step 2:** The constraints are partitioned to form a nested series of GP problems with respect to the priority rankings assigned to the subproblems $S_1 \supset S_2 \supset \ldots S_c \supset \ldots$, where S_c designates the subproblem consisting of those selection criteria constraints, and the corresponding terms in the objective function, assigned the first c priorities.

- **Step 3:** The partitioning algorithm begins by solving the smallest subproblem S_1 which is composed of those selection criteria and the corresponding terms in the objective function assigned the highest priority. At the optimal solution for this subproblem the slack variable of the budgetary constraint is examined. If the slack variable has a value of zero, then there is no need to consider the second highest score projects, since the available budget is already used up by the highest score projects. However, if the slack variable has a non-zero value, and ideally is also substantial, then the algorithm proceeds to Step 4. Efficiency of the optimal solution for this subproblem can be checked using the Hannan's procedure outlined in the previous subsection. If no alternate optima exist then the solution is optimal and efficient as well. Conversely, if alternate optima exist the efficient solution can be found by maximizing the sum of the opposite deviational variables, as explained in subsection previously, and algorithm can then proceed to next score level.

- **Step 4:** The residual budget (Value of the slack variable of budgetary constraint carried over from Step 3) is applied to the next largest subproblem in the series (those assigned to the second highest score) and the optimization resumes. The algorithm continues in this manner until the value of the slack variable related to available budget is zero or close to zero and can be therefore neglected.

A diagram showing the process of the proposed scoring-criterion-based optimization is given in Figure 6.5. It should be noted that there is a difference between the procedure outlined above and the one suggested by Arthur and Ravindran (1980). In the above procedure the indicator of whether algorithm should resume or stop is the value of slack variable of

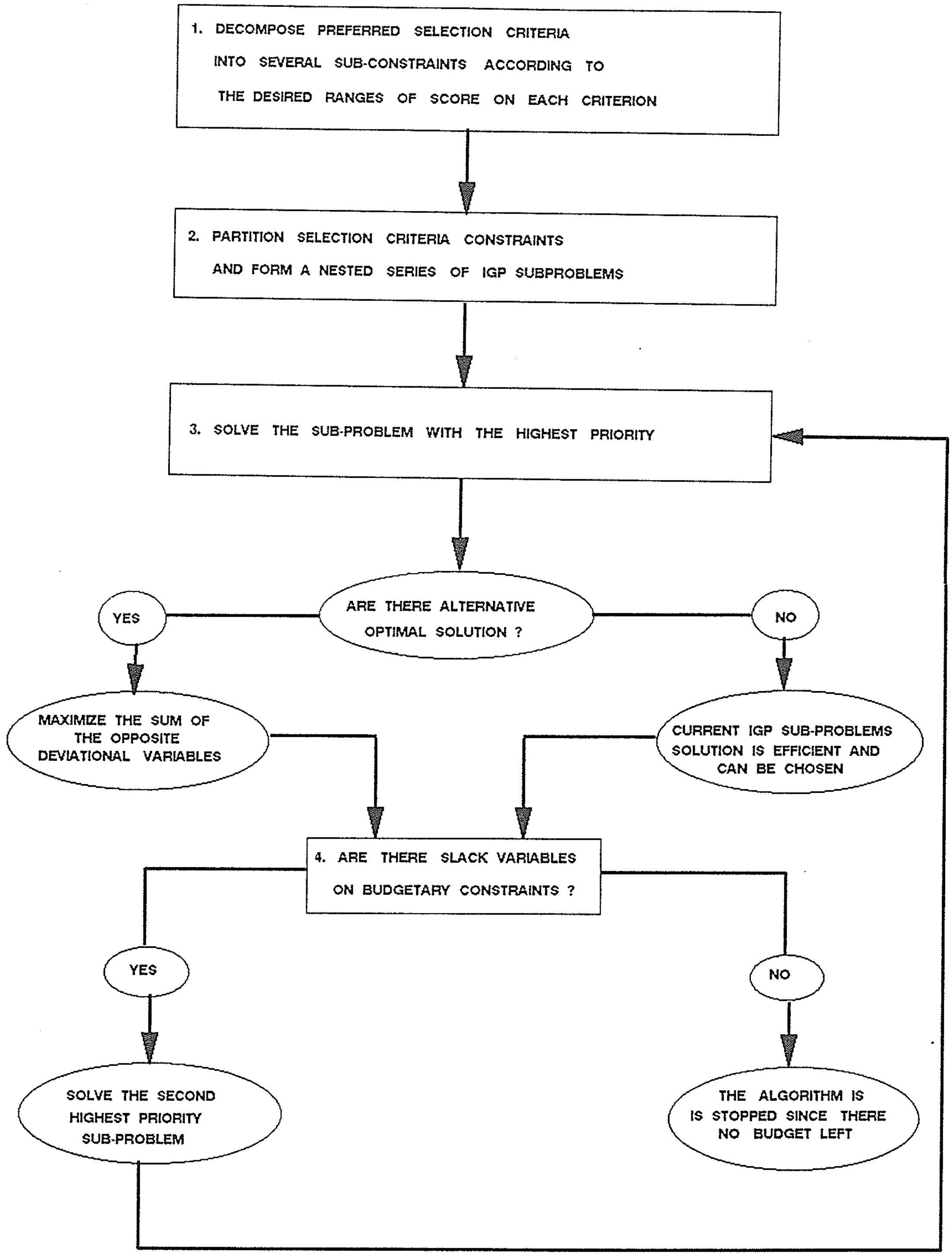


Figure 6.5: Diagram of Procedure of Partitioning Algorithm for Scoring -Criterion-Based-Optimization

budgetary binding constraint. On the other hand in the original Partitioning Algorithm of Arthur and Ravindran (1980) the existence of alternate optimal solution is used as the indicator.

6.4 Chance Constrained Integer Goal Programming (CCIGP)

In its most general formulation, the CCIGP approach is used to minimize the deviations of the expected value from the targeted goals subject to managerial constraints and economic constraints that are allowed to be violated some given percentage of the time due to random variations in the system. In this study, inclusion of probabilistic constraints in the proposed model enables the dispersion of random variables to be explored such that the risk aversion of the DM can be incorporated explicitly in the decision making process.

The chance constraints are incorporated in the IGP-based portfolio model based on the following rationale.

Consider the usual constraints of LP:

$$\sum_{j=1}^{M_t} a_{qj} X_j \leq b_q \tag{6.11}$$

where a_{qj} is a contribution of project X_j for the q^{th} resource and b_q is a resource capacity of the q^{th} resource. Due to randomness in either the a_{qj} coefficient or the b_q right- hand-side values this constraint may be probabilistic rather than deterministic in nature. Under such probabilistic circumstances constraints may not have, or even be able to be satisfied, i.e., 100% all the time. This capability to accept non-compliance with the constraint for some specified proportion of the time can be achieved by using *chance constraints* rather than the usual deterministic form. These chance constraints are written:

$$P\left\{\sum_{j=1}^{M_t} a_{qj} X_j \leq b_q\right\} \geq \beta_q \tag{6.12}$$

where $P\{\ \}$ = probability of the event in $\{\ \}$

β_q = degree of the confidence limit, reflecting minimum probability that the DM is willing to accept that the q^{th} constraint is satisfied.

$\beta_q = 0.90$, for example, means that the DM requires that the constraint be satisfied at least 90% of the time and that he/she is willing to allow $\sum a_{qj}X_j$ to exceed b_q up to 10% of the time.

The solution methodology for CCIGP problems requires that a *deterministic equivalent* of the probabilistic process be derived for all those features to be reflected in the chance constraints. This process is undertaken by taking into account the shape and parameters of the probability distribution for all random variables, as well as the degree of correlation between all pairs of random variables. This derivation usually results in nonlinear equations, which greatly affects the feasibility of large problems. Difficulties in problem solution escalate rapidly, particularly for integer based formulations, as the size of the problem grows or as the distributions of random variable describing the system depart from normality. To keep the model operational and computationally tractable some simplifications in the derivation may therefore be required. However, considering the characteristics of the other problems associated with the IGP-based portfolio model such simplifications may not significantly reduce the model accuracy (Hillier, 1969).

The following subsections address analysis of aggregated uncertainties reflecting the uncertainty inherent in the NPVB criterion that underly the need for a probabilistic economic criterion such as a chance constraint, the derivation of the appropriate deterministic equivalent of the chance constraint, and the subsequent formulation of the CCIGP model.

6.4.1 Analysis of Aggregated Uncertainties Inherent in NPVB Criterion

As mentioned in Chapter 3 all types of uncertainties, whether they are physical or non-physical, that may affect the outcome of investment in water resources projects can be aggregated in uncertainty inherent in NPVB criterion as long as their impacts can be quantified and represented in monetary terms.

In the proposed CCIGP model the uncertainty inherent in Benefit-Cost type of analysis is treated by assuming component of costs and benefits as random variables. The mean and variance of these random variables can be obtained from an estimate of "most likely" (expected), "upper" (optimistic) , "lower" (pessimistic) values of individual components using the approaches of Goicoechea (1982) and Dandy (1985). However, the approaches applied in this study differ from these and other approaches used in previous studies, e.g., Mercer and Morgan (1975 and 1978), Taylor et al. (1976), and Tung (1992) in the following manner:

1) Instead of using the Benefit-Cost ratio, a Net Present Value of Benefit will be applied for evaluating the economic return of water resources projects. As noted earlier the reason for this choice are as follows:

- The value of the Benefit-Cost ratio will change in the Benefit-Cost ratio approach depending on how the annual benefit and cost streams are defined.
- When used (solely) for selection criteria of mutually exclusive projects the Benefit-Cost ratio approach can lead to an erroneous investment choice as it discriminates against projects with higher gross returns and operating costs even though these may be shown to have a greater wealth generating capacity (net benefit) than an alternative with a higher B/C ratio (McKean, 1958; Gittinger, 1984).

2) Instead of using a project manager's or expert's estimate to determine boundary values, e.g., the upper, lower bounds and the most likely, this approach employs historical data of completed schemes and the contingency index offered by Lutz and Cowles (1971) to estimate boundary values. The combination of historical data, subjective inputs from the expert or project manager and the contingency index provides a better estimate of future conditions than subjective estimates extracted from the project manager, or the expert in isolation for the following reasons:

- The project manager may make biased estimates. Managers are sometimes hesitant to admit that they are not certain about things which they feel they should be extremely certain, i.e., the basic elements of their jobs. As a result, their estimates may be less than candid and yield less accurate expected values and standard deviations (Hanke and Walker, 1974; Taylor et al., 1979).
- Historical data extracted from the completed schemes can be used as base rates. Using

these base rates subjective estimates reflecting the project manager's or the planner's assessment on the likelihood of future projects outcome can be made (Taylor, 1984).

- The use of the contingency index for correcting any bias inherent in the estimation of future projects outcomes enables elements of subjective inputs to be traced and updated to accomodate any current information and trends.

Discussion on analysis of aggregated uncertainty related to the NPVB criterion is performed in two parts. The first part consists of examination of estimates of uncertain parameters using historical data and the contingency index. The second part is concerned with the statistical analysis of Net-Benefit criterion.

Estimates of Uncertain Parameters Using Historical Data

The variation of the possible values of each component of benefit and cost may be estimated in three levels: an expected value (Θ_e^M), an optimistic value (Θ_e^U) and a pessimistic value (Θ_e^L). The expected value is the value that is likely to occur, on the average, if the activity, e.g., cropping intensity, cropping pattern, productivity, price, etc, could be repeated a number of times under similar circumstances. An optimistic value is the maximum net benefit that can be realized if "everything goes right". Finally, the pessimistic value is the minimum benefit that can be realized if "everything goes wrong". Effectively, then, the optimistic and pessimistic values identify the range of possible values for a given input component.

It should be noted that, instead of using information based solely on the subjective estimates of an experienced manager or experts for estimating uncertain parameters, e.g., the most likely, upper and lower values of benefit and cost components, the case study used to demonstrate the overall approach in this study makes use of available historical data, covering about 50 medium-large scale irrigation projects in Indonesia which have been completed during the last 20 years. This approach is undertaken by jointly applying the modified approaches based on the work of Lutz and Cowles (1971) and Dandy (1985).

The Lutz and Cowles (1971) model can be described in terms of the following indices:

1. Contingency Index.

A preliminary index of deviation of the Benefit-Cost Ratio (BCR) is used to define how well the benefit, costs and the BCR have been estimated in the past relative to actual outcomes of the projects. Mathematically, a preliminary index of deviation E, can be stated as:

$$E = [R_B \text{ x } R_C] - 1 \quad (6.13)$$

R_B= ratio of actual to estimated benefit.
R_C= ratio of estimated cost to actual cost.
E = preliminary index of deviation.

The properties of Expression (6.13) are:

- unitless symmetrical relationship: Positive values of E indicate a greater gain to the economy than expected and negative values correspondingly indicate less gain
- insensitivity to differences in relative magnitude of the benefit-cost components
- it approaches zero when estimates of the components are close to those ultimately experienced

Expression (6.13) can be converted to a logarithmic form to make the index the sum of two variables.

$$\nu_{BC} = \nu_B + \nu_C \quad (6.14)$$

where :

ν_{BC}= $\ln(E)$ = contingency index of BCR
ν_B = $\ln(R_B)$ = contingency index of benefit component
ν_C = $\ln(R_C)$ = contingency index of cost component

The properties of Expression (6.13) are also hold for Expression (6.14).

2. Observed Contingency Index, I_{BC} :

If a sufficiently large sample of completed investment projects are analysed with respect to deviations of actual costs and benefits from the expected quantities, the observed contingency index, I_{BC}, will be the expected value of contingency indexes of all projects considered and can be defined as:

$$I_{BC} = E(\nu_B) + E(\nu_C) \quad (6.15)$$

or

$$I_{BC} = I_B + I_C \tag{6.16}$$

where:

I_{BC}= observed contingency index

I_B = expected value of contingency index of benefit component

I_C = expected value of contingency index of cost component.

3. Accuracy Index (J_{BC}):

An accuracy index, J_{BC}, based on the variances of the deviations of the component estimates of benefits and costs, J_B and J_C, can be respectively defined as:

$$J_{BC} = J_B + J_C + 2\rho\sqrt{(J_B)(J_C)} \tag{6.17}$$

where :

J_{BC}=variance of BCR

J_B $=E(\nu_B^2) - [E(\nu_B)]^2$ = variance of ν_B

J_C $=E(\nu_C^2) - [E(\nu_C)]^2$ = variance of ν_C.

ρ =correlation coefficient of ν_B and ν_C

These indices are used in the following manner.

4. Adjustment by the Index :

An observed contingency index other than zero indicates a consistent bias in the previous estimation. This information provides a basis for correcting future estimates with respect to this bias. Z_a, an adjusted value of benefit-cost ratio of a contemplated project, can be obtained by utilizing the observed contingency index I_{BC} and the initial value of BCR, Z_p as follows:

$$lnZ_a = lnZ_p + I_{BC} \tag{6.18}$$

Furthermore, by adoption of the normal distribution convention, a range of confidence can be approximated for the adjusted benefit-cost ratio, Z_a, to reflect the observed variation. In terms of a confidence interval, δ, the range of Z_a is expressed as:

$$ln(Z_a \pm \delta) = ln(Z_a) \pm K_\alpha\sqrt{J}_{BC} \tag{6.19}$$

where K_α is the number of standard deviations in either side of the mean. For example, for a normal distribution of Z_a, at the 95% confidence interval (δ) of Z_a can be stated as follows:

$$ln(Z_a \pm \delta) = ln(Z_a) \pm 1.65\sqrt{J_{BC}} \quad (6.20)$$

5. Probability of the Observed Contingency Index, I_{BC}

Since the lowest acceptable value of BCR is unity, this value becomes a threshold of acceptability that, in the absence of over-riding social and political aspects, has to be met or exceeded by the estimate of actual BCR. As noted by Lutz and Cowles (1971) in this situation Z_a=1 and $ln\, Z_a$ =0. Hence, Expression (6.18) indicates that the contingency index equals the logarithm of the reciprocal of the benefit-cost ratio estimate, i.e.,

$$I_{BC} = ln(1/Z_p) \quad (6.21)$$

Therefore Expression (6.18) becomes :

$$ln(Z_a) = ln(Z_p) + ln(1/Z_p) \quad (6.22)$$

By making an assumption of normality for the distribution of I_{BC}, the probability of I_{BC} exceeding a value of $ln(1/Z_p)$, or more precisely, a Benefit-Cost ratio of one can be defined. The standardized variable, K_α, in this instance can be defined as :

$$K_\alpha = \frac{ln(1/Z_p) - I_{BC}}{\sqrt{J_{BC}}} \quad (6.23)$$

Based on historical data from completed projects, and using this statistical approach and the probability density function of the contingency index, the distribution of random variables (benefit and cost variables) contributing to the outcome of a project can be defined to determine the most likely, upper and lower values of uncertain parameters for the projects under consideration. The procedure is applied as follows:

- **Step 1:** Regionalize the historical data from completed projects with respect to their regional characteristics similar to the regionalization applied to the selection criteria, e.g., developed regions in and off Java and underdeveloped regions off Java.

- **Step 2:** Perform statistical analysis using the Lutz and Cowles (1971) approach as outlined above (Expressions (6.13)-(6.20)) for each region to determine the contingency index and other parameters required for prediction in the next step.

- **Step 3:** Using the contingency index and the other parameters obtained in Step 2, benefit and cost parameters of the project under consideration determined by traditional Benefit-Cost analysis are corrected by taking into account regional characteristics. Such corrections are required in order to eliminate over-and under- estimations of component of benefits and costs due to various types of uncertainties inherent in future predictions.

An example application of the Lutz and Cowles (1971) method for determination of contingency indices for the completed irrigation projects in three regional profiles, i.e., developed regions in and off Java and underdeveloped region off Java are shown in Tables A.8, A.9, and A.10 respectively (see the bottom of these tables). These features are required in the determination of the 'correct' values of the upper and lower values of component of benefit and cost that were calculated by the traditional method. The correct values of the bounds are required by the FOSM method (Goicoechea et al., 1982; Dandy, 1985) in the probabilistic analysis of the NPVB criterion.

Statistical Analysis of Net Present Value of Benefit Criterion

Consider a water resources project which has a number of components of benefit ($\Theta_e, e = 1, \ldots, y$) and cost ($\Theta_e, e = y+1, \ldots, y+z$). Typical benefit components include those due to irrigation, swamp reclamation, flood control, water supply and hydro power. Typical cost components are the construction cost, operating cost and maintenance cost. In all cases the benefits and costs are expressed in present value terms using an appropriate discount rate. It should be noted that, in deriving these components of benefits and costs, any implications of uncertainties, whether they are physical or non-physical, have to be taken into consideration. Ideally these impacts can be quantified in monetary terms in which case the implications can be directly incorporated into the Benefit-Cost analysis. In this case when the implications of uncertainties cannot be quantified in monetary terms a combination of Point Allocation and Multiple Variable Regression approaches similar to those discussed earlier may be applied in order to consider these factors appropriately.

If the separate components $\Theta_e (e = 1, \ldots, y+z)$ can be estimated with certainty, the net benefit for a given project, NB, can be computed and used for comparison with other possible projects.

$$NB = \sum_{e=1}^{y} \Theta_e - \sum_{e=y+1}^{y+z} \Theta_e = B - C \tag{6.24}$$

where B is the total project benefit, and C is total project cost.

However, there are usually uncertainties involved in estimating future values of $\Theta_e(e = 1, \ldots, y + z)$, and hence there will be uncertainty in the estimated value of NB. An economic comparison of projects should take this uncertainty into account, as a risk-averse decision maker may well prefer project A, which has less uncertainty in its NB to project B, which has a higher expected NB but much greater uncertainty.

The mean and variance of any particular component Θ_e can be obtained from an estimate of the "expected value" (Θ_e^M), an "optimistic value" (Θ_e^U) and a pessimistic value "(Θ_e^L)" which are determined based on historical data and subjective inputs using the contingency index suggested by Lutz and Cowles (1971) as described in Expressions (6.13)-(6.20) previously. The optimistic and pessimistic values can be assumed to represent some form of confidence intervals for the true value. A means for obtaining the mean and variance of each individual Θ_e, derived from these boundaries, is given by Dandy (1985):

$$\bar{\Theta}_e = \Theta_e^M \tag{6.25}$$

$$S_e^2 = \left[\frac{1}{K}(\Theta_e^U - \Theta_e^L)\right]^2 \tag{6.26}$$

where :

$\bar{\Theta}_e$ =mean value of the benefit or cost component Θ_e,

S_e^2 =variance of the benefit or cost component Θ_i,

K =constant defining the confidence limits (For example, if the benefits and costs are normally distributed and Θ_e^U and Θ_e^L define a 95% confidence limit, K equals 1.65).

The mean value of the total project benefits is then equal to the sum of the means of the individual benefits components. The variance of the total benefits S_B^2 can be found from the following equation (Benjamin and Cornell, 1970) as follows:

$$S_B^2 = \sum_{e=1}^{y} S_e^2 + 2\sum_{e=1}^{y} \sum_{u=e+1}^{y} \rho_{eu} S_e S_u \tag{6.27}$$

Where ρ_{eu} is the correlation coefficient between benefit components Θ_e and Θ_u. An approximate expression for the mean and variance of NB, derived using a first order second-moment analysis (Benjamin and Cornell, 1970), is

$$\overline{NB} = \bar{B} - \bar{C} \tag{6.28}$$

$$S^2_{NB} = S^2_B + S^2_C - 2\rho_{BC} S_B S_C \tag{6.29}$$

where $\bar{B}$ and $\bar{C}$ are the mean values of the total benefits and total costs respectively and S^2_{NB} is variance of the net benefits.

The correlation coefficient between B and C, ρ_{BC}, can be found using the following equation (Dandy, 1985):

$$\rho_{BC} = \frac{(\sum_{e=1}^{y} \sum_{f=1}^{z} \rho_{ef} S_e S_f)}{S_B S_C} \tag{6.30}$$

As mentioned earlier, unlike the approach of Goicochea (1982) and Dandy (1985), in this study the estimate of "most likely", "upper" and "lower" values of components of benefits and costs are not based solely on the subjective estimate of an expert, but rather on original benefit and cost data of individual projects under consideration, having corrected those data with respect to the tendency of overestimating benefits and underestimating costs using Contingency Index approach proposed by Lutz and Cowles (1971). (In this study historical data of completed irrigation schemes which have been regionalized with respect to underdeveloped and developed regions in Indonesia are used to determine the characteristics of the contingency index.)

Once estimates for the means and variances of the net benefit, NB, are obtained approximation of the full probability density function (pdf) is required to assess the likelihood of NB lying within certain range. An appropriate distribution, e.g., normal, lognormal or gamma, can then be used to determine values of net benefit which will be exceeded with appropriate probabilities. Tung (1992) investigated various probability distributions commonly used in describing the random nature of net benefit criteria and concluded that, relative to the other distributions investigated, e.g., lognormal, gamma and Weibull, the normal distribution provides a favourable probability model for the net benefit criterion.

The decision variable is then specified, on the basis of the Net Benefits following a Normal distribution, such that the specified portion of the probability distribution is covered. Issues addressed in this step are related to such questions as; plans with a smaller variance may be preferred over other plans with larger variance at confidence limit of 95%, while the plans with a larger variance maybe preferred over the plans with a smaller variance at a confidence limit of only 5%.

Probabilistic Analysis of NPVB

The overall procedures for the probabilistic analysis of the NPVB criterion can be summarized as follows:

Step 1: Calculate the components of costs and benefits relevant to NPVB criterion for each individual project under consideration. Perform an economic analysis to determine the NPVB score for each project using the acceptable standard.

Step 2: Collect economic historical data relevant to NPVB criterion from the completed projects related to the regions of the projects under consideration.

Step 3: Regionalize data from the completed projects with respect to their social profile e.g., developed and underdeveloped regions.

Step 4: Perform statistical analysis for the characteristics of each region using the modified Lutz and Cowles (1971) approach described in Expressions (6.13)-(6.20) to determine the contingency index parameters associated with each region in which the potential projects are located and any other parameters required for performing the correction analysis in the Step 5.

Step 5: Determine statistical parameters e.g., the estimate of "most likely", "upper" and "lower" values of components, of benefits and costs for each of the individual projects based on the original values obtained in Step 1 having been corrected using the contingency index defined in Step 4 taking into account relevant region characteritics.

Step 6: Compute statistical parameters, e.g., the estimate of mean, variance and standard deviation of the NPVB criterion that are required by the deterministic equivalent of the chance constraint for the NPVB criterion using the FOSM (First Order Second Moment) analysis described in Expressions (6.25)-(6.30). By assuming normality for the NPVB distribution, the values of NPVB criterion for the critical level of confidence limits (β) e.g., 95% (the upper level), 55% (rounding up of the mean between the absolute upper limit [100%] and the lower limit [5%]), and 5% (the lower limit) of the time the value of NPVB criterion are exceeded respectively, can be obtained.

The diagram showing the above procedures is presented in Figure 6.6.

Derivation of Deterministic Equivalent

The net benefits defined in the above procedure are used as one of the screening or decision criteria in the model formulation. In the proposed CCIGP model, the goal constraint of net benefit is modified to allow small violations with a specified probability. Assuming normal distribution for the distribution of net benefits this modified equation can be written

$$Prob(\sum_{j=1}^{M_t} NB_j X_j \geq \ NBG) \geq \ \beta \quad j = 1, ..., M_t \tag{6.31}$$

Where:

NB_j = net present value of benefit of project j defined as a random variable,

$E(NB_j)$ = expected net present value of benefit of project j,

X_j = {0-1} decision variables

$$= \begin{cases} 1 & \text{if project } j \text{ selected} \\ 0 & \text{otherwise} \end{cases}$$

NBG = net present value of benefit goal,

β = degree of the confidence limit,

M_t = number of potential projects being considered in the scheduling horizon t,

t = index corresponding to one of the scheduling horizon (stages) taking integer values in the range of $1, ..., S$,

S = number of scheduling horizons (stages) of the SDP model within a given long term planning horizon.

Since almost all water resources projects to be implemented in a given time period are located away from each other, i.e., they are located at different provinces and different catchment areas, the correlations between project performances are insignificant (In the Indonesian case study used to demonstrate use of the procedure this is normally the case). Thus it can be reasonably assumed that there is no correlation between the projects considered. However, some recognition of the relationships between projects such as mutually exclusive, prerequisite

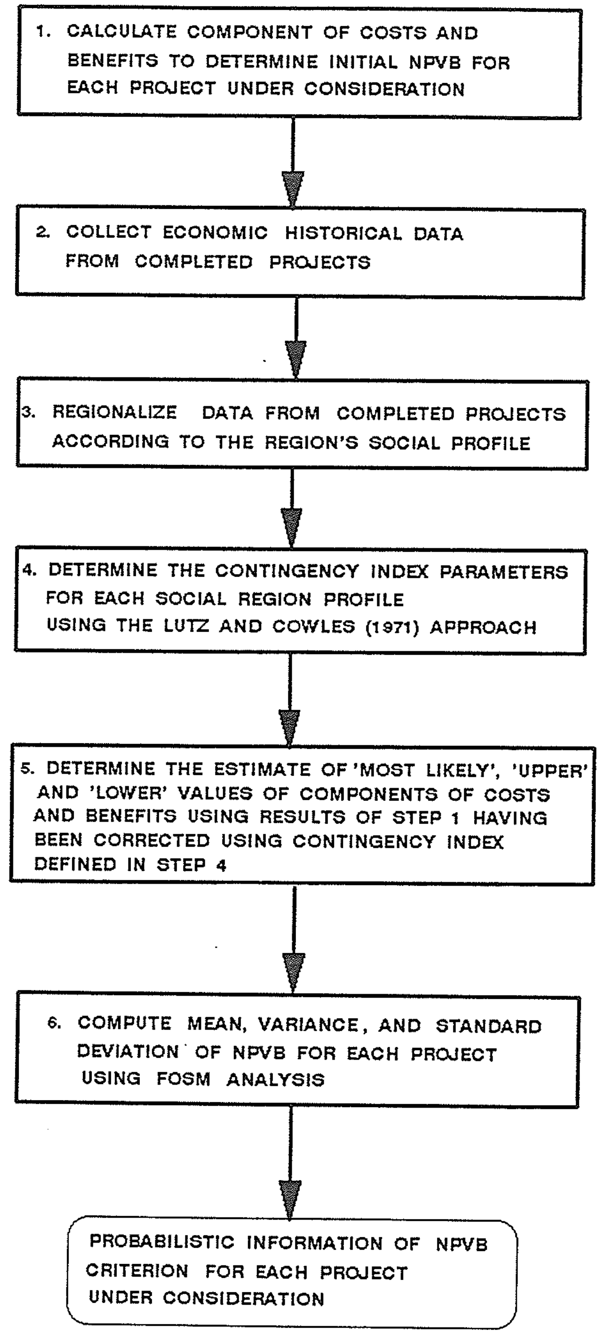


Figure 6.6: A Diagram of Procedure for Probabilistic Analysis of NPVB

and complementary projects can be articulated using the IP formulation as described earlier rather than using coefficient of correlation, covariance, etc.

The deterministic equivalent of Expression (6.31) can be derived as follows: By subtracting $\sum_{j=1}^{M_t} E(NB_jX_j)$ from both sides of the probability expression on the left-hand-side of Expression (6.31), and then dividing both sides by $\sqrt{\mathrm{Var}\left\{\sum_{j=1}^{M_t} NB_jX_j\right\}}$, i.e., the positive square root or the standard deviation of the sum of variances of Net Benefit for M_t independent/uncorrelated X_j projects (for $j = 1, ..M_t$), the probabilistic constraint in Equation (6.31) may be restated as:

$$Prob\left[\frac{\sum_{j=1}^{M_t} NB_jX_j - \sum_{j=1}^{M_t} E(NB_jX_j)}{\sqrt{\mathrm{Var}\left\{\sum_{j=1}^{M_t} NB_jX_j\right\}}} \geq \frac{NBG - \sum_{j=1}^{M_t} E(NB_jX_j)}{\sqrt{\mathrm{Var}\left\{\sum_{j=1}^{M_t} NB_jX_j\right\}}}\right] \geq \beta \qquad (6.32)$$

If each NB_j is assumed to have a normal distribution, $\frac{\sum_{j=1}^{M_t} NB_jX_j - \sum_{j=1}^{M_t} E(NB_jX_j)}{\sqrt{\mathrm{Var}\left\{\sum_{j=1}^{M_t} NB_jX_j\right\}}}$ must also be normal with mean of zero and standard deviation one. A value K_β (number of standard deviations to the left or to the right of zero) can then be determined from the area under a normal curve such that

$$Prob\;[\bar{Z} \geq K_\beta] = \int_{K_\beta}^{\infty} \frac{1}{\sqrt{2\pi}} exp(-\frac{z}{2})dz = \beta \qquad (6.33)$$

where $\bar{Z}$ is standard normal variable and z is random variable

Thus, for given levels of β,

$$Prob\left[\frac{\sum_{j=1}^{M_t} NB_jX_j - \sum_{j=1}^{M_t} E(NB_jX_j)}{\sqrt{\mathrm{Var}\left\{\sum_{j=1}^{M_t} NB_jX_j\right\}}} \geq K_\beta\right] = \beta \qquad (6.34)$$

Expression (6.32) holds for the goal constraint if and only if:

$$\frac{NBG - \sum_{j=1}^{M_t} E(NB_jX_j)}{\sqrt{\mathrm{Var}\left\{\sum_{j=1}^{M_t} NB_jX_j\right\}}} \leq K_\beta \qquad (6.35)$$

Rearranging Expression (6.35) results

$$\sum_{j=1}^{M_t} E(NB_jX_j) + K_\beta\left[\sqrt{\mathrm{Var}\left\{\sum_{j=1}^{M_t} NB_jX_j\right\}}\right] \geq NBG \qquad (6.36)$$

Non-linearities can be seen to appear in Expression (6.36). Since $NB_1, ..., NB_{M_t}$ together with $X_1, ..., X_{M_t}$ are assumed to be mutually independent and the X_j are restricted to values of zero or one, the method suggested by Hillier (1969) is applied to linearize the Expression (6.36). In the approach of Hillier (1969) the non-linear deterministic equivalent represented by Expression (6.36) is converted to a linear form by replacing the non-linear term of the expression by its linear upper bound as defined below

$$\sqrt{\operatorname{Var}\left\{\sum_{j=1}^{M_t} NB_j X_j\right\}} = \sigma - \sum_{j=1}^{M_t}[\sigma - \sqrt{\sigma^2 - \sigma_j^2}](1 - X_j) \tag{6.37}$$

where:

$\sigma = \sqrt{\sum_{j=1}^{M_t} \operatorname{Var}(NB_j)}$ = standard deviation of the sum of Net Benefit for M_t projects; $NB_1, ..., NB_{M_t}$,

$\sigma^2 = \sum_{j=1}^{M_t} \operatorname{Var}(NB_j)$ = variance of the sum of variances of Net Benefits for M_t projects; $NB_1, ..., NB_{M_t}$,

$\sigma_j^2 = \operatorname{Var}(NB_j)$ = variance of Net Benefit of individual project j for $j = 1, ..., M_t$, obtained by Equation (6.29).

Thus linear deterministic equivalent of the probabilistic constraint as specified in Expression (6.31) can be written as

$$\sum_{j=1}^{M_t} E(NB_j X_j) + K_\beta \left\{\sigma - \sum_{j=1}^{M_t}[\sigma - \sqrt{\sigma^2 - \sigma_j^2}](1 - X_j)\right\} \geq NBG \tag{6.38}$$

Reformulating Expression (38) as an equality by using deviational variables yields the following goal constraint for the CCIGP:

$$\sum_{j=1}^{M_t} E(NB_j X_j) + K_\beta \left\{\sigma - \sum_{j=1}^{M_t}[\sigma - \sqrt{\sigma^2 - \sigma_j^2}](1 - X_j)\right\} + DNB^- - DNB^+ = NBG \tag{6.39}$$

6.5 Overall Formulation of CCIGP Model

The CCIGP model is used to select, schedule, and also to budget the projects that are candidates for implementation in the specified planning horizon. In formulating decision problems for the portfolio approach for investment in water resources projects using the goal programming format, four major components are required:

1) The usual *economic resource constraints* of LP, which are also called *hard constraints* in that they cannot be violated since they represent resource limitations or restrictions imposed on the decision environment. However, these types of constraints are subject to uncertainty or fluctuation in their level of availability and imprecision in target setting. A proposed integrated approach to handle these problems will be addressed in the next chapter.

2) *Goal or criteria constraints*, which are also called *soft constraints* because they represent managerial policies and desired level of various objectives or criteria which being sought from the decision maker. As shown for the NPVB goal, some of these objectives may be represented in probabilistic form.

3) Managerial constraints, which are also called *system constraints* because they articulate the systems by which management want to achieve the overall objective, for example, by scheduling constraints, project interrelationship, etc.

4) The *objective function,* which minimizes the weighted deviations from the desired levels of the various objectives according to a specified priority ranking.

The consideration of each of these issues in the proposed CCIGP are described in the following sections.

6.5.1 Budgetary Constraints

The budgetary constraints require the total funds expended in any given time period (scheduling period or stage of the SDP) to be less than or equal to the total funds BT_t available for the t^{th} scheduling horizon. The range of actual values of BT_t^k for $k = 1, ..., N_{D_{t,i,m}}$ and $t = 1, ..., S$ to be used in the CCIGP analysis are supplied by the SDP (As described in Chapter 5, this range is defined as the range of levels of possible funding decisions.) The value of BT_t^k $\forall$ k, t is therefore the communication from the SDP to the CCIGP. In this case, BT_t^k takes various values to reflect budgetary fluctuations or estimation discrepancies between range of levels of possible funding decision, D_t^k, and range of levels of actual funding recieved F_t^l for $l = 1, ..., N_{F_{t,i,m}}$. The detailed description of the approach to handle such discrepancies is given in the next Subsection.

Defining Optimal Annual Budget Allocation

In the integrated formulation CCIGP-SDP proposed in this study, the total budget available BT_t^k in each of the scheduling periods (stages of SDP) becomes an uncertain parameter. However, its optimal allocation in each year over the specified scheduling horizon NT needs to be determined by an optimization technique to obtain 'optimal' annual budget uses. The budget level to be planned for, i.e., anticipated in each year of the NT-year scheduling horizon can be set or treated as a variable to be optimized. The implications of various modes of annual budget allocations relative to the goal achievement has been examined according to the budget options listed below:

1. Existing modes of allocation: $13\%BT_t^k$; $24\%BT_t^k$; $21\%BT_t^k$; $20\%BT_t^k$; $22\%BT_t^k$ per year over a period of five years (determined in this case from examination of the historical allocation of money to irrigation project in Indonesia which is the case study used in Chapter 7 to demonstrate the model)

2. Equal allocation : $20\%BT_t^k$; $20\%BT_t^k$; $20\%BT_t^k$; $20\%BT_t^k$; $20\%BT_t^k$

3. Variable to be optimized by model : $B_t^1, B_t^2, .., B_t^t, .., B_t^{NT}$ where B_t^n = Budget allocated in the t^{th} year of NT year of the scheduling horizon of the stage t, for $n = 1, ..., NT$ and $t = 1, ..., S$.

Examination of all three budget options showed the expected results that the third mode produced the best goal achievement over a range of total budget BT (Sutardi et al., 1990). It will therefore be used as the basis to run the models.

In this proposed CCIGP model two types of budgetary constraints are formulated. The first budgetary constraint is the annual budget constraint, which states that funds committed to projects to be implemented in the n^{th} year cannot exceed the funds allocated in that year (B_t^n). The annual budget allocations B_t^n become decision variables that have to be optimized in the second budgetary constraint.

The second budgetary constraint defines a restriction on the total budget available (BT_t^k) during a given scheduling horizon. This constraint specifies that the sum of annual budget allocations, as represented by the sum of the values of the decision variables B_t^n over the duration of the scheduling horizon, cannot exceed the total funds available in the t^{th} scheduling horizon (BT_t^k).

6.5.2 The Consequences of Imperfect Budgetary Information

As described in Section 5.4 and previous Subsections, due to the uncertainty in the actual amount of money to be made available in any scheduling horizon t, there is a need to address the implication of the difference between the level of possible funding decision planned D_t^k in a given scheduling horizon t and the level of funding actually being received F_t^l in the same scheduling horizon t. The consequences of this imperfect estimation of the anticipated funds available for investment can be further explained as follows. Consider the case in which the level of funding being planned for scheduling horizon t is at level one $(k = 1)$, D_t^1, and implies a monetary value of F_1. However, the level of funding actually being received in scheduling horizon t may be level two $(l = 2)$, F_t^2, implying a monetary value of F_2 in which $F_2 < F_1$. In such a case, at the end of the scheduling period (t), only a portion of the project will be completed. Moreover, the ratio of the actual level of development completed at the end of the period to the level of development anticipated, and similarly the ratio of net benefit accrued from it at the end of the period to the net benefit anticipated, are likely to be less than the ratio F_2/F_1. The deviation from the ratio F_2/F_1 occurs due to the inability to complete works already planned/started because of the need for extra costs for adjustments such as a design adjustment and adjustments of preparation works. Both factors relate to the typical non-linear proportion between cost and physical achievements.

Implications of the imperfect budget estimation can be incorporated in the formulation of the CCIGP model by introducing a penalty in terms of a cost escalation coefficient in proportion (percentage) to the contruction cost components in order to accomodate any extra costs required for any adjustments necessary in response to actual budget allocations different from those anticipated in the planning process. The larger the difference between the planned funding level and the funding actually received (the farther l is from k), the larger is the cost escalation coefficient (cost escalation coefficients greater than one). When

Table 6.3: Example of the Cost Escalation Coefficients

Level of Actual Funding Received F_t^l	Level of Planned Funding D_t^k	Cost[1)] Escalation Coefficient	Remarks
$l = 1$	$k = 1$	1.0*)	*) Without cost escalation
$l = 1$	$k = 2$	1.04	when $k = l$
$l = 1$	$k = 3$	1.07	for $k = 1, ..., N_{D_{t,i,m}}$,
$l = 1$	$k = 4$	1.10	for $l = 1, ..., N_{F_{t,i,m}}$, and
$l = 1$	$k = 5$	1.13	$N_{D_{t,i,m}} = 5$ and $N_{F_{t,i,m}} = 1$

1) Based on the experience during the last 20 years of water resources development in Indonesia.

$l = k$, the cost escalation coefficient is equal to one. In general, if the number of levels of possible funding decision planned is $N_{D_{t,i,m}}$, i.e., $k = 1, ..., N_{D_{t,i,m}}$ and the number of levels of actual funding being received is $N_{F_{t,i,m}}$, i.e., $l = 1, ..., N_{F_{t,i,m}}$ there will be $N_{D_{t,i,m}} * N_{F_{t,i,m}}$ cost escalation coefficients. An example of defining cost escalation coefficients for $N_{D_{t,i,m}}$=5 and $N_{F_{t,i,m}}$=1 is given in Table 6.3.

To demonstrate and examine the implications of imperfect budgetary information in project selection decision making processes, ($N_{D_{t,i,m}} * NLAF_n$) CCIGP models, reflecting $N_{D_{t,i,m}} * N_{F_{t,i,m}}$ possible cost escalation coefficients are run for each scheduling horizon (stage) of the SDP in the demonstration application of the model described later in the thesis.

6.5.3 The Goal and Criteria Constraints

As has been described earlier, there are three major objectives considered in this CCIGP model:

1) Optimizing economic efficiency as measured in monetary units in terms of Net Present Value of Benefit (NPVB) criterion. As noted previously this economic criterion is subject to various types of uncertainties. Therefore, the contribution of the individual projects in achieving NPVB goal should be quantified in probabilistic terms.

2) Optimizing achievement of non-economic objectives measured in non-monetary units, for example number of hectares of irrigation area developed, number of families to be moved to new agricultural areas, etc. These non-economic objectives are considered to accomodate

the need to achieve specified aspirational levels of Regional Development, Other Social Effects (OSE), and Environmental Quality (EQ) objectives being sought through implementation of water resources projects.

3) Optimizing achievement of selection criteria in which projects' eligibilities for implementation in terms of a certain criterion are compared to each other and with respect to a minimum eligible scoring grade. As described earlier, these selection criteria are required to accomodate the need to provide the DM with information concerning the certainty of those socio-technical and political factors which contribute to success of water resources projects but which cannot be quantified in monetary terms. It should be noted that the coefficients on left hand side of these constraints represent the score or level of satisfaction of individual project with respect to each criterion. In this thesis, these scores are obtained using: i) a point allocation and weighting approach which suitable for situation when there are insufficent data to perform regression analysis , and ii) a combination of point allocation and multiple variable regession analysis when sufficient data are available (Expressions (6.1) and (6.2))

Note that the term 'optimizing' used above refers to the DM's desire to achieve a set of goals and selection criteria as close as possible to a set of specified aspiration levels.

6.5.4 The Managerial Constraints

In the proposed portfolio model the construction period contraints for scheduling the projects and the socio-political contraints are categorized as managerial constraints.

The Construction Period: These constraints are needed to ensure that a project is selected for a sufficient number of years to ensure completion of the construction and that it is started at the optimum position of the construction period within the NT years of the development scheduling horizon. The construction period constraints introduced in this model are able to select the optimum period, designated henceforth as NP^* of the construction period in which to implement each project selected for development within the scheduling horizon. The scheduling formulation in this model assumes that small to medium projects are constructed over periods of 2-5 years and must be scheduled in one scheduling horizon (NT) or stage of the SDP model. Various values of NT ranging from 5 years to 10 years will be examined in the demonstration example.

Socio-Political Constraints: Socio-political constraints are defined as those which influence or require project acceptance regardless of the economic desirability of a project. Such projects may be required to boost regional economic development for less developed regions in which government intervention is required for any projects or development to go ahead. The validity of such concerns is relevant in the context of centrally planned and funded policies such as those used in developing countries, such as Indonesia. The approach permits these "required" projects to be optimally scheduled and budgeted within the appropriate time period. The other projects which are candidates for selection can then be allocated around these required projects.

6.5.5 Objective Function

To formally represent the objective function in a GP method, the following three parameters must be specified:

1) The *priority levels* placed on the goals and criteria. These priorities indicate the ordinal ranking scheme by which the goals and constraints will be optimized.

2) The *relative weights* attached to the goal deviations in the objective function. These weights have two purposes (Hartley, 1976):

- the weights may be used to rank goals according to the importance of one relative to another in order to reflect the DM's preferences for one goal over another. The goals with higher weights are therefore satisfied more completely in preference to the goal with the lower weighted goals,
- the weights may also be used as weight adjustors to make the goal deviations additive, i.e., to remove the incommensurability of goal deviations measured in different units.

It should be noted that, if some goals are given the same priority, i.e., some goals are considered equally important, the weights might still not be equal because of the implicit differences in the units of measurement of the goal deviations. In order to counter the implicit weighting differences , weights (W_r^+ and W_r^-) may still be required to equalize the relative weights assigned to each goal (Sutardi et al., 1990, and 1991a).

Table 6.4: Appropriate Objective Function Terms in Goal Programming

Desired Action	*Objective Function Term*
Achieve a minimum level of some goal	minimize d^-
Do not exceed a specified level of some goal	minimize d^+
Come as close as possible to a specified goal level	minimize $(d^+ + d^-)$
Maximize the value achieved relative to a given goal level	minimize $(d^- - d^+)$
Minimize the value achieved relative to a given goal level	minimize $(d^+ - d^-)$

Source: Clark et al. (1984)

3) The *relevant deviational variable(s)*; These variables should be weighted with respect to the priority preferences given to the associated goal and criterion and 'optimized' according to the desired action on type of performance required. The range of formulations which can be used in the objective function to achieve the desired type of optimization is shown in Table 6.4.

6.6 Mathematical Formulation of CCIGP Model

The mathematical formulation of a CCIGP under these requirements for the specific example of irrigation investment planning in Indonesia describe earlier in this thesis is given below. Note that this formulation reflects the range of goals and selection criteria discussed earlier with respect to the social and economic objective and selection criteria of irrigation development in Indonesia and is applicable for one scheduling horizon. The formulation must also be solved for each possible combination of levels of possible funding decisions D_t^k and levels of actual funding received F_t^l at each scheduling horizon (stage) t, i.e., a BT_t^k value is required for $k = 1, ..., N_{D_{t,i,m}}$; $l = 1, ..., N_{F_{t,i,m}}$, and $t = 1, ..., S$.

Objective Function:

$$\text{MIN:} \quad WIAD_t^- DIAD_t^- + WNB_t^- DNB_t^- + WTS_t^- DTS_t^- + WPPE_t^- DPPE_t^- + WERF_t^- DERF_t^- + WFRD_t^- DFRD_t^- \tag{6.40}$$

subject to:

Goals

1) Irrigable Area Demand:

$$\sum_{j=1}^{M_t} IAD_j X_j + DIAD_t^- - DIAD_t^+ = IADG_t \tag{6.41}$$

2) Economic Return:

$$\sum_{j=1}^{M_t} E(NB_j X_j) + K_\beta \left\{ \sigma - \sum_{j=1}^{M_t} [\sigma - \sqrt{\sigma^2 - \sigma_j^2}](1 - X_j) \right\} + DNB_t^- - DNB_t^+ = NBG_t \tag{6.42}$$

3) Transmigration Support:

$$\sum_{j=1}^{M_t} TS_j X_j + DTS_t^- - DTS_t^+ = TSG_t \tag{6.43}$$

Criteria

4) Physical Potential and Environmental Aspects:

$$\sum_{j=1}^{M_t} E(PPE_j)X_j + DPPE_t^- - DPPE_t^+ = PPEG_t \tag{6.44}$$

5) Extent of Existing Rice Fields:

$$\sum_{j=1}^{M_t} ERF_jX_j + DERF_t^- - DERF_t^+ = ERFG_t \tag{6.45}$$

6) Agricultural Production and Marketing Factors Related to Farmer Readiness:

$$\sum_{j=1}^{M_t} E(FRD_j)X_j + DFRD_t^- - DFRD_t^+ = FRDG_t \tag{6.46}$$

Operational and Managerial Constraints:

7) Construction Period: to ensure a project is scheduled in sequential year without interruption:

$$\sum_{(np_j)=1}^{NP_j} Y_{j(np_j)} - X_j = 0 \quad j = 1, ..., M_t \tag{6.47}$$

8) Annual Budget Constraints: to define budget expenditure in each year n of the scheduling horizon t:

$$\sum_{j \in M_t^n} (C_{jt})^* Y_{j(np_j)} \leq B_t^n \quad n = 1, ..., NT; \quad (np_j) = 1, ..., NP_j; \quad j = 1, ..., M_t, \tag{6.48}$$

9) Total Budget Constraints: to ensure the budget spent over a scheduling period t (stage) of the SDP is less than or equal to total budget available for that scheduling horizon:

$$\sum_{n=1}^{NT} B_t^n \leq BT_t^k \quad k = 1, ..., N_{D_{t,i,m}} \quad t = 1, ..., S, \tag{6.49}$$

9) Binary Constraints: to ensure 'go' or 'no go' status of the potential projects under consideration at each scheduling horizon.

$$X_j = 0, 1 \quad j = 1, ..., M_t \tag{6.50}$$

$$Y_{j(np_j)} = 0, 1 \quad j = 1, ..., M_t, \quad (np_j) = 1, ..., NP_j \tag{6.51}$$

where:

$WIAD_t^-$ = weighting factor for the Irrigation Area Developed goal at stage t,

$DIAD_t^-$ = underachievement for the Irrigation Area Developed goal at stage t,

$DIAD_t^+$ = overachievement for the Irrigation Area Developed goal at stage t,

$IADG_t$ = specified target or aspiration level for IAD goal at stage t,

WNB_t^- = weighting factor for the Net Present Value of Benefit goal at stage t,

DNB_t^- = underachievement for the Net Present Value of Benefit goal at stage t,

DNB_t^+ = overachievement for the Net Present Value of Benefit goal at stage t,

NBG_t = specified target or aspiration level for NPVB goal at stage t

WTS_t^- = weighting factor for Transmigration Support goal at stage t,

DTS_t^- = underachievement for Transmigration Support goal at stage t,

DTS_t^+ = overachievement for Transmigration Support goal at stage t,

TSG_t = specified target or aspiration level for TS goal at stage t,

$WPPE_t^-$ = weighting factors for Physical Potential and Environmental goal at stage t,

$DPPE_t^-$ = underachievement for Physical Potential and Environmental goal at stage t,

$DPPE_t^+$ = overachievement for Physical Potential and Environmental goal at stage t,

$PPEG_t$ = specified target or aspiration level for PPE goal at stage t,

$WERF_t^-$ = weighting factor for Extent of Existing Rice Field goal,

$DERF_t^-$ = underachievement for Extent of Existing Rice Field goal at stage t,

$DERF_t^+$ = overachievement for Extent of Existing Rice Field goal at stage t,

$WFRD_t^-$ = weighting factor for Farmer Readiness goal at stage t,

$DFRD_t^-$ = underachievement for Farmer Readiness goal at stage t,

$DFRD_t^+$ = overachievement for Farmer Readiness goal at stage t,

$FRDG_t$ = specified target or aspiration level for FRD goal at stage t,

IAD_j = level of contribution of the j^{th} project to the IAD goal in terms of the amount of irrigation area developed (in hectares) in that project,

TS_j = level of contribution of the j^{th} project to the TS goal in terms of of the number of transmigrant families to be settled in that project,

$E(PPE_j)$ = level of contribution of the j^{th} project to the PPE goal in terms of the scoring (in % relative to the ideal condition within the prespecified lower and upper bounds (Table 6.1)) of the Physical Potential and Environmental criteria defined by the scoring prediction model expressed in Expression (6.1),

ERF_j = level of contribution of the j^{th} project to the ERF goal in terms of the existence of rice fields (in hectares) in the vicinity of that project,

$E(FRD_j)$ = level of contribution of the j^{th} project to the FRD goal in terms of the scoring (in % relative to the ideal condition within a prespecified lower and upper bounds (Table 6.2)) of the Farmer Readiness criteria defined by the scoring prediction model expressed in Expression (6.2),

X_j = {0-1} integer decision variable for the j^{th} project selected in the NT years of the development scheduling period,

$$= \begin{cases} 1 & \text{if the } j^{th} \text{ project is selected} \\ 0 & \text{otherwise} \end{cases}$$

$Y_{j(np_j)}$ = {0-1} integer decision variable for the project j accepted in the $(np_j)^{th}$ construction period position in which the CP_j years of contruction period of project j is started within a given development scheduling horizon NT,

$$= \begin{cases} 1 & \text{if the } j^{th} \text{ project is selected for construction} \\ 0 & \text{otherwise} \end{cases}$$

(np_j) = index corresponding to one of the possible positions in which the construction period of project j is started, taking integer values in the range of $(np_j) = 1, ..., NP_j$,

NP_j = number of possible positions in which the construction period of project j is started within a specified scheduling horizon. NP_j is defined by the following relationship: $NP_j = NT - CP_j + 1$.

NT = number of years of the duration of development scheduling horizon,

CP_j = number of years of construction period required by the project j,

C^*_{jt} = cost of project j in the t^{th} year of development scheduling period. Two influential parameters govern calculation of this cost, i.e., interest rate ($\Im$) and cost escalation coefficient. In this model, $\Im$ is defined as a function of NT. Cost escalation coefficient is applied to penalize potential discrepancies for each possible combination of D^k_t and F^l_t. Mathematically this relationship is defined as: $C^*_{jt} = C_{jt}(\Im NT, D^k_t, F^l_t)$

M_t^n = set of projects eligible for selection at the n^{th} year of the NT years of development scheduling period of the stage t,

B_t^n = annual budget at the n^{th} year of the t^{th} scheduling horizon,

BT_t^k = total budget allocated in the t^{th} scheduling horizon,

NB_j = net present value of benefit of the project j,

NBG_t = specified target or aspiration level for the NPVB goal at stage t,

σ = $\sqrt{\sum_{j=1}^{M_t} \text{Var}(NB_j)}$ = standard deviation of the sum of Net Benefits for the M_t projects; $NB_1, ..., NB_{M_t}$,

σ_j^2 = $\text{Var}(NB_j)$ = variance of Net Benefit of individual project j for $j = 1, ..., M_t$, (obtained by Expression (6.29)),

$E(NB_j)$ = expected Net Present Value of Benefit of project j,

β = level of confidence limit of Net Present Value of Benefit,

K_β = number of standard deviations to the left or to right of zero at confidence level β.

6.7 Fuzzy Chance Constrained Integer Goal Programming (FCCIGP)

It has been shown by Bector et al. (1992) and Sutardi et al. (1992b) that imprecise goals or targets setting in water resources planning can be handled effectively by taking advantage of fuzzy set theory (Zadeh, 1965; Zimmerman, 1988). Fuzzy Set theory recognizes that a DM might not be able to specify targets and/or goals precisely. For example, in many situations when specifying a budget level the DM may only be able to provide an upper bound on the budget (BT_t^k), and establish a tolerance in the form of a fraction of BT_t^k (for example 10% of BT_t^k below the budget limit BT_t^k) around that budget. Such conditions of fuzzy (imprecise) budget allocation may not be properly articulated into a traditional GP formulation and therefore formulation of GP in a fuzzy linear environment is more appropriate, especially to handle this type of non-random uncertainty.

This section addresses how fuzzy set theory can be used to incorporate imprecision in: i) target or goal settings, ii) upper and lower limit (dispersion) setting of uncertain parameters, and iii) qualitative determination of confidence limit levels in a decision-making process. The budgetary binding constraint, goal constraints, selection criteria constraints and chance constraints of the Chance Constrained Integer Goal Programming (CCIGP) portfolio project selection model proposed in the previous sections have been identified as potential components which may be better articulated if they are expressed in a fuzzy manner (Zimmermann, 1988). To achieve these improvements, specific procedures have been proposed in this study. Such procedures require knowledge of basic concept of fuzzy set theory.

6.7.1 Fuzzy Set Theory Derivation

The following are some basic concepts of fuzzy set theory (extracted from Zimmermann, 1988) that are relevant for formulating the above CCIGP for a fuzzy environment. [A more detailed analysis of the theory behind the incorporation of fuzzy set theory in the formulation can be found in Zadeh (1965) and Zimmermann (1988).]

Fuzzy Set Theory. The theory of fuzzy sets is basically a theory of graded concepts. A central concept of fuzzy set theory is that it is permissible for an element to belong partly to a set. Let X be a space of points or objects, with a generic element of X denoted by x. Thus $X = \{x\}$ or $x \in X$.

Fuzzy Set. A fuzzy set A in X is characterized by a membership function (MF) $\mu_A(x)$ which associates with each point in X a real number in the interval [0,1] with the value of $\mu_A(x)$ at x representing the "grade of membership" of x in A. Thus the nearer the value of $\mu_A(x)$ is to 1, the higher the grade of 'belongingness' of x to A.

In conventional (crisp) set theory, $\mu_A(x)$ takes only two values 1 or 0 depending on whether the element belongs or does not belong respectively to the set A.

Therefore, formally speaking, if

$X = \{x\}$ is collection of objects denoted generically by x, then a fuzzy set A in X is a set of ordered pairs, $A = \{(x, \mu_A(x))/x \in X\}$, where $\mu_A(x)$ maps X to the membership space [0,1].

The analysis used to incorporate fuzzy theory into the CCIGP is based on the following propositions of fuzzy sets (Zadeh, 1965 and Zimmermann, 1988).

Union of fuzzy sets. The union of two fuzzy sets A and B with respective MF's $\mu_A(x)$ and $\mu_B(x)$ is a fuzzy set C whose MF is $\mu_C(x) = Max\,[\mu_A(x), \mu_B(x)],\ x \in X.$

Intersection of fuzzy sets. The intersection of two fuzzy sets A and B with respective M.F.,'s $\mu_A(x)$ and $\mu_B(x)$ is a fuzzy set C whose MF is $\mu_C(x) = Min\,[\mu_A(x), \mu_B(x)],\ x \in X.$

The specific characteristics of the project selection problem that suggest it might be appropriately formulated in a fuzzy environment are:

1) **Imprecise budget limit levels.** In this case the DM only provides an upper bound on the estimated budget available, BT_t^k, over the entire scheduling horizon t. The actual budget realisation is likely to lie below this upper bond. A tolerance which defines the acceptable (with varying degrees of membership or support) dispersion of budget estimation which lies within the 'range' of the budget definition may be given in the form of fraction of BT_t^k for example, 10% or 20% below BT_t^k.

2) **Imprecise aspiration levels.** Aspiration level of goals or target may also be imprecisely specified. In this situation, instead of setting a fixed target, the DM may specify intervals reflecting his or her satisfaction level relative to the goal achievements. Lower bounds and spreads of the tolerance interval in this case have to be specified quantitatively.

3) **Imprecision of choice of level of the confidence limit.** The choice of level of the confidence limit for the NPVB criterion in the existing approach (CCP) may be rather abritrary as it is based largely on a subjective choice by the DM and therefore subject to some degree of imprecision. The problems associated with the subjective nature of such choices can be mitigated by the use of membership grades allowing qualitative judgments to be incorporated in the decision making process through a basic scaling method for priority proposed by Saaty (1977). (The scaling procedure to determine membership grade is discussed in the next subsection.)

Based on the above conditions it can be shown that the proposed model is a symmetric fuzzy LP.

Notation

Following Zimmermann (1988), let

BT_{BL}= BT_n^k = upper bound estimate of budget available as specified by the DM,

P_{BL} = tolerance interval which defines the range of budget below the upper bound,

μ_{BL} = membership function (MF) for the budgetary constraint,

μ_{qL} = MF for lower side of the fuzzy region of fuzzy constraint corresponding to the q^{th} goal or criterion,

μ_{qU} = MF for upper side of the fuzzy region of fuzzy constraint corresponding to the q^{th} goal or criterion,

P_q = tolerance interval for the q^{th} goal or criterion,

q = index corresponding to one of the goals and criteria under consideration, taking integer values in the range of $q = 1, ..., Q$,

Q = number of goal and criteria constraints considered in the CCIGP formulation consisting of the three goals, i.e., IAD; NPVB; TS, and the three criteria, i.e., PPE; ERF; FRD,

G_q = specified target or aspiration level for the q^{th} goal or criterion,

A_{jq} = level of contribution of the j^{th} project to the q^{th} goal or criterion.

All other symbols and variables have the same meaning as in crisp formulation of CCIGP. When converted to a fuzzy environment, the CCIGP formulation becomes the following problem:

Determine X_j's, $j = 1, ..., M_t$, that satisfy:

1.**Fuzzy constraints.**

(i) Budgetary constraints

$\sum_{t=1}^{NT} B_t^n \lesssim BT_{BL}$

with μ_{BL} as the corresponding MF for the budgetary constraint. Note that only deviations below the budget available need to be considered here. where,

"$\lesssim$" ("$\gtrsim$")" has the linguistic interpretation "smaller than or equal to with certain degree lying between 0 and 1" "(greater than or equal to with certain degree lying between 0 and 1)" denoting the fuzzified equivalent of "$\leq$"("$\geq$").

(ii) General fuzzy goal and criterion constraints

$\sum_{j=1}^{M_t} A_{jq}X_j \lesssim G_q \quad \forall\, q$ with μ_{qL} as the corresponding MF, and

$\sum_{j=1}^{M_t} A_{jq}X_j \gtrsim G_q \quad \forall\, q$ with μ_{qU} as the correponding MF

2.**Crisp constraints**

(i) Annual Budget Constraints:

$\sum_{j \in M_t^n} C_{jt}^* Y_{j(np_j)} \leq B_t^n \quad n = 1, ..., NT; \quad (np_j) = 1, ..., NP_j; \quad j = 1, ..., M_t$

(ii) Construction Period Constraints:

$\sum_{(np_j)=1}^{NP_j} Y_{j(np_j)} - X_j = 0 \quad j = 1, ..., M_t$

The MF's for the fuzzy budgetary constraint and the general fuzzy constraints are defined as follows (Zimmermann, 1988):

For budgetary binding constraints the MF is

$$\mu_{BL} = \begin{cases} 1 & \text{if} \sum_{n=1}^{NT} B_t^n \leq BT_{BL} - P_{BL} \\ 0 & \text{if} \sum_{n=1}^{NT} B_t^n \geq BT_{BL} \end{cases}$$

and

$$\mu_{BL} = 1 - \frac{\sum_{n=1}^{NT} B_t^n - (BT_{BL} - P_{BL})}{P_{BL}} \quad \text{if} \quad BT_{BL} - P_{BL} < \sum_{n=1}^{NT} B_t^n \leq BT_{BL}$$

For the goal and selection criterion constraints the MF's are:

$$\mu_{qL} = \begin{cases} 1 & \text{if} \sum_{j=1}^{M_t} A_{jq} X_j = G_q \\ 0 & \text{if} \sum_{j=1}^{M_t} A_{jq} X_j < G_q - P_q \end{cases}$$

and

$$\mu_{qL} = 1 + \frac{\sum_{j=1}^{M_t} A_{jq} X_j - G_q}{P_q} \quad \text{if} \quad G_q > \sum_{j=1}^{M_t} A_{jq} X_j \geq G_q - P_q$$

$$\mu_{qU} = \begin{cases} 1 & \text{if} \sum_{j=1}^{M_t} A_{jq} X_j = G_q \\ 0 & \text{if} \sum_{j=1}^{M_t} A_{jq} X_j > G_q + P_q \end{cases}$$

and

$$\mu_{rU} = 1 - \frac{\sum_{j=1}^{M_t} A_{jq} X_j - G_q}{P_q} \quad \text{if} \quad G_q < \sum_{j=1}^{M_t} A_{jq} X_{jq} \leq G_q + P_q$$

Let $\mu_D(X)$ be the MF of the decision in the fuzzy set of the model. Since, for $q = 1, 2, ..., Q$, μ_{qL} and μ_{qU} are the lower and upper membership functions respectively of the fuzzy goal constraints, the decision space in the corresponding fuzzy environment is the intersection of the fuzzy sets corresponding to the fuzzy budget limit and the fuzzy goal constraints. Hence,

$$\mu_D(X) = Min\,[\mu_{BL}, \mu_{1L}, \mu_{2L}, ..., \mu_{QL}, \mu_{1U}, \mu_{2U}, ..., \mu_{QU}]$$

The operational solution of the model in a crisp "optimal" format can be obtained by maximizing $\mu_D(X)$ (Zimmermann, 1988) in the formulation:

$$\text{Max}\ \mu_D(x) = \text{Min}\,[\mu_{BL}, \mu_{1L}, \mu_{2L}, ..., \mu_{QL}, \mu_{1U}, \mu_{2U}, ..., \mu_{QU}] \quad (6.52)$$

subject to:

$$\mu_{qL} \geq \mu_D(X) \tag{6.53}$$

$$\mu_{qU} \geq \mu_D(X) \tag{6.54}$$

$$\mu_{BL} \geq \mu_D(X) \tag{6.55}$$

and

$$\sum_{j \in M_t^n} C_{jt}^* Y_{j(np_j)} \leq B_t^n \quad n = 1, ..., NT; \quad (np_j) = 1, ..., NP_j; \quad j = 1, ..., M_t \tag{6.56}$$

$$\sum_{(np_j)=1}^{NP_j} Y_{j(np_j)} - X_j = 0 \quad j = 1, ..., M_t \tag{6.57}$$

from the original CCIGP.

Denoting $\mu_D(X)$ by λ and using the expressions for the membership functions μ_{BL}, μ_{qL} and μ_{qU} for $q = 1, 2, ..., Q$, respectively, the following equivalent crisp problem can be defined:

$$\text{Max} \quad \lambda \tag{6.58}$$

subject to:

$$\sum_{j=1}^{M_t} A_{jq} X_j - P_q \lambda \geq G_q - P_q \quad \forall\, q \tag{6.59}$$

$$\sum_{j=1}^{M_t} A_{jq} X_j + P_q \lambda \leq G_q + P_q \quad \forall\, q \tag{6.60}$$

$$\sum_{n=1}^{NT} B_t^n + P_{BL} \lambda \leq BT_{BL} \tag{6.61}$$

$$\sum_{j \in M_t^n} C_{nt}^* Y_{j(np_j)} \leq B_t^n \quad n = 1, ..., NT; \quad (np_j) = 1, ..., NP_j; \quad j = 1, ..., M_t \tag{6.62}$$

$$\sum_{(np_j)=1}^{NP_j} Y_{j(np_j)} - X_j = 0 \quad j = 1, ..., M_t \tag{6.63}$$

$$\lambda \leq a \quad \text{for} \quad a \leq 1 \tag{6.64}$$

$$\lambda \geq b \quad \text{for} \quad b \geq 0 \tag{6.65}$$

where a and b are the prespecified range of values of λ which the DM's or assessors plan to accomplish. In addition to the formulation stated in Expressions (6.58)-(6.65), the total budget [Expression (6.49)] and binary/integer constraints as in the crisp CCIGP formulation are required.

It should be noted that, as shown in Expressions (6.58)-(6.65), the membership grade of fuzzy parameters, i.e., goal and budgetary constraints have the same membership grade λ to ensure that the implications of binding constraints to the achievements of goals and project portfolios are properly articulated and explicitly evaluated. Formulation in this way enables the DMs/assessors to easily observe implications of any changes on the values of lower bound and tolerance of binding constraints to the model solution (e.g., goals achievements and project portfolios).

Effect of Constraint Violation

A slightly modified version of the model described by Expressions (6.58)-(6.65) is required to explicitly evaluate the degree of constraint violation with respect to the tolerance interval. This modification involves the introduction of an additional decision variable v_q which measures the degree of violation of the qth constraint in the model formulation. The membership function μ_{qL} of the qth constraint is then defined as follows:

$$\mu_q = 1 - \frac{v_q}{P_q} \tag{6.66}$$

The crisp equivalent model is then:

$$\text{Max} \quad \lambda \tag{6.67}$$

subject to:

$$\lambda P_q + v_q \leq P_q \quad \forall\, q \tag{6.68}$$

$$\sum_{j=1}^{M_t} A_{jq} X_j + v_q \geq G_q \quad \forall\, q \tag{6.69}$$

with other constraints as specified by Expressions (6.58)-(6.65), (6.49), and the binary/integer constraints in the crisp CCIGP formulation.

6.7.2 Membership Function Estimation.

In general, there are three approaches for estimation of the membership function (Savic, 1990):

1) The first approach uses the basic scaling method for priorities proposed by Saaty (1977). One important feature of this eigenvalue based method with respect to its ability to generate priority ranking is that it provides a means of identifying any inconsistencies and intransitivities associated with subjective assessments elicited from a DM.

2) The second approach relies on judgment of the DM by asking assessors to draw their membership functions, or give thresholds for grades 0 and 1 on the basis of an assumed functional relationship between the two grades (Bogardi et al., 1983; Sakawa et al., 1987). However, in this method, it is difficult to get consistent membership functions by asking assessors to state their membership function choices directly and there is no means of checking any inconsistencies that might occur.

3) The third approach is based on statistical data manipulation. This approach uses a population of assessors, each of which can respond to certain questions related to membership of an element in a set with a "yes" or "no" answer. The grade of membership is taken to be the proportion of the population replying "yes" to the question. This approach enables a confidence interval to be assigned to the grade of membership for each element of interest (Freeling, 1980; Bharati and Sarma, 1985). However, this approach is only applicable for certain types of problems that involve group decision making. In addition to having similar difficulties to the second approach, this approach also does not take into account the development of new relationships and possible changes in trends.

The following subsections discuss the characteristics of the first approach which is used in the proposed model. This approach was chosen due to its simplicity and the other advantageous capabilities of providing a means for checking any inconsistencies and intransitivities associated with an individual judgment as well as a group judgment as described in Subsection 5.6.6 of Chapter 5.

The Eigenvalue Method

A basic problem in the theory of fuzzy sets is the actual specification or determination of the degree of belonging of each member to the set. Saaty (1977) and Chu et al. (1979) have shown that the problem of determining the degree of belonging of each member to a fuzzy set can be reduced to a matrix eigenvalue problem. To describe the rationale of association between choices of level of the confidence limits and appropriate determination of membership grade, a typical chance constraint is used:

$$P\left\{\sum_{j=1}^{M_t} A_{jq}X_j \geq b_q\right\} \geq \beta_q$$

where $P\{\}$ is probability of the event in the $\{\}$, A_{jq} the coefficient and b_q are right-hand side values of an equation (constraint) (either one or both of these two terms might be random variables), X_j is a {0-1} decision variable representing the selection of project j and β_r is the minimum probability that the DM is willing to accept that a given constraint q is satisfied (β_q= level of confidence limit for constraint q). It should be noted that under this formulation there is $(1 - \beta)$ probability that this constraint will be violated.

In the fuzzy formulation of CCIGP model proposed in this study, it is possible to evaluate and incorporate explicitly preferences toward uncertainty as well as its effect in the model formulation. This is achieved by making use of the definition of membership grade (λ). In this case, the grade of 'belonginess' (λ) of each level of discrete confidence limit to the fuzzy set is determined by the eigenvalue method using the Analytical Hierarchy Process (AHP) (Saaty, 1977). The actual preference for a particular level of confidence limit used as input to the AHP is provided by the DM. Such assessments by the DM are performed by comparing every pair of discrete confidence limits and giving qualitative preference judgments rather than numerical values to the components of each pair. These pairwise comparisons of confidence limit levels use the nine-level qualitative scale provided by Saaty (1977) adopted for this problem as shown in Table 6.5.

The pairwise comparisons are performed in a matrix form. The matrix form is preferred since: i) it is a simple and well-established tool that offers a framework for testing consistency, ii) it handles additional information easily by making all possible comparisons and iii) it is easy to analyze the sensitivity of overall weights to changes in judgment. In this matrix technique let **W** be the vector whose elements $W_g > 0$, $g = 1, 2, \ldots, s$, are the unknown degrees(weights) of belonging of each of s different probability levels of a set of confidence limit levels. As described above, the basic tool for making judgment of pairwise comparison is a matrix of numbers, the elements of which represent relative weights of the constituents. The vector **W** is obtained from such a matrix using the eigenvalue approach suggested by

Table 6.5: The Pairwise Comparison Scale

Intensity of Importance	Definition	Explanation
1	Equal importance	Two confidence limit levels are equally important
3	Weak importance of one over another	Experience and judgment slightly favour one confidence limit level over another
5	Essential or strong over another	Experience and judgment favour one confidence limit level over another
7	Very strong or demonstrated importance	A confidence limit level is strongly favoured; its dominance is demonstrated in practice
9	Absolute importance	The evidence favouring one confidence limit level over another is unquestionable
2, 4, 6, 8	Intermediate values between between adjacent scales value	When compromise is needed

Source: Saaty (1977) with the terminology modified to have meaning in terms of confidence limits.

Saaty (1977) described in Chapter 5.

The following is an outline of an example of determination of degree of belonging or membership grade for a set of confidence limit levels using the eigenvalue method. These three steps are required to accomplish: 1) discretization of confidence limit levels into manageable levels taking into account their dispersion, i.e., mean, upper and lower limits and the determination of their associated economic return in terms of NPVB, 2) presentation of these critical levels of confidence limit on the NPVB criterion, with their associated economic returns, to guide elicitation of DM's preferences toward uncertainty inherent in the NPVB criterion, and 3) qualitative pairwise comparison judgments using the AHP method.

Based on a probabilistic analysis of NPVB criterion using the combination of the Contingency Index approach (Lutz and Cowles, 1971) and the FOSM method (Benjamin and Cornell, 1970 and Dandy, 1985) as described in Expressions (6.24)-(6.30) (Subsection 6.4.1) previously for a range of confidence limits from a very conservative level (95% time exceeded) to a very optimistic/risky level (5% time exceeded) to an example set of potential projects in stage 1 (shown in Table 7.1) the following five critical levels of confidence limit CL_1 =95%,CL_2=75%,CL_3=55%, CL_4 = 30% and CL_5=5% with their associated NPVB achievements shown in Table 6.6 were chosen. These values were selected because they were

Table 6.6: Example Assessment of the Degree of Confidence Limits for Demonstration Problem

Level of Confidence Limit	Degree of Confidence Level (% Time Exceeded)	Net Present Value of Benefit ($ Million)	Notes
1	95	792.85	Very conservative choice of confidence limit
2	75	1272.90	Less conservative choice of confidence limit
3	55	1590.4	Moderate choice of confidence limit
4	30	1836.70	Less optimistic/risky choice of confidence limit
5	5	2378.80	Very optimistic/risky choice of confidence limit

Source: potential projects in stage 1 of the SDP model listed in Table 7.1.

sufficiently representative to cover the range of dispersions of confidence limits generally adopted in a chance constrained model (Kweon, 1977; Choi and Levary, 1989). Before eliciting qualitative pairwise comparison judgments from an assessor or a group of assessors, it is necessary to provide the assessor(s) with information consisting of the explicit assessment of the degrees of uncertainty prevailing for each level of confidence limit (specified in terms of percentage of time of exceedance of an event) and the economic characteristics of the probabilistic analysis (described below). An example of the type of information required is shown in Table 6.6. The values in this table were calculated using the steps described above for the potential projects in stage 1 of the demonstration application of the SDP model. The following are characteristics of probabilistic economic analysis that should be considered in giving information to guide those pairwise comparison judgments required by the AHP method.

1. The purpose of probabilistic analysis of the NPVB economic criterion for water resources project investment model is to measure "upside" potential and "downside" danger, i.e., to assess the potential that the returns may exceed the estimate and the danger that returns may be less than anticipated respectively. In other words, an attempt to obtain a measure of how wrong the forecast could be is needed.

2. Attitudes toward uncertainty can range from a very optimistic view of the success of projects to an extremely conservative approach. In the first case there is potential

for overestimating or inflating returns. Conversely, the second case represents the danger of missing opportunities. The choice depends on the DM's attitude toward uncertainty. A risk-averse DM may prefer projects with low risk (variance) , whereas a risk taker may prefer projects with greater variance and commensurately higher returns. A compromise choice may be extracted from participants in the political process who have been informed of explicit assessment of the degrees of uncertainty and economic consequences prevailing for each level of confidence limits.

Following the appropriate specification of these probabilistic considerations it is necessary to construct a pairwise comparison matrix for discrete confidence limit levels, such as the five confidence interval levels given previously, based on the qualitative scale described in Table 6.5, the explicit assessment of the degree of uncertainty associated with each level of confidence limits and their probabilistic economic outcomes shown in Table 6.6, and the characteristics of probabilistic economic analysis described above. The following are examples of qualitative pairwise comparison judgments which might be elicited from an assessor with respect to the five confidence levels given above.

Confidence limit level 2 (CL_2) has a very weak importance over CL_1, and CL_5.

Confidence limit level 2 (CL_2) has equal importance with CL_4.

Confidence limit level 3 (CL_3) has an absolute importance over CL_1, CL_2, CL_4 and CL_5.

Confidence limit level 4 (CL_4) has a very weak importance over CL_1 and CL_5.

The remainder of the assessments can be derived from reciprocal interpretations of the above relationship.

On the basis of these qualitative assessments, the following pairwise comparison matrix can be obtained for this demonstration example using the Saaty scale shown in Table 6.5:

$$B = \begin{array}{c} \\ CL_1 \\ CL_2 \\ CL_3 \\ CL_4 \\ CL_5 \end{array} \begin{array}{c} \begin{array}{ccccc} CL_1 & CL_2 & CL_3 & CL_4 & CL_5 \end{array} \\ \left[\begin{array}{ccccc} 1 & 1/2 & 1/9 & 1/2 & 1 \\ 2 & 1 & 2/9 & 1 & 2 \\ 9 & 9 & 1 & 9 & 9 \\ 2 & 1 & 2/9 & 1 & 2 \\ 1 & 1/2 & 1/9 & 1/2 & 1 \end{array}\right] \end{array}$$

Applying the procedure to evaluate maximum eigenvalues, and their associated unit eigenvectors (see Equation (5.25)), the following features are obtained:

$$\lambda_{max} = 5.36; \quad W = \begin{bmatrix} 0.06 \\ 0.11 \\ 0.66 \\ 0.11 \\ 0.06 \end{bmatrix}$$

Applying the definition of CI and CR (given in Section 5.7.6, Chapter 5) for the example of matrix comparison described above, the value of $CI = 0.091$ and $CR = 0.081$ ($CR = 0.081 < 0.10$, acceptable).

Based on the above results, the membership grades for various confidence limits can be defined by normalising the weights in such a fashion that the maximal value of membership grade is equal to 1. The resulting membership grades are shown in Table 6.7. As discussed previously, the eigenvalue method requires inputs from the DM, whether the DM is an individual or a group of DMs. In eliciting such inputs concerning pairwise comparison judgments, questionnaires are presented to the assessors. These assessors are asked to make pairwise comparison judgments between critical values of the discrete confidence limits shown in Table 6.6 using Saaty's (1977) list of the qualitative statements described in Table 6.5. The final values of a group assessment may be derived from the geometric mean of the individual judgments (Saaty and Vargas, 1991). Consistency of these judgments can be checked, and reassessment considered, if the consistency ratio obtained exceeds the allowable margin.

It should be noted that the values of membership grade shown in Table 6.7 for an exam-

Table 6.7: Example Membership Grade for Various Confidence Limits for Demonstration Problem

Confidence Limit (CL_n)	Membership Grade
0.95	0.084
0.75	0.168
0.55	1.000
0.30	0.168
0.05	0.084

ple of problem demonstration are obtained using the assessments made by the writer. This simplification is made due to the time limitations committment required for an approprite interactive communication with the real DMs. However, it is believed that the experience of the writer in water resources planning for 14 years in a government agency make these assessments reasonably close to the assessments of the actual DM.

The effect of the numerical upper bound of the Saaty's (1977) pairwise comparison scale, i.e., the 5 point scale, the 7 point scale, and the 9 point scale, on the membership grade of the various confidence limits is shown in Figure 6.7. It was observed from the demonstration problem, which uses values typical of those in the case study described later in Chapter 7, that the membership grade levels are not significantly affected by variation of the upper bound values of the numerical scale, e.g., differences in membership grade for three numerical scales described above remain fairly constant, i.e., the gaps between the 5, 7 and 9 point scales increase from confidence limit 5% to confidence limit 30% and decrease in the same manner on the other side. The difference actually decrease as the value of membership grade approaches one and as the value of confidence limits of NPVB criterion approach to the medium level (55% of time the value of NPVB exceeded).

It was also observed that the same preference relationship is maintained between consecutive confidence limits regardless which upper bound value of comparison scale is applied, e.g., the lowest membership grades occur at both extreme conditions of a very optimistic/risky and a very conservative choice of confidence limit (5% and 95% of time the value of NPVB exceeded respectively) and increasingly higher membership grades occur as confidence limits of NPVB criterion approaches medium level. Furthermore, Figure 6.7 shows that the medium

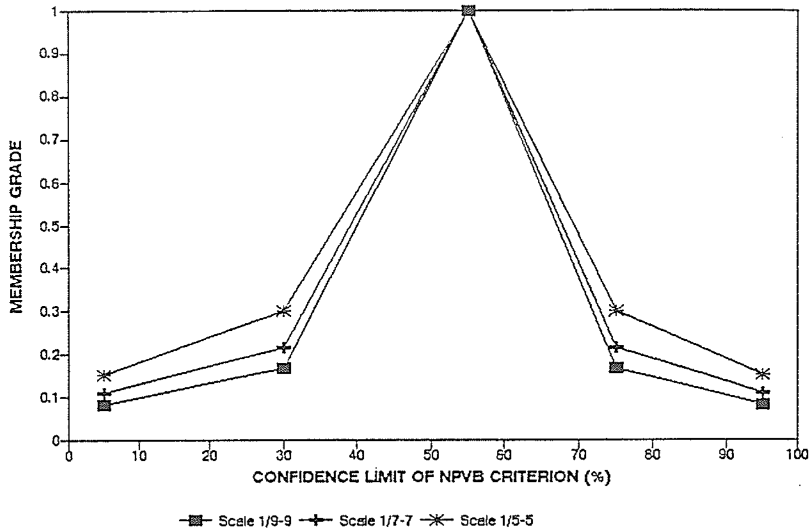


Figure 6.7: Example Membership Grades of Various Levels of Confidence Limit on NPVB for Various Comparison Scales for the Demonstration Problem

level of confidence limit of NPVB criterion as shown by the highest membership grade for that level of confidence limit is preferred by the assessor, since it provides a satisfactory level confidence limit in terms of both the degree of certainty/reliability as well as the level of achievement of a specified level of aspiration (goal). Table 6.6 also confirms this observation.

In summary it can be concluded that determination of the choice of level of confidence limit in a fuzzy context through membership grade (λ) and application of the Analytical Hierarchy Process approach significantly reduces the various limitations inherent in CCP in the following manner: i) the qualitative preference of a DM or a group of DM toward uncertainty can be explicitly incorporated in model formulation and hence in the decision process, ii) the effect of such choice can be directly evaluated in the model solutions, i.e., a different value of λ will result in different solutions, iii) the consistency of the DM's assessment can be verified and reassessment performed if necessary, and iv) the effect of constraint violation with respect to the tolerance intervals can be observed by introducing an additional decision variable which measures the degree of constraints violation relative to their tolerances in the FCCIGP formulation.

An example of the evaluation of constraint violation of the NPVB goal constraint using

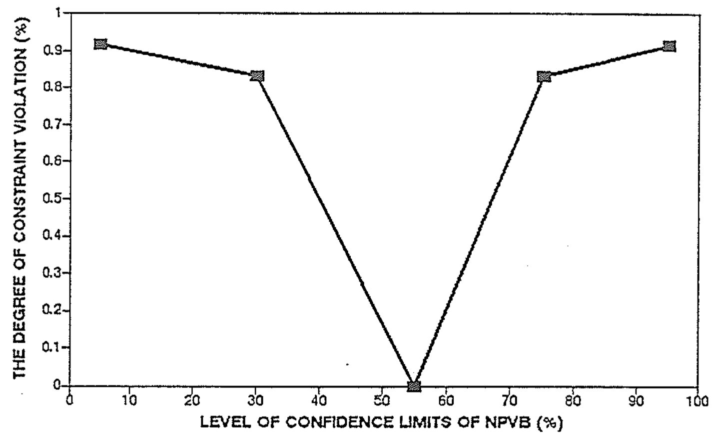


Figure 6.8: Example Relationship Between the Degree of Actual Constraint Violation of the NPVB Goal Constraint and Confidence Limits for the Demonstration Problem

the formulation described in Expressions (6.66)-(6.69) and data from the potential projects at stage 1 of the SDP model listed in Table 7.1 is shown in Figure 6.8. This figure shows the relationship between actual constraint violation with respect to the tolerance interval of NPVB goal and preferences toward confidence limits of NPVB criterion. Examination of Figures 6.7 and 6.8 indicates that the degree of constraint violation of the NPVB goal is actually a reciprocal of the membership grade of the confidence limits of NPVB criterion. At the lower levels of confidence limit, i.e., at the levels smaller than the medium level, the degrees of constraint violation are at higher levels. The violation with respect to constraint tolerance in this lower region of confidence limits reflects a degree of uncertainty of the achievement of NPVB goal. Similarly, at higher levels of the confidence limit, i.e., at the levels greater than the medium level, the degrees of constraint violation are also at a higher level. The violation in this higher region of confidence limits reflects a degree of deviation of the achievement of NPVB goal from a specified aspiration level. On the other hand, the closer the confidence levels to the medium confidence limit the lower the degree of constraint violation. The lowest degree of constraint violation reflects the highest level of satisfaction of the goal achievement in terms of both the degree of certainty/reliability as well as the level of achievement of a specified aspiration level.

6.8 Integration of the Multiobjective Optimization and the SDP Method Into A Unified Model

6.8.1 Objective of the Overall Approach

The objective of the first level Stochastic Dynamic Programming (SDP) optimization, for the planning model is the development of an investment planning policy which permits decision makers to define and select the optimal investment planning decisions ($D^*_{t,i,m}$) in terms of the level of development with its associated optimal project portfolio to pursue for each possible state combination $L_t^{i,m}$ (i.e., current level of development L_t^i and level of funding received in the previous stage PF_t^m) at any scheduling horizon under direct consideration of conditions of current and future budgetary fluctuation and, indirectly, through the information (results) provided by the Fuzzy Chance Constrained Integer Goal Programming (FCCIGP), under consideration of uncertain investment outcome. In particular the investment decision policy generated by the model is able to recognize explicitly the possibility that, in any scheduling horizon, the actual level of funding received is different than that desired or anticipated for the scheduling horizon. The risk aversion attitude of the DM, e.g., "risk taker" or "risk averter", with respect to uncertainty of outcome can also be incorporated, through the FCCIGP, in any investment planning decision.

The second level of optimisation, in this case, the FCCIGP approach develops, for each scheduling horizon (stage) of the SDP, the immediate economic returns for each possible combination of level of possible funding decision (D_t^k) and level of actual funding received (F_t^l) within each stage of the SDP model. These immediate returns explicitly recognize and incorporate the inherent uncertainties (through confidence limits) of the NPVB analysis, imprecision of target settings and budget limits, and multiobjective-multicriteria issues inherent in determination of the optimal multiobjective project portfolio. The FCCIGP model also determines the optimal sequencing, scheduling, and associated budgeting for the portfolios it selects for each possible combination of D_t^k and F_t^l, but with direct consideration of the socio-technical, economic and political uncertainties on each scheduling horizon (stage).

Subjective probabilities for each level of actual funding (F_t^l), (derived from the subjective model described in Chapter 5 Subsection 5.6.4) are directly incorporated into the SDP to determine the "optimal" policy. The decision in any scheduling horizon can then be made based on these probabilities and the choice of level of confidence limits associated with the returns (NPVB) generated by FCCIGP methods.

A schematic description of the operational procedures to handle the various types of uncertainties inherent in the water resources investment planning through the integrated SDP-FCCIGP models are shown in Figure 6.9.

6.8.2 Communication of the Integrated SDP-FCCIGP Model

In this integrated model the output of the FCCIGP becomes the input to the SDP model or more specifically the linking variables between the FCCIGP and SDP models. These linking variables are: a) the optimal project portfolio based on goals and criteria preferences for each combination of D_t^k and F_t^l, b) the optimal economic return in terms of NPVB criterion accrued from the optimal project portfolio obtained in a) ($V_t^{k,l}$), and c) Irrigation Area Developed (IAD) in terms of hectares of irrigated rice fields generated by the optimal project portfolio obtained in a) ($AD_t^{k,l}$).

6.8.3 Additional Features of the Integrated FCCIGP-SDP Model

Project Scheduling and Minimization of Discounted Costs

The introduction of construction period constraints in the FCCIGP model defined by Expressions (6.47) to (6.48) enables the DM to schedule a project in which the construction period is begun at the optimum position, i.e., the position that minimizes discounted construction

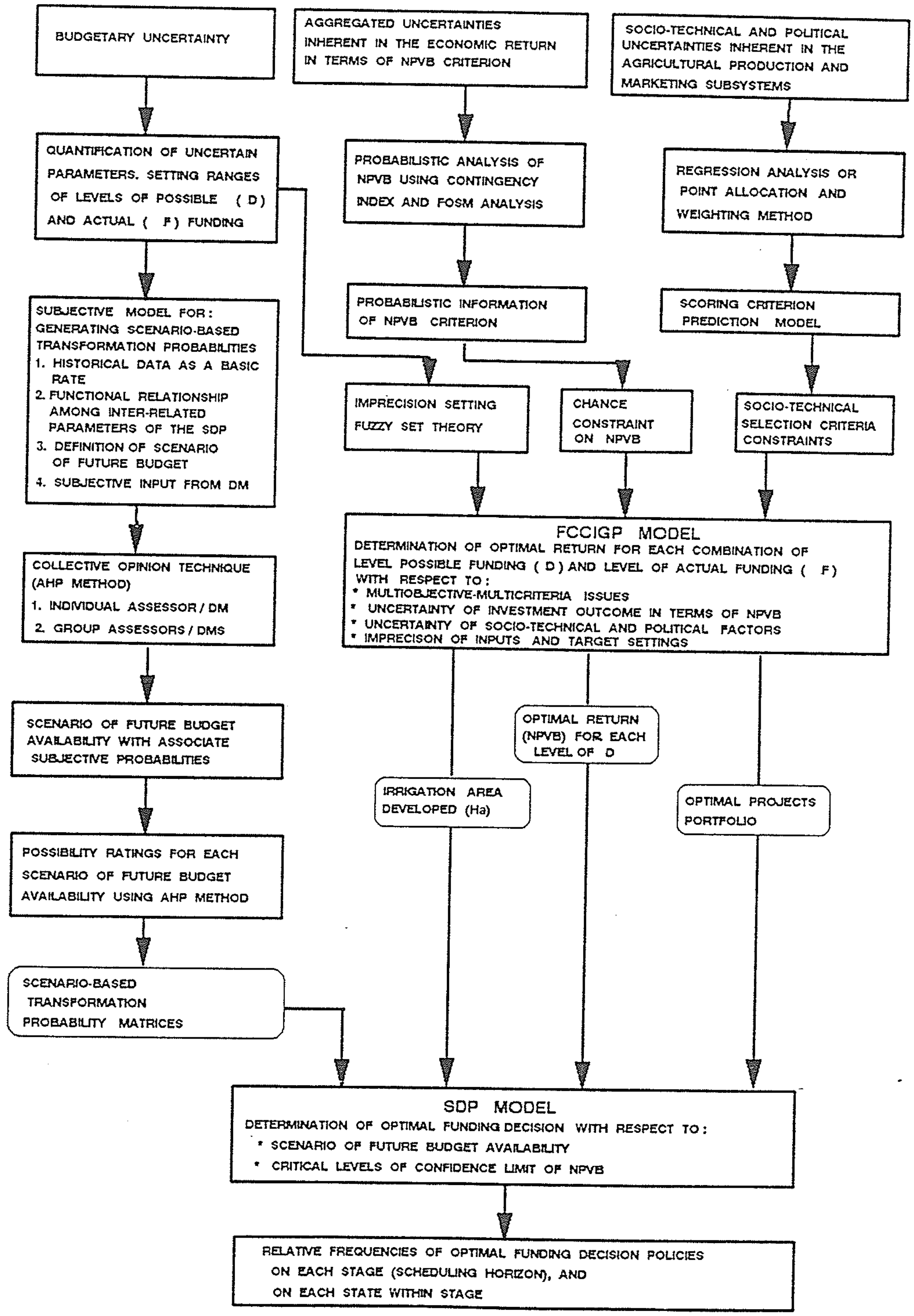


Figure 6.9: Diagram of Integrated FCCIGP-SDP Model

costs and also ensures completion of the whole project, as opposed to partial completion, under conditions of a limited budget. If NT is the number of years of the development scheduling horizon and CP_j is a construction period required by project j, then the number of positions for the construction period of project j within a given NT, i.e., NP_j, has to satisfy the following relationship:

$$NP_j = NT - CP_j + 1 \qquad (6.70)$$

From the above equation, it is observed that the longer the duration of NT, the larger the number of NP_j and hence the higher the number associated with the choice of the optimum position of the construction period.

These construction period constraints are incorporated into the FCCIGP model by using the approach outlined below:

- **Step 1:** Define new decision variables for each project j under consideration which represent the positions in the construction period in which that project may be started, i.e., $Y_{j(np_j)}$ for $(np_j) = 1, ..., NP_j$. for each project under consideration.

- **Step 2:** Define a constraint for each project under consideration (see Equation (6.47)) to ensure that if a certain project is accepted only one decision variable representing the position of the starting point of construction period of selected project defined in Step 1 is selected, i.e., $Y^*_{j(np_j)} \in Y_{j(np_j)}$.

An example of formulation for the construction period constraint is given as follows. Consider a project j with $CP_j = 3$ years, to be constructed within a given scheduling horizon of $NT = 5$ years. Therefore, according to Equation (6.70) the number of possible positions of the starting point of construction of project j is 3, i.e., $NP_j = 3$. The construction period constraint defined in Step 2 (Equation (6.47)) for this case can be written:

$$Y_{j1} + Y_{j2} + Y_{j3} - X_j = 0$$

To examine a project scheduling plan that minimizes the discounted construction cost due to the monetary value of time, a number of FCCIGP models incorporating different scheduling horizons (NT) can be solved. (In the demonstration in Chapter 7 the FCCIGP is run for $NT \leq 5$ years; $NT \leq 6$ years; $NT \leq 7$ years; $NT \leq 8$ years; $NT \leq 9$ years and $NT \leq 10$ years.) The results of these models are linking variables e.g., Net Present Value of Benefit (NPVB), Irrigation Area Developed (IAD) and the associated optimal project portfolio which become inputs to the SDP model for the various values of NT. The optimal planning decisions and their relative frequency and total expected net present value of benefit (TENB) at the beginning of the scheduling horizon can then be evaluated.

Trade-off between Longer vs. Shorter Scheduling Horizon (NT)

In determining the duration of the scheduling horizon, or more specifically, the period in which construction of the projects can be undertaken, the role of external factors governing the future availability of budget for development over the scheduling horizon should be considered.

The issue underlying these possibilities for changing allocation policies is the longer the scheduling horizon (NT) the higher the risk of the project being not completed due to the change of government policies that might occur during the period in question. On the other hand, the longer scheduling horizon the higher net benefit due to decreased discounted construction costs. Therefore, the trade-offs between the shorter scheduling horizon with a lower risk of the project being not completed and also with a lower net benefit versus the longer scheduling horizon with a higher net benefit but bearing a higher risk of the project being interrupted should be examined.

On the basis of variation in NPVB with NT the optimal construction period can be determined or judged subjectively on the basis of the trade-off between risk of non-completion and reduced cost (improved benefit). A demonstration example of how the trade-off is obtained is given in the application of the model to Indonesia situations described in Chapter 7.

The risk of the project being not completed is very difficult, if not impossible, to quantify explicitly. It is therefore proposed that this category of risk be evaluated using the surrogate measure of time "time required for implementation" in combination with the projects selected, i.e., the longer the time required for implementation the greater the risk of projects being interrupted or delayed and even cancelled. Therefore in order to develop the trade-off betweeen risk of non-completion and net benefits, the SDP model would be run a number of times, each time using the different result provided by the FCCIGP for the various restriction on NT, i.e., $NT \leq 5$ years;$NT \leq 6$ years etc. and the appropriate level of discount factor (α) in the SDP model. The value of the discount factor α applied in the calculation of the long range return in the SDP model appraises the impact of uncertain future outcomes reflecting the potential for interruption (Hasting, 1971 and Kennedy, 1986). The longer the duration of NT the higher the interest rate and therefore the lower the present worth factor (discount factor).

The actual trade-off between shorter and longer scheduling horizon can be evaluated using the four axioms of utility function shown below (Benjamin and Cornell, 1970):

1. For two alternatives, A_1 and A_2, one of the following must be true: the individual prefers A_1 to A_2, prefers A_2 to A_1 , or is indifferent between them.

2. The individual's evaluation of alternatives is transitive: if he/she prefers A_1 to A_2 and A_2 to A_3, then he/she prefers A_1 to A_3.

3. Assume that A_1 is preferred to A_2 and A_2 to A_3. There then exists some probability p, $0 \leq p \leq 1$, that the individual is indifferent between outcome A_2 with certainty or getting A_1 with probability p and A_3 with probability (1-p). In other words, there exists a level of certainty equivalent to any risky event.

4. Assuming an individual is indifferent between two choices, A_1 and A_2, and if A_3 is any third alternative, then he will be indifferent between the following two risky choices: Choice 1 offers a probability p of receiving A_1 and a probability (1-p) of receiving A_3, and Choice 2 offers a probability p of receiving A_2 and a probability (1-p) of receiving A_3.

Thus if an individual conforms to the four axioms, a utility function can be constructed.

In this case, the trade off between shorter and longer scheduling horizon can be evaluated by determining the threshold probability (the cross over value p^*) between 0 and 1 such that the planner will be indifferent to the option of shorter ($NT \leq 5$ years) and longer scheduling ($NT \leq 6$, 7, 8, 9, 10 years). (Note: probability of not being interrupted is not equivalent to the probability of non-completion). In this problem the DM will face the following choice of actions:

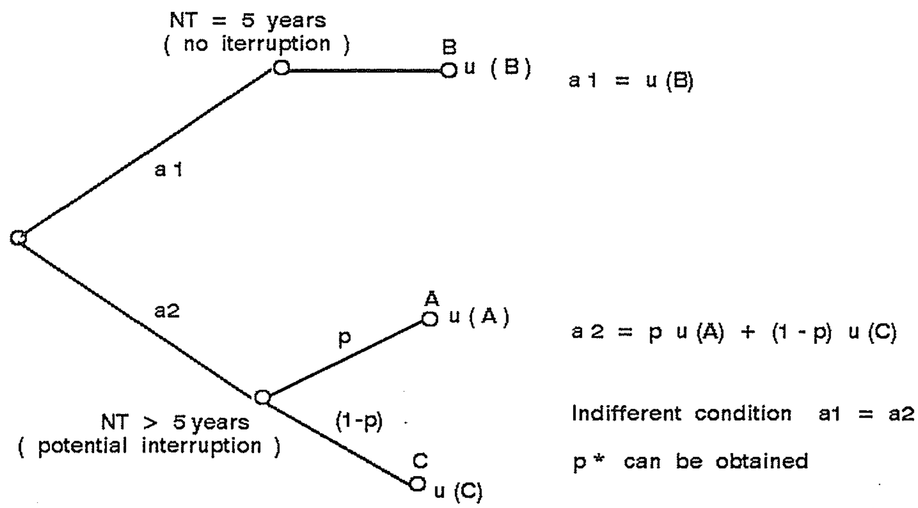


Figure 6.10: Decision Tree for Potential Project Interruption

a_1: implement the projects with $NT \leq 5$ years with a certain return B.

a_2: implement the projects with $NT \leq 6, 7, 8, 9$ and 10 years respectively with p probability of not being interrupted and (1-p) probability of being interrupted.

Note that the action a_1 is also subject to uncertainty which can be reflected in the choice of discount factor (α). However, the above comparison is an effort to examine the presence of 'incremental' uncertainty inherent in such longer scheduling horizons, when these longer scheduling horizons are being considered by the DM or analysist.

The problem is to define p^* such that the DM will be indifferent between choosing a_1 with its a certain consequence B and choosing action a_2 with chance p^* of receiving A and (1-p) of receiving C. Therefore, p^* can be obtained from the following equation:

$$B = p^* u(A) + (1 - p^*) u(C)$$

Figure 6.10 demonstrates schematically how this process is accomplished.

When the probability of the projects not being interrupted (p) is greater than p^* ($p \geq p^*$) the longer scheduling times of $NT \leq 6, 7, 8, 9$ and 10 are optimal. Conversely, if $p \leq p^*$ the shorter scheduling of $NT \leq 5$ years is optimal.

An example of the application this procedure is given in Chapter 7 using a study case of water resources investment planning in Indonesia for the next twenty-five years.

6.9 Comparison with Other Models

Qualitative comparisons of characteristics between existing probabilistic models, e.g., PROTRADE (1979) and STRANGE (1986) and the integrated model of SDP-FCCIGP developed in this study are discussed in the following section by contrasting such models on a one-to-one basis.

6.9.1 Comparison with PROTRADE and STRANGE

Common Characteristics:

These three models (SDP-FCCIGP, PROTRADE, and STRANGE) are investment planning models for specified time horizons which involve multiple and conflicting objectives and criteria taking into consideration time dependent uncertainties affecting the coefficients and the right hand side of constraints. In handling the uncertainty in the left hand sides, all models make use of the "deterministic equivalent" concept adopted from the CCP or "stochastic programming with resource". An interactive process with a DM is required for all models to determine the best satisfying, or efficient, solution with respect to the trade-off between goal achivement and the degree of uncertainty involved. In addition to these features, a part of the uncertainties considered in all models involves subjective probabilities which are largely depended on subjective inputs or judgments from a DM or a planner.

Differences:

1. Type of Uncertainties:

PROTRADE and STRANGE: The PROTRADE model only deals with uncertainty in which uncertain parameters, e.g., mean, variance, and standard deviation can be statistically defined. On the other hand, the STRANGE model, is mainly concerned with uncertainty in which uncertain parameters cannot be statistically defined, and thereby require probabilities of the occurence of such parameters to be defined subjectively.

SDP-FCCIGP: This integrated model offers more a comprehensive consideration of various types of uncertainties inherent in real life problems of investment planning. These uncertainties are:

- External Uncertainty: This type of uncertainty is beyond the control of DM and its parameters cannot be statistically defined. To handle this problem subjective probabilities are assigned, in this case to the transformation probabilities matrix in the SDP model.
- External Risk: This type of risk is also beyond the control of DM but its uncertain parameters can be defined statistically. To handle this problems, chance constrained programming is employed in the second level FCCIGP optimization.
- Internal Uncertainty: This type of uncertainty, characterized by such factors as imprecise input data, is partly beyond the control of DM and its uncertain parameters cannot be statistically defined. To handle this problem, fuzzy set theory is employed in the FCCIGP model.

2. Treatment of Subjective Probabilities:

PROTRADE: At present, there is no means in this approach for handling subjective probability. Since the preferences of the DM in this method are reflected in the form of the utility function, the AHP method, which is based on a linear scale of judgment, may not be used to replace this utility function in a satisfactory manner.

STRANGE: In this model, the subjectively derived scenario-based probabilities are defined by experts without an explicit rationale for assessing the value of such probabilities. In general, it is difficult to obtain reliable and consistent assessments, especially when the number of criteria considered are large. In addition to this problem, the definition of the scenario for describing future uncertainties in the resolution algorithm is difficult to interpret. However, these difficulties may be able to be mitigated to some extent by using an appropriate collective opinion technique, namely the AHP method.

SDP-FCCIGP: Subjective probabilities are determined by qualitative pairwise comparison judgments using the eigenvalue method (the AHP method) with historical data providing the basic rate. The pairwise comparison itself is performed in a matrix form in a simple and well-established tool offering a framework for testing consistency. Furthermore, the definition of scenario in an exploratory manner (examination of events that might influence the future and parametrization of the principal components of the system) is well defined and easy to understand.

3. Decision Maker Involvement:

PROTRADE and STRANGE: Both models require an intensive interaction procedure with a DM or group of DMs and as such suffer from a complex and extensive questioning procedure. This makes elicitation of subjective input and trade-offs analysis difficult, time consuming and tedious, perhaps lessening the quality of responses given.

SDP-FCCIGP: This integrated approach requires somewhat less interaction with the DM, namely, at the beginning of the optimization process to determine the goals and target settings, the specification of the lower bound of budget limits and the spread of tolerance, the qualitative pairwise comparisons to generate the subjective probabilities of budget likelihood, and at the end of the process to check his or her satisfaction with the solution relative to the ideal solution. Although it requires a number of interactions with the DM, the degree of complexity of such interactions is less than that required in both PROTRADE and STRANGE models.

Chapter 7

APPLICATION OF MODEL

7.1 Application to Water Resources Investment Planning Problem

In this chapter the integrated SDP-FCCIGP model described in the previous chapters is demonstrated by employing it to analyze the problem of water resources planning for irrigation development in Indonesia for the next long term (25 years) development planning horizon.

7.1.1 Description of Problem

Timely and appropriate exploitation of water resources is often a key factor in the economic and social progress of developing countries. In the case of Indonesia, water resource development has been an important factor in attaining and maintaining the Government of Indonesia's (GOI) objective of self-sufficiency in rice production. The planning and implementation of projects associated with this water resources development have been performed in a very uncertain budgeting environment. The high demands for water resource development in terms of irrigation facilities, swamp reclamation, flood control and hydro power have also forced the decision makers to perform "target oriented" implementation planning policies without due consideration of the fact that the actual funding realisation is generally different from, and often less than, the amount required or anticipated.

Three major causes of budget allocation uncertainty imposed on water resource projects, and their implications, have been identified

1. The sudden drop in oil revenue due to the fall of the world market price of oil in 1982 and 1986, and also the increasing burden of debt service payments, severely restricted the GOI's ability to support continuation of on-going water resource projects. As a result many hundreds of small and medium scale (500 ha-3000 ha) on-going irrigation projects (constituting a total area about 100,000 ha) were rescheduled, postponed or even cancelled because of the drop in available funds.

2. Changing priorities in budget allocation related to changing government policies with respect to the following socio-economic issues:

   - Current GOI policy is to improve the equitable distribution of investment between developed areas and less developed areas.

   - Achievement of self-sufficiency in rice production since 1984 has changed the emphasis on irrigation development. The current irrigation policy is to maintain self-sufficiency in rice production by rehabilitating and maintaining completed schemes with extension of new irrigation facilities being primarily directed to replace losses of irrigated areas due to shifting of land to non-rice production purposes. As a result of these changes some on-going multipurpose projects, which cover an area about 145,000 ha. located in the relatively developed island of Java, have been postponed and even cancelled.

3. There has been a decrease in the agriculture sector's contribution to Indonesia's Gross Domestic Product (GDP), from 47% in 1969 to 26% in 1986. This fact may influence GOI's policy in budget allocation priorities among competing sectors in future. The sectors such as industry, transportation and communication and energy may receive a greater emphasis than previously with a consequent reduction in budget allocation to the agriculture-irrigation sector.

Examination of the water resource development funding allocations in Indonesia, over the past 17 years confirms that in each time period there have been significant deviations between the anticipated target levels of funding and their actual funding realization (see Table 7.1). The delays in implementation of ongoing water resource projects caused by these budgetary uncertainties also exist in an environment where future project benefits may be overestimated even for 'on-time' completion of projects. Furthermore, postponement of projects can give rise to partial completion of projects with significant or even total reduction in economic returns.

In spite of their multiobjective-multicriteria definition, irrigation projects in Indonesia have generally been selected by procedures dominated by traditional Benefit-Cost analysis without an appropriate or complete analysis of the social-technical aspects inherent in the agricultural production and marketing subsystems. These aspects include social responses in terms of the readiness of farmers to exploit irrigation facilities, a feature which contributes significantly to the rate at which an irrigation project reaches its full development stage and ultimately to the overall output of the project. As a result, many thousands of hectares of completed irrigation and swamp reclamation, particularly in regions off Java (Sutardi, 1988; Sutardi et al., 1991a), were not utilized to the optimum level projected by economic analysis for more than five years after completion of the projects.

The investment outcome uncertainty arising from these socio-technical, economic, data political uncertainties, and imprecision (fuzziness) of input planning data may lead to non-optimal investment decisions on the implementation of water resource projects.

7.1.2 Data and Assumptions for Model Application

The long term water resources development planning horizon (25 years) for the demonstration of the model is divided into 5 scheduling horizons/stages ($t = 1, ..., S = 5$) with each stage reflecting the medium term (Five-Year Development Plan or PELITA) planning policy. Some 160 medium and large scale irrigation projects covering a total area of 2.68 million hectares are appraised in the model. These projects are made up of M_t= 33; 32; 30; 32; and 33 projects for stages t =1; 2; 3; 4; and 5 respectively. Five levels of possible funding decision, (D_t^k, for $k = 1, ..., N_{D_{t,i,m}}$ and $N_{D_{t,i,m}}$=5 $\forall$ t, i, m) were defined at each stage to fund those candidate projects (recall that i is the index of levels of development or state, and m is

Table 7.1: Historical Data of Planned and Actual Funding Realization for Irrigation Development in Indonesia During the Last Seventeen Years

Period	Planned Target and Funding		Realization of Target and Funding	
(Fiscal Year)	Physical Target (Hectares)[a]	Planned Funding (Rupiah 10^6)	Physical Realization (Hectares)	Actual Funding (Rupiah 10^6)
Pelita II[b]				
1974-1975	152,000	76,000	62,500	31,280
1975-1976	171,000	89,775	70,380	36,950
1976-1977	190,000	102,600	78,200	42,228
1977-1978	209,000	117,040	86,020	48,171
1978-1979	228,000	131,000	93,840	53,958
Pelita III				
1979-1980	130,900	274,890	72,136	151,486
1980-1981	146,300	313,375	80,622	172,692
1981-1982	161,700	349,757	89,109	192,743
1982-1983	161,400	369,970	84,866	185,347
1983-1984	161,700	356,548	97,596	215,199
Pelita IV				
1984-1985	118,417	710,502	49,087	331,337
1985-1986	110,576	707,686	63,823	430,805
1986-1987	122,651	797,232	21,934	148,054
1987-1988	119,908	791,393	59,930	404,528
1988-1989	128,448	854,179	23,677	159,820
Pelita V				
1989-1990	110,000	715,000	79,416	472,678
1990-1991	100,000	670,000	54,470	420,872

Note:

[a] Hectares of irrigated areas planned/developed

[b] Pelita II = Second Five-Year Development Plan

Source: DGWRD PELITA I-IV Reports

the index of levels of previous funding). The associated levels of possible funding allocation at each stage t are given as BT_1^k= \$ 924; 809; 693; 578; 462 (10^6) for $k = 1, ..., N_{D_{1,i,m}}$ respectively; BT_2^k= \$ 792; 690; 580; 478; 370 (10^6) for $k = 1, ..., N_{D_{2,i,m}}$ respectively; BT_3^k= \$ 1050; 910; 770; 630; 490 (10^6) for $k = 1, ..., N_{D_{3,i,m}}$ respectively; BT_4^k = \$ 1080; 936; 792; 648; 504 (10^6) for $k = 1, ..., N_{D_{4,i,m}}$ respectively; and BT_5^k= \$ 1185; 1027; 869; 711; 553 (10^6) for $k = 1, ..., N_{D_{5,i,m}}$ respectively.

Technical and socio-economic data related to the selection criteria described in Section 6.1.1 of Chapter 6 were collected for each projects under consideration. The aggregate score for each criterion was then determined by the scoring prediction model described in Chapter 6 (Expressions (6.1) and (6.2)) based on regression analysis of 40 similar projects that were completed during the last fifteen (15) years. The lists of these previously completed projects with their associated scores on each constituent criterion are given in Tables A.1 and A.2 for the Physical Potential and Environmental (PPE) criteria, and the Agricultural Production and Marketing factors related to the Farmer Readiness (FRD) criteria respectively. These two tables also summarize the results of the regression analysis for predicting PPE and FRD criteria. It should be noted that for available data (from the completed projects over the last 15 years) listed in Tables A.1 and A.2 not all parameters (explanatory variables) defined in Expressions (6.1) and (6.2) are statistically significant for predicting PPE and FRD criteria. The results of statistical analysis based on the **stepwise regression procedure** using *Forward selection* and *Backward elimination* at 95% confidence limit indicate that only *Land Fertility*; *Land Uses*; and *Site Location* are significant for predicting PPE, and similarly only *Number of Farmers*; *Irrigation Efficiency*; and *Land Ownership* are significant for predicting FRD criteria. It should be noted, however, that the observation on the correlation matrix shows that these explanatory variables are highly correlated to each other indicating the existence of multicollinearity. Further diagnostic tests using the variance inflation factor, the eigenvalue, and the condition index (Montgomery and Peck, 1991, and Neter et al., 1983) indicates that there is a moderate degree of multicollinearity. As consequences, the following implications are observed in the presence of multicollinearity : 1) nonsignificant results in individual t tests on the regression coefficients for anticipated important variables accompanied by a large overall F statistic. For example *Water Availability*, *Topography*, and *Land*

Distribution for PPE criteria and *Productivity of Existing Schemes*, *Agricultural Support*, *Operation and Maintenance*, and *Use of Input* for FRD criteria, have small absolute values of t statistic, and 2) estimated regression coefficients with an algebraic sign that is the opposite of that expected from theoretical consideration or prior experience, for example *Use of Input*, *Agricultural Support*, and *Operation and Maintenance* for FRD criteria have **negative** coefficients when **positive** coefficients were expected. In this situation, the following assertions of Montgomery and Peck (1991) and Neter et al., (1983) are adopted to guide the interpretation of the regression results: 1) in the case of highly intercorrelated explanatory variables, the small value of t statistic should not be used solely as a criteria to screen the set of explanatory variables since this procedure can lead to the dropping of important intercorrelated variables, 2) the common interpretation of the regression coefficients as measuring marginal effects on dependent variable is often unwarranted with highly correlated independent variables. For example, a planner could not decrease *Agricultural Support* (holding the other explanatory variable constant) and expect *Rate of Utilization* to increase as the negative coefficient might seem to suggest since there is in fact a **positive** correlation in the correlation matrix between *Rate of Utilization* and *Agricultural Support.* Furthermore, both factors are highly intercorrelated and intuition suggests that as the *Agricultural Support* increases, *Rate of Utilization* of newly completed irrigation scheme will increase. It is also observed that while least squares produces poor estimates of individual model parameters when multicollinearity is present, this does not always imply that the fitted model is a poor predictor. For example, the results of prediction of response for new observations for both the 'complete' and 'the only significant variables' models are the same. Based on these facts, it can be concluded that multicollinearity can be tolerated since the aim of these regression models is to predict PPE and ERF criteria. In this case, the complete model defined in Expressions (6.1) and (6.2) are still applicable for general usage since there is no one subset of parameters (explanatory variables) which is usually 'best' for all uses and regions (Neter et al., 1983).

Scores of the selection criteria, i.e., Physical Potential and Environmental (PPE), Farmer Readiness (FRD), Existing Rice Fields (ERF), and Transmigration Support (TS), and other relevant information for each project under consideration in stages 1, 2, 3, 4, and 5 are given in Tables A.3, A.4, A.5, A.6, and A.7 respectively.

Statistical analyses to determine the parameters describing the uncertainty in economic outcome for each of the candidate projects were performed according to the procedure described in Chapter 6 (Section 6.3.1). The economic historical data of completed projects were regionalized with respect to their social profile, e.g., developed regions on and off Java versus underdeveloped regions off Java, and the Contingency Index of each of the proposed projects calculated. The results of this analysis are given in Tables A.8, A.9, and A.10 for developed regions on and off Java and the underdeveloped regions off Java respectively. Similarly the economic values for the potential/proposed projects were based on the investment study report for the potential irrigation projects in Indonesia (BCEOM, 1989). The economic desirability of the potential projects in terms of the 'original' (without considering inherent risks) NPVB criterion are given in Table 7.2 for the projects proposed in stage 1 and Tables A.11, A.12, A.13, and A.14 in the Appendix for the potential projects in stages 2, 3, 4, and 5 respectively. A discount rate of 7% (a value generally used for agricultural projects in Indonesia) and a 5% annual inflation rate were assumed in the economic analysis (Gittinger, 1984).

7.2 Model Application

7.2.1 The SDP Application

Historical data describing the levels of deviation between the projected and the actual funding realisation of the budgets for irrigation development in Indonesia over the last 17 years are shown in Table 7.1. Based on this table the relative frequencies of discretized level of deviations between planned and actual funding over the last 17 years were calculated and are shown in Table 7.3. The information extracted from Tables 7.1 and 7.3 were then used as the basic rate in developing relevant scenario-based transformation probabilities, i.e., Limited, Non-limited, and Undetermined Budget scenarios for use in the model. [The examples used in Chapter 5 (Section 5.6) to demonstrate development of the transformation probabilities using the Subjective Model with both the Direct Assessment and AHP methods were based on the Indonesian historical data shown in Tables 7.1 and 7.3 which are relevant to this

Table 7.2: Summary of the Probabilistic Information of NPVB Criterion for the Candidate Projects at Stage 1

PROJECTS NUMBER AND NAME	LOCATION (PROVINCE)	AREA (HA)	ORIGINAL*) NET BENEFIT ($ 10^6)	VARIANCE OF NET BENEFIT	STANDARD DEVIATION OF NET BENEFIT	MEAN OF NET BENEFIT ($ 10^6)	LOWER LIMIT [95% EXCEEDED] ($ 10^6)	UPPER LIMIT [5% EXCEEDED] ($ 10^6)
1 KRUENG BARO	ACEH	16772	66.86	478.22	21.87	47.05	10.97	83.14
2 NORTH SUMATRA	N. SUMATRA	41000	136.86	1933.35	43.97	99.38	26.83	171.93
3 PASAMAN	WEST SUMATRA	4926	19.01	24.92	4.99	15.09	6.86	23.33
4 BATANG KUMU	RIAU	13800	54.9	324.44	18.01	38.57	8.84	68.29
5 LIMUN SUNGKAT	JAMBI	2500	10.65	9.95	3.15	7.92	2.71	13.12
6 KOMERING	S. SUMATRA	55904	194.61	6016.37	77.57	119.62	-8.37	247.60
7 BAAL	S. SUMATRA	5500	7.7	123.88	11.13	-4.71	-23.08	13.65
8 WAY ABUNG	LAMPUNG	5000	17.73	27.47	5.24	13.40	4.75	22.04
9 WAY PEDADA	LAMPUNG	13550	51.45	193.74	13.92	40.37	17.40	63.34
10 ALAS	BENGKULU	4400	3.87	62.41	7.90	-5.03	-18.07	8.00
11 MANJUTO KANAN	BENGKULU	10000	5.8	302.33	17.39	-13.94	-42.63	14.75
12 TELUK LADA	WEST JAVA	18923	79.5	668.60	25.86	66.54	23.88	109.21
13 JATIGEDE	WEST JAVA	130158	489.658	34097.04	184.65	391.44	86.76	696.12
14 JRATUNSELUNA	CENTRAL JAVA	74537	460.71	7816.41	88.41	433.14	287.26	579.01
15 DUMPIL	CENTRAL JAVA	25415	131.24	1035.02	32.17	117.73	64.65	170.82
16 MADURA	EAST JAVA	2580	13.68	10.45	3.23	12.37	7.03	17.70
17 EAST JAVA IMP.	EAST JAVA	143042	342.49	12642.92	112.44	285.90	100.37	471.43
18 SANGGAU LEDO	W. KALIMANTAN	555	2.19	0.36	0.60	1.69	0.69	2.68
19 KASAU	C. KALIMANTAN	5000	7.55	58.62	7.66	-0.84	-13.48	11.79
20 RIAM KANAN	S. KALIMANTAN	12000	21.09	314.80	17.74	1.89	-27.39	31.16
21 TORAUT BONGO	N. SULAWESI	7820	13.142	160.30	12.66	-0.69	-21.58	20.20
22 TAOPA	C. SULAWESI	8000	14.24	163.35	12.78	0.34	-20.75	21.43
23 KALONG	C. SULAWESI	1200	3.85	2.50	1.58	2.31	-0.30	4.92
24 BOYA	S. SULAWESI	10000	26.1	204.05	14.28	11.36	-12.21	34.93
25 SAN REGO	S. SULAWESI	7500	11.1	155.41	12.47	-2.65	-23.22	17.92
26 WAWOTOBI	S.E. SULAWESI	21200	83.4	646.15	25.42	61.07	19.13	103.01
27 DATARAN KOBI	MALUKU	1950	5.3	7.57	2.75	2.49	-2.05	7.03
28 WIMBO ERANG	IRIAN JAYA	1963	1.42	11.22	3.35	-2.37	-7.90	3.16
29 IRIGASI BALI	BALI	3425	7.98	30.70	5.54	4.60	-4.54	13.74
30 EMBUNG NTB	WEST NUSA TG.	1520	1.01	7.12	2.67	-1.38	-5.79	3.02
31 KALIMANTONG	WEST NUSA TG.	2850	5.64	19.65	4.43	0.87	-6.44	8.18
32 IRIGASI NTT	EAST NUSA TG.	3360	5.98	28.82	5.37	0.14	-8.72	9.00
33 EMBUNG NTT	EAST NUSA TG.	8276	8.52	183.47	13.55	-6.64	-28.99	15.71

NOTE : *) SOURCE BCEOM (1989) IRRIGATION INVESTMENT STUDY

Table 7.3: Frequency Distribution for Level of Deviation Between Funding Decision and Actual Funding Realisation for Irrigation Development in Indonesia Over the Last Seventeen Years

Level of Deviation	Frequency	Relative Frequency (%)
0.20-0.30	2	12
0.31-0.40	0	0
0.41-0.50	6	35
0.51-0.60	6	35
0.61-0.70	3	18
0.71-0.80	0	0
0.81-0.90	0	0
0.91-1.00	0	0
	17	100

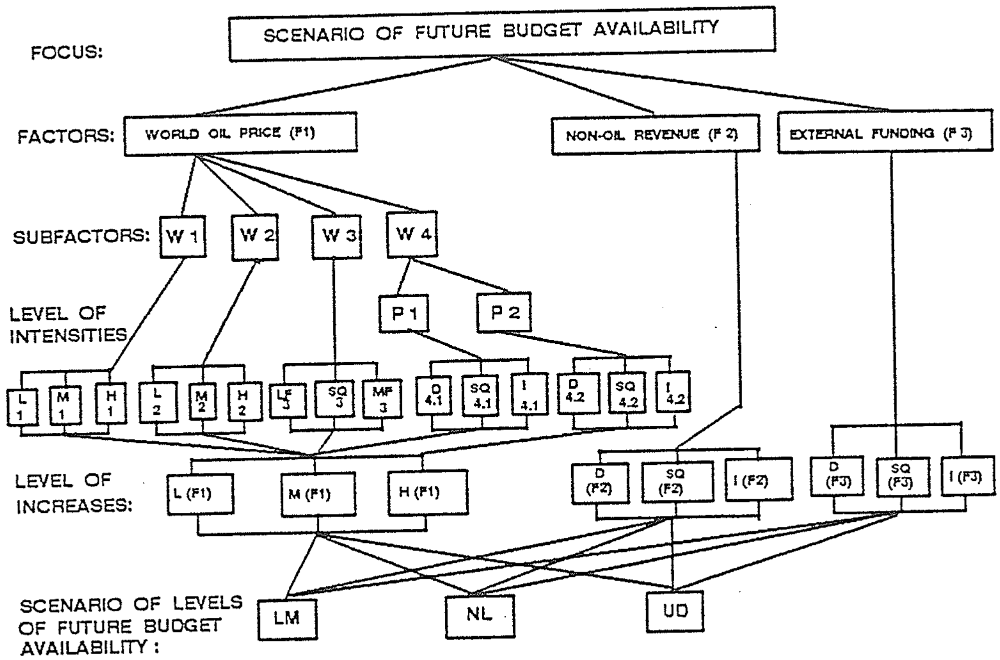
demonstration example.] The transformation probabilities derived by the Subjective Model with Direct Assessment (based on data shown in Tables 7.1 and 7.3) for the three scenarios of future budget availability, namely Limited, Non-limited, and Undetermined Budget (shown in Tables A.15; A.16; and A.17 respectively) were applied for the model demonstration. [The similarities and the differences between the SDP results from transformation probabilities generated by the Direct Assessment and the AHP methods for a particular confidence limit on NPVB and for all scenarios of future budget availability are addressed in the discussion of the results.]

The AHP method is also used to guide DM(s) or planner(s) to determine the likelihood, or possibility rating, for each scenario of future budget availability for the various levels of investment anticipated, i.e., which scenario is the most likely to occur given the relevant factors and information believed to govern the occurence of such scenarios.

Application of the possibility ratings to the Indonesian water resources development problem is as follows.

Scenario of Future Budget Availability Rating Using the AHP Method

As described in Chapter 5 (Subsection 5.6.7), the relevant factors contributing to the future budget availability for investment can be structured in a hierarchy of levels ranging from the highest level factors to the lowest level of sub-factors as shown in Figure 7.1. The main factors relevant to defining the future availability of budget for water rescources (public)



NOTE:

PRIMARY FACTORS: WORLD OIL PRICE (F 1)
NON-OIL REVENUE (F 2)
EXTERNAL FUNDING (F 3)

SUBFACTORS: W1 - WORLD OIL CONSUMPTION GROWTH
W2 - INTENSITY OF DEVELOPMENT ALTERNATIVE FUELS
W3 - INFLUENCE OF INTERNATIONAL FINANCIAL INSTITUTIONS
W4 - POLITICAL FACTORS : P1 - OPEC PRICING BEHAVIOUR
P2 - TENSION BETWEEN INDIVIDUAL STATE

LEVEL OF INTENSITIES : L I - LOW INTENSITY OF SUBFACTOR I (I - 1, 2)
M I - MEDIUM INTENSITY OF SUBFACTOR I
H I - HIGH INTENSITY OF SUBFACTOR I

LF 3 - LESS FAVORABLE OF SUBFACTOR 3
SQ 3 - STATUS QUO CONDITION OF SUBFACTOR 3
MF 3 - MOST FAVORABLE OF SUBFACTOR 3

D J - DECREASE OF SUB-SUBFACTOR J (J - 1, 2)
SQ J - STATUS QUO CONDITION OF SUB-SUBFACTOR J
I J - INCREASE OF SUB-SUBFACTOR J

LEVEL OF INCREASES : L m - LOW INCREASE OF FACTOR m (m - 1, 2)
M m - MEDIUM INCREASE OF FACTOR m
H m - HIGH INCREASE OF FACTOR m

D 3 - DECEREASE OF FACTOR 3
SQ 3 - STATUS QUO OF FACTOR 3
I 3 - INCREASE OF FACTOR 3

SCENARIO OF LEVELS OF FUTURE BUDGET AVAILABILITY :
LM - LIMITED BUDGET SCENARIO
NL - NON LIMITED BUDGET SCENARIO
UD - UNDETERMINED BUDGET SCENARIO

Figure 7.1: Hierarchy for Scenario of Future Budget Availability

investment in Indonesia can be described as follows:

1. **World Oil Price:** Revenues from oil and gas constitute about 50% of total budget allocated for sectoral development in Indonesia. Therefore, any fluctuations of world oil price will significantly affect budget availability level. There have been a number of predictions of world oil prices by major oil companies (World Energy Outlook, Exxon 1980) and government agencies (International Energy Outlook 1985 with Projection to 1995, United States Department of Energy, 1986). However, in today's world, oil market economics and politics are interwoven with political decisions increasingly influencing the level of oil production, consumption, and prices (Gholamnezhad, 1987). This macro factor is therefore divided into several sub- factors. The following sub-factors, assumed to affect the price of oil over the next decades, as extracted from Gholamnezhad (1987), consist of the following elements:

a) World Oil-Consumption Increase:

At present, the United States, Japan, and Europe account for about 75% of the total world oil consumption. No substantial increase in demand is anticipated for these countries. However, in the developing countries, particularly the oil-exporting countries, the demand for oil is expected to increase significantly due to industrialization and development. The overall oil consumption increase depends greatly on the co-operative and unilateral strategies of the oil-consuming nations.

b) Intensity of the Development of Alternative Fuels:

A substantial amount of oil could be replaced by synthethic fuels from large coal, oil shale, tar sands reserves, and biomass resources. However, due to the long lead times required for such development (about 6 to 10 years), the large capital requirements, and environmental constraints, such fuels are not expected to make a significant contribution during the next decade. However, in the 2000s synthetic fuels could play an important role in the world energy market.

c) Influence of International Financial Institutions:

Most of the excess oil revenues are circulated around the world by these institutions. If these excess funds were circulated properly, they would provide more incentive to a special group of oil producers to increase oil supply beyond their domestic financial needs. The resulting pressure to raise the price of oil would not then be as great as it would if the surplus money was invested in non-profitable ways, leading to a general depreciation in the value of the funds (Gholamnezhad, 1987).

d) Political Factors:

The political factors considered in this model are as follows: i) *OPEC Pricing Behaviour.* OPEC managed well for its members in the 1970's. Increased radicalization in member nations could however force prices upward. Moderate members have had a damping effect on price increases but in the long run they may be outnumbered and gradually lose their influence. At this time it is thought that OPEC's behaviour will be increasingly unfavourable towards stable and reasonable oil prices (Gholamnezhad, 1987). ii) *Instability in the Persian Gulf Region*: The Persian Gulf is surrounded by a number of major oil-exporting countries such as Iran, Saudi Arabia, Iraq, Kuwait, Qatar, Bahrain and the United Arab Emirates. These countries are members of OPEC and together account for over 80% of its proved oil reserves or nearly half of the world's total reserves. Over 30% of the world's oil supply comes from this region. The stability of the Persian Gulf itself depends on several other factors, particularly the social strains due to economic development, industrialization, unstable political system, religious movement, and also tension between the individual states, as evidenced by the war between Iraq and Kuwait recently. The region will continue to be of extreme importance in the future supply and prices of oil from the Middle East, particularly the Persian Gulf states.

2. Non-Oil Revenue: Revenue from non-oil sources such as exported agricultural commodities and various taxes contribute to about 25% of the total budget allocated for development in Indonesia. However, it is assumed in this demonstration example that the future contribution from this revenue source will increase considerably.

3. Availability of External Funding: Over the last 15 years external funds available at international lending agencies such as the World Bank, the Asian Development Bank, etc. have been utilized as matching budgets to fulfill any shortages of internal funding sources such as Oil-Gas revenues and Non-Oil revenues. Such external funding constitutes about 25% of the total budget allocated for development. The future contribution from this source is assumed to remain at the status quo.

These factors and their hierarchy, as shown in Figure 7.1, were used to develop the allocation (in monetary term) associated with the index k.

As described in previous chapters, the second level optimization is a multiobjective-multicriteria technique. Three 'versions' of the Goal Programming based multiobjective investment model in this second level optimisation were considered for this application. The first version is IGP with its variant PIGP (Partitioning IGP) deals only with the problem of project selection related to multiobjective issues and managerial concerns as described by Expressions (6.40)-(6.49) (see Chapter 6). Note that in this formulation the economic return (NPVB) goal constraint in Expression (6.42) is expressed in its "original" form without consideration of uncertainty in NPVB. The second version is a CCIGP which extends the first version by considering some form of the risks inherent in the NPVB. In this case, the NPVB goal constraint in Expression (6.42) is expressed in probabilistic terms and the other components of the model remain the same as the first version (IGP). The third version of the model is FCCIGP which extends the second version further by considering imprecison (fuzziness) of input data, e.g., imprecision of the range of budget limits and the imprecise qualitative preference for the confidence limits of the NPVB objective. In this case, the N-PVB goal constraint of Expression (6.42) and the budgetary constraint of Expression (6.49) are expressed in fuzzy constraints as described in Expressions (6.59)-(6.61) taking into account the membership grade of the fuzzy components and the effect of constraint violations. All three versions of the model were run in this application to demonstrate how each feature contributes to the values provided by the FCCIGP to the SDP.

The multiobjective-multicriteria analysis itself was performed by considering; three different goal preferences with respect to NPVB, IAD, TS, and two trade-off analyses between NPVB versus IAD (Irrigation Area Developed), and TS (Transmigration Support) respectively. Optimization with respect to the individual selection criterion PPE, ERF and FRD individually and to these three selection criteria simultaneously are also examined.

The SDP model was coded in WATFOR IV and implemented on an AMDHAL with each run requiring just under the twenty seconds to execute. To make the SDP model more computationally efficient, the state reflecting level of development expressed in terms of hectares of irrigated areas were discretized into 26 values for the first three stages (J_t=26 for $t = 1, 2, 3$) and into 31 values for stages 4 and 5 (J_t=31 for $t = 4, 5$). The reduced number of states at the first two stages reflect the smaller possible ranges of levels of development that can exist after only three scheduling horizon have gone by.

The SDP model was run for each of the three scenarios of future budget availability (see Table 7.4) for a range of cases to take into account: i) the range of possible scheduling horizons, e.g., $NT \leq 5$, 6, 7, 8, 9 and 10 years, ii) a range of values of the discount factors α which reflect the likelihood of a potential interruption of a project, and iii) the various confidence limits on return (NPVB) β, representing the risk aversion attitude of the DM.

The results of the SDP are the optimal funding/investment decision $D^*_{t,i,m} \in N_{t,i,m}$, where $N_{t,i,m}$ is the index of set of number of levels of possible funding decision at each stage t for each state combination of level of development L_t^i and level of previous funding PF_t^m, for $t = 1, ..., S = 5$; $i = 1, ..., J_t$ in which J_t=26 for $t = 1, 2, 3$ and J_t=31 for $t = 4, 5$; and $m = 1, ..., N_{PF_{t,i}}$ ($N_{PF_{t,i}} = 5$).

7.3 Discussion of the Results

Presentation and discussion of the results of the integrated SDP-FCCIGP model for the range situations described above is organized as follows: the first part addresses characteristics of the results of probabilistic analysis of NPVB criterion; the second part discusses the performance of the FCCIGP model in terms of its ability to provide operational guidance for a public investment planning relative to the basic and intermediate IGP and CCIGP models, and the third part describes specific characteristics of the integration of FCCIGP-SDP and the summary of the results of the integrated model for all stages within a 25 year long term planning horizon.

7.3.1 Probabilistic Analysis of NPVB

An example of the results of the probabilistic analysis for NPVB criterion for each candidate project for scheduling horizon (stage) 1 of the SDP model using the FOSM analysis and the Lutz and Cowles (1971) approach in terms of variance, standard deviation, and dispersion of NPVB criterion, i.e., mean, upper, and lower limits are listed in Table 7.2. [The results of this analysis for the potential projects in stages 2, 3, 4, and 5 are given in Tables A11, A.12, A.13, and A.14 respectively.] These results show that there are significant 'discrepancies' between the original NPVB (BCEOM, 1989) and the "corrected" NPVB. Such significant 'discrepancies' are especially prevalent in underdeveloped areas off Java. In particular, almost all of these projects have a 'negative' NPVB at their upper limit (95% of time exceeded) and some still have negative NPVB even at their mean level (55% ['rounding up' of mean between maximum level 100% and minimum level 5%] of the time the NPVB will be exceeded). The values of original NPVB are generally comparable only at the "lower" limits with confidence level of only 5% of the time exceeded.

These prediction results may seem extreme. However they are based on the past performance of completed irrigation projects and have validity on that basis. Although practical use of these predictions would require further detailed analysis, the numbers are sufficiently realistic for use in this demonstration of the model.

7.3.2 Discussion of the IGP, CCIGP, and FCCIGP Results

The important features of each of the three versions of the goal program formulated as weighting and partitioning (for scoring criterion based optimization) models for candidate projects in stage 1 are summarized and shown in Table 7.5 and Tables A.19 and A.20 and summarized in Tables A.21, A.22, A.23, and A.24 for candidate projects in stages 2, 3, 4, and 5 respectively. The following conclusions can be drawn from those results.

1) Articulation of Goal and Criteria Preferences and Managerial Concerns

In terms of providing the operational guidances for the decision making process in investment planning of water resources projects all three models perform similarly. In terms of project selection with respect to goals and selection criteria preferences, as expected, they are able to handle very efficiently both economic and non-economic goals, e.g., maximizing achievement of NPVB goal vs. maximizing support for the transmigration program. When preference is given to the physical, environmental, and sociotechnical criteria related to the agricultural production and marketing subsystems (PPE, ERF, and FRD), whether simultaneously (Case D) or individually (Cases E, F, and G), all models tend to discriminate against the projects that have a higher cost although these projects might have higher score in these criteria (see Table A.19 in the Appendix). This tendency occurs because the model

Table 7.5: Comparison of The Results of IGP, CCIGP and FCCIGP Model for Level of Possible Funding Allocation BT_1^1, When Preference is Given to NPVB

PROPOSED PROJECTS — YEAR IN WHICH CONSTRUCTION STARTED

PROJECT NUMBER & NAME	AREA (ha)	IGP MODEL	CCIGP CONFIDENCE LEVELS MEAN	CCIGP LOWER LIMIT	CCIGP UPPER LIMIT	FCCIGP CONFIDENCE LEVELS MEAN	FCCIGP LOWER LIMIT	FCCIGP UPPER LIMIT	CCIGP BUDGET LIMIT 90%BT_1^1	FCCIGP BUDGET LIMIT $BT_1^1 - 90\%BT_1^1$
1 Krueng Baro	16772	1st	1st	1st	0	1st	1st	0	1st	1st
2 North Sumatra	41000	1st	1st	0	1st	1st	0	1st	0	0
3 Pasaman	4926	2nd	2nd	2nd	1st	2nd	2nd	1st	2nd	2nd
4 Batang Kumu	13800	1st	1st	1st	0	1st	1st	0	1st	1st
5 Limun Sungkat	2500	4th	4th	4th	3rd	4th	4th	3rd	4th	3rd
6 Komering	55904	0	0	1st	0	0	1st	0	0	0
7 Baal	5500	1st	0	0	0	0	0	0	0	0
8 Way Abung	5000	0	2nd	0	2nd	2nd	0	2nd	2nd	2nd
9 Way Perdada	13550	1st	1st	0	1st	1st	0	1st	1st	1st
10 Alas	4400	0	0	0	0	0	0	0	0	0
11 Manjuto Kanan	10000	0	0	0	0	0	0	0	0	0
12 Teluk Lada	18923	0	0	0	1st	0	0	1st	0	1st
13 Jatigede	130158	1st	1st	1st	1st	1st	1st	1st	1st	1st
14 Jratunseluna	74537	1st	1st	1st	1st	1st	1st	1st	1st	1st
15 Dumpil	25415	1st	1st	1st	1st	1st	1st	1st	1st	1st
16 Madura	2580	4th	4th	2nd	4th	4th	4th	4th	4th	4th
17 East Java Rehab	42912	1st	1st	1st	1st	1st	1st	1st	1st	1st
18 Sanggau Ledo	555	4th	0	4th	0	0	4th	0	4th	3rd
19 Kasau	5000	0	0	0	0	0	0	0	0	0
20 Riam Kanan	12000	0	0	0	0	0	0	0	0	0
21 Toraut Bongo	7820	0	0	0	0	0	0	0	0	0
22 Taopa	8000	0	0	0	0	0	0	0	0	0
23 Kalong	1200	0	0	2nd	0	0	2nd	0	0	2nd
24 Boya	10000	0	0	0	0	0	0	0	0	0
25 San Rego	7500	0	0	0	0	0	0	0	0	0
26 Wawotobi	21200	1st	1st	1st	1st	1st	1st	1st	1st	1st
27 Dataran Kobi	1950	0	0	2nd	0	0	2nd	0	4th	4th
28 Wimbo Erang	1963	0	0	0	0	0	0	0	0	0
29 Irigasi Bali	3425	0	0	0	0	0	0	0	0	0
30 Embung NTB	1520	0	0	0	0	0	0	0	0	0
31 Kalimantong	2850	1st	0	0	0	0	0	0	0	0
32 Irigasi NTT	3360	0	0	0	0	0	0	0	0	0
33 Embung NTB	8276	0	0	0	0	0	0	0	0	0

PARAMETERS	IGP MODEL	CCIGP MEAN	CCIGP LOWER LIMIT	CCIGP UPPER LIMIT	FCCIGP MEAN	FCCIGP LOWER LIMIT	FCCIGP UPPER LIMIT	CCIGP 90%BT_1^1	FCCIGP $BT_1^1 - 90\%BT_1^1$
1 Irrigation Area (ha)	392841	415570	415629	404476	415570	415629	404476	377075	397198
2 N.P.V. of Benefit ($10^6)	1957.4	1590.5	2379.5	796.6	1590.5	2379.5	796.6	1489.7	1555.5
3 Transmigration Support (number of families)	11500	16500	27500	6500	16500	27500	6500	13000	27500
4 Number Selected Projects	15	13	14	12	13	14	12	14	16
5 Total Budget ($10^6)	922.99	923.87	923.77	920.43	923.87	923.77	920.43	832	885.24
6 Membership Grade of Budgetary Constraints	-	-	-	-	-	-	-	-	0.4213
7 Membership Grade of Confidence Limits	-	-	-	-	1	0.085	0.083	-	-
8 Degree of Constraint Violation	-	-	-	-	0	0.915	0.917	-	0.5787

ANNUAL BUDGET ALLOCATION

	IGP MODEL	CCIGP MEAN	CCIGP LOWER LIMIT	CCIGP UPPER LIMIT	FCCIGP MEAN	FCCIGP LOWER LIMIT	FCCIGP UPPER LIMIT	CCIGP 90%BT_1^1	FCCIGP $BT_1^1 - 90\%BT_1^1$
First Year (B1)	147.33	147.33	147.53	148.3	147.33	147.53	148.3	131.64	142.1
Second Year (B2)	283.11	285.51	286.16	284.29	285.51	286.16	284.29	254.96	271.95
Third Year (B3)	186.23	184.82	185.64	187.38	184.82	185.64	187.38	165.46	175
Fourth Year (B4)	180.25	178.59	177.27	176.78	178.59	177.27	176.78	162.86	169.23
Fifth Year (B5)	126.07	127.62	126.17	123.68	127.62	126.17	123.68	117.08	120.99

NOTE: 90%BT_1^1 = REFLECTING 10% REDUCTION FROM POSSIBLE FUNDING ALLOCATION BT_1^1
$BT_1^1 - 90\%BT_1^1$ = REFLECTING 10% TOLERANCE INTERVAL BELOW POSSIBLE FUNDING ALLOCATION BT_1^1

tries to minimize underachievement of the sum of the scores of individual projects from the targeted goal rather selecting in hierarchial manner the individual projects that have a high scores. If, however, it is desired that the projects which have higher scores have to be selected and satisfied at the maximum possible levels before the projects with lower score are even considered (scoring criterion based optimization), the model can be reformulated using the modified Partitioning Algorithm.

Observation of the solutions for this Partitioning IGP (PIGP) for scoring criterion based optimization (for PPE, ERF, and FRD criteria) indicates that this formulation produces a better goal achievement in terms of NPVB, IAD and a higher level of satisfaction of selection criteria, even though the resulting portfolio covers a smaller number of selected projects than that selected by the original IGP formulation (see Table A.19).

Recall that when the same priority is given to two goals, for example NPVB and IAD (Case H) and NPVB and TS (Case I), it is not possible to optimize one goal before the other and hence only the weighting model can be used. A set of weights that minimizes the distance between each solution and its ideal solution is therefore used to satisfy achievements of the two goals simultaneously.

Examination of the goal achievements and the projects selected for the five levels of possible funding allocation BT_1^1 *to* BT_1^5 for the weighting model (Table A.20) allows the following characteristics to be observed. For the decisions to anticipate lower levels of funding allocation, the model tends to select those projects with lower costs to fit the anticipated available budget. The goal achievements for NPVB and IAD decrease in these cases. The TS goal, on the other hand is not affected because it is satisfied at the lowest level of BT_1^k (for $k = 5$).

With respect to the managerial concerns related to the optimal project scheduling, project unity, project dependencies, and optimal annual budget allocation, all of the three models effectively perform in the similar manner (see Tables 7.5, A.19, and A.20).

Similar conclusions with respect to multiobjective-multicriteria analysis, scoring criterion based optimization, and managerial concerns can be drawn from the other stages of the SDP. The summary of the results of the FCCIGP model for the whole range of levels of possible funding allocation BT_t^k (for $k = 1, ..., 5$) and $t = 2, .., 5$ are shown in Tables A.21, A.22, A.23, and A.24 respectively.

2) Means for Handling Risk Preferences

The CCIGP and FCCIGP models are able to incorporate preference towards risk in investment outcome using the probabilistic information of the NPVB criterion for each project (See Table 7.2 for stage 1 and Tables A.11, A.12, A.13, and A.14 for stages 2, 3, 4, and 5 respectively). In both models, preferences toward risk are reflected in the various levels of confidence limit on the NPVB criterion. In this case, the CCIGP and FCCIGP models were run for the three predetermined levels of confidence limits, i.e., upper (95% of the time the NPVB will be exceeded), mean (50% [mean between the upper level 95% and the lower level 5%] of the time the NPVB will be exceeded), and lower (5% of the time the NPVB will be exceeded). The results of each these three cases of confidence levels are shown in Table 7.5 for stage 1 of the SDP model.

Observation of the results in Table 7.5 indicates, not unexpectedly, that the CCIGP and FCCIGP models are enable to screen the more 'reliable' projects (the projects that have smaller variances) and to eliminate the 'risky' projects (the projects that have larger variances). At the upper level of confidence limit (95% of the time the NPVB of the selected projects will be exceeded), both models select fewer projects and hence yield the smallest but the most reliable economic return. On the other hand, when both models were run at lower level of confidence limit (only 5% of the time the NPVB of selected project will be exceeded), they tended to select the largest number of projects and hence the largest, but the least reliable economic return.

A compromise result is obtained when both models were run at mean level of confidence limit (55% of the time the NPVB of the selected projects will be exceeded). In this case, the models not unexpectedly tend to select a medium number of projects and hence yield the medium economic return with a reasonable reliability. It can also be seen that the results of the IGP model are comparable to (almost the same as) the results of the CCIGP and the FCCIGP at the upper limit of the confidence level. More detailed descriptions about issues related to risk preferences are given in the next subsection.

Similar conclusion with respect to handling risk preferences can also be drawn for the other stages. The summary of the results for BT_t^k for $k = 1, ..., 5$, and $t = 2, ..., 5$ are shown in Tables A.21, A.22, A.23, and A.24 respectively.

3) Means for Handling Imprecision of Input Data

Although both CCIGP and FCCIGP provide a means of handling probabilistic information and risk preferences for a 'risky' variable, only the FCCIGP model has the ability to handle the imprecision (fuzziness) of input data through introduction of a membership grade for a fuzzy variable (λ) and a variable which measures the degree of violation of a constraint. Examination of the results of the CCIGP and the FCCIGP in Table 7.5 reveals that, in terms of project selection and scheduling, the number of selected projects, the goal and criteria achievement, and the optimal annual budget allocation both models yield the same solutions. However, the FCCIGP provides additional information on the following issues:

i) Means for handling imprecise qualitative preference toward risk

As described in Chapter 6, there is a 'one-to-one' relationship between membership grade of the confidence limit on NPVB and the levels of confidence limit on NPVB (see Table 6.7 and Figure 6.7). Therefore, any preferred level of confidence limit can be represented in a specified value of membership grade. Recall also that any preference toward any uncertainty inherent in public decision making is ideally determined by a group of DM's/assessors (Major, 1977). However, it is difficult to obtain a precise and consistent preference (Yager, 1979). Therefore, to reduce imprecision and inconsistency inherent in the preference toward confidence limit on NPVB in this FCCIGP, a combination of the AHP and Fuzzy Set theory (membership grade) is used to elicit preference (subjective inputs) from a group of DM's/assessors.

In this case, the membership grade for each level of critical confidence limit on the NPVB criterion is interpreted as the degree of preference of the assessors/DM's to the associated confidence level expressed as a value between 0 to 1. For example, the membership grade of the lower confidence limit ($\lambda_{lower} = 0.085$) represents the lowest preferences for that confidence limit. Similarly, $\lambda_{mean} = 1$ and $\lambda_{upper} = 0.083$ represent the highest and the lowest preferences for the mean and upper level of confidence limit respectively. Introduction of the variable v_r measuring the degree of violation of constraint with respect to its tolerance interval also provides complementary information that can be interpreted as the level of dissatisfaction of the assessor/DM with the associated confidence limit. For example, $v_{lower} = 1 - \lambda_{lower} = 0.915$ represents the highest dissatisfaction for the lower confidence limit. Similarly, $v_{mean} =$

0, and $v_{upper} = 0.917$ represent the lowest and the highest dissatisfactions for the mean and upper levels of the confidence limit respectively.

ii) Means for handling imprecise budget limit levels

In this case, the membership grade of the binding budgetary constraint represents 'the grade of membership' of the budget limit within the specified tolerance interval. To achieve such purpose, membership grades of budgetary constraints and goal constraints are related to each other (see mathematical formulation in Chapter 6). This feature is particularly useful for the situation when the DM is not able to specify precisely the budget limit, but is rather only able to provide lower or upper bounds, with a prespecified tolerance interval above or below these bounds taken as representing imprecision in setting of such bounds. For example, in situation in which the DM anticipates a budget reduction in between 0% to 10% from the planned level (BT_t^k), in this case, for the 'crisp' formulation (CCIGP) the upper bound of budget limit is $90\%BT_t^1$. On the other hand, for the FCCIGP formulation the upper bound of budget limit is BT_t^1 with the tolerance interval of $10\%BT_t^1$ below this upper bound. Solutions of the CCIGP for a budget reduction of $10\%BT_t^1$ and the FCCIGP for budget tolerance interval $10\%BT_t^1$ for Case A (preference given to NPVB goal), as shown in Table 7.5, indicate that the FCCIGP formulation produces a 4.40% better achievement of NPVB goal than the CCIGP. The reason for this improvement is due to the flexibility of fuzzy set theory which permits an element to belong partly to a fuzzy set characterized by a membership function that takes values in the interval [0,1]. Thus FCCIGP produces an optimum solution within a specified interval, e.g., within a lower and an upper bound of the binding constraints. In contrast by its nature, a conventional (crisp) set theory constraint only permits an element either to belong (membership grade 1) or not to belong (membership grade 0) to the set. In this example case shown in Table 7.5, $\lambda = 0.42$ can be interpreted as the degree of the support of budgetary constraint to the solution and $v_{budget} = 0.58$ represents the degree of actual constraint violation with respect to its tolerance interval.

7.3.3 Important Features of CCIGP and FCCIGP Models

1. Identification of 'Risky' Projects

Further examination of the results of the CCIGP and FCCIGP models where preference is given to NPVB goal for: i) the three confidence limits on NPVB with the associated membership grade, and ii) the five levels of possible funding allocation BT_1^1 *to* BT_1^5 (these results are shown in Table A.20 and represented graphically in Figures 7.2 and 7.3), and Tables A.21, A.22, A.23, and A.24 for BT_t^1 to BT_t^5 for $t = 2, ..., 5$ (without graphical display) reveals the followings characteristics:

a) *Identification of 'risky' projects in terms of economic return.*

As shown in Figure 7.2, the maximum achievement of NPVB goal only can be achieved at the lower confidence limits (only 5% of the time the NPVB of the selected projects exceed such maximum level). On the contrary maximizing the confidence limit at around 95% decreases the achievement of NPVB and TS (Transmigration Support) goal by 67% and 61% respectively although there is no significant reduction of the achievement of IAD (Irrigation Area Developed) goal. It should be noted, at the upper limit (95% of the time the benefit is exceeded) the model tends to select only the projects that have positive NPVB and smaller variance. These projects are also characterized by being mostly located in developed regions. However, at the lower limit, the model tends to select more projects than at the mean and the upper limit, and includes more "risky" projects, i.e., those projects that have a larger variance in NPVB. Such projects are characterized by the fact that they are mostly located on less developed regions in support of regional development and transmigration program.

Similar tendencies with respect to the ability to handle 'risky' projects in terms of economic return are also observed for the other levels of possible funding allocation (BT_1^2 *to* BT_1^5). and for the other stages, i.e, BT_t^1 to BT_t^5 for $t = 2, ..., 5$ as shown in Tables A.21, A.22, A.23, and A.24 respectively. The above discussion illustrates the advantages of applying the chance constraints formulation in that additional information with respect to the dispersion of the economic return defined in the NPVB criterion is provided.

b) *Identification of 'risky' projects in terms of social factors.*

As shown by the results of CCIGP and FCCIGP models in Tables A.25 and A.26, the application of the sociotechnical selection criteria of Equations (6.44)-(6.46) and the scoring criterion-based optimization procedure enables the DM/planner, through the model, to select those projects that satisfy sociotechnical criteria such as the readiness of the farmer to utilize the completed irrigation schemes without significant reduction in the achievement of

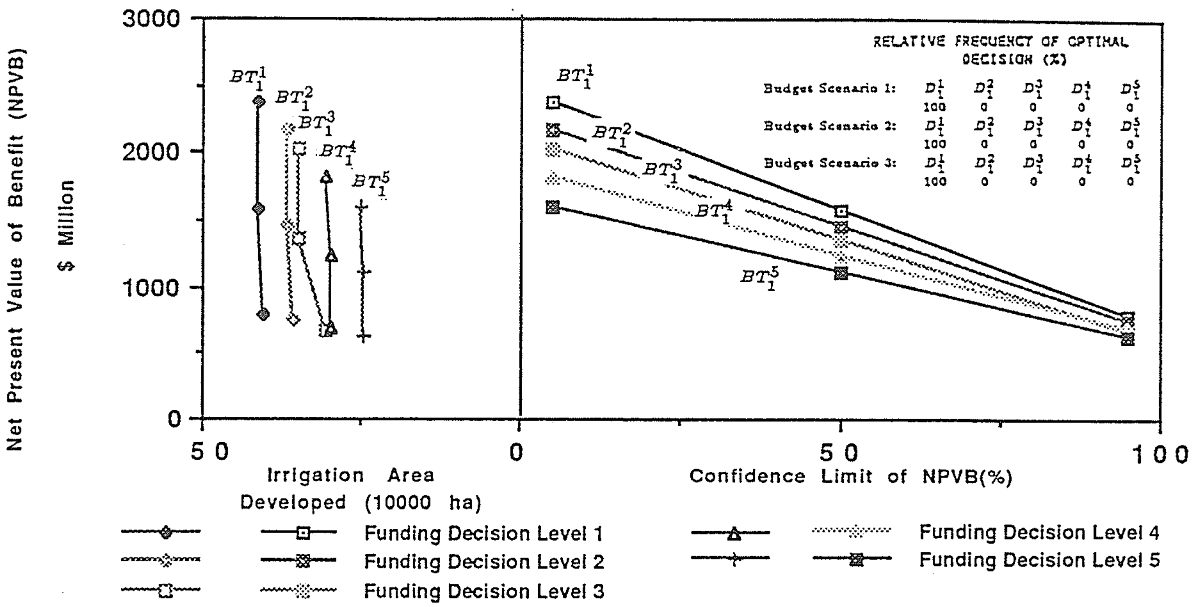


Figure 7.2: Trade-off Between NPVB Vs. Confidence Limit Vs. IAD for the Five Levels of Possible Funding Allocation BT_1^1 *to* BT_1^5 When Preference is Given to the NPVB Criterion

NPVB goal.

A similar conclusion with respect to the ability to handle 'risky' projects in terms of social factors is also oberved for other stages, i.e., BT_t^1 to BT_t^5 for $t = 2, ..., 5$ as shown implicitly in Tables A.21, A.22, A.23 and A.24.

This ability is useful in attempting to reduce (minimize) the excessive delays in the full utilization of the completed schemes experienced previously due to lack of consideration of sociotechnical and political aspects inherent in the agricultural production and marketing subsystems in the traditional Benefit-Cost procedure. It also helps in adjusting for over/underestimation of benefit/cost components in order to determine the "true" Benefit-Cost parameters.

2) Trade-off Analysis Between Risk vs. Goal Achievements

The trade-offs between: 1) maximizing NPVB vs. maximizing the Confidence Limit on NPVB vs. maximizing IAD, and 2) maximizing NPVB vs. maximizing the confidence limit

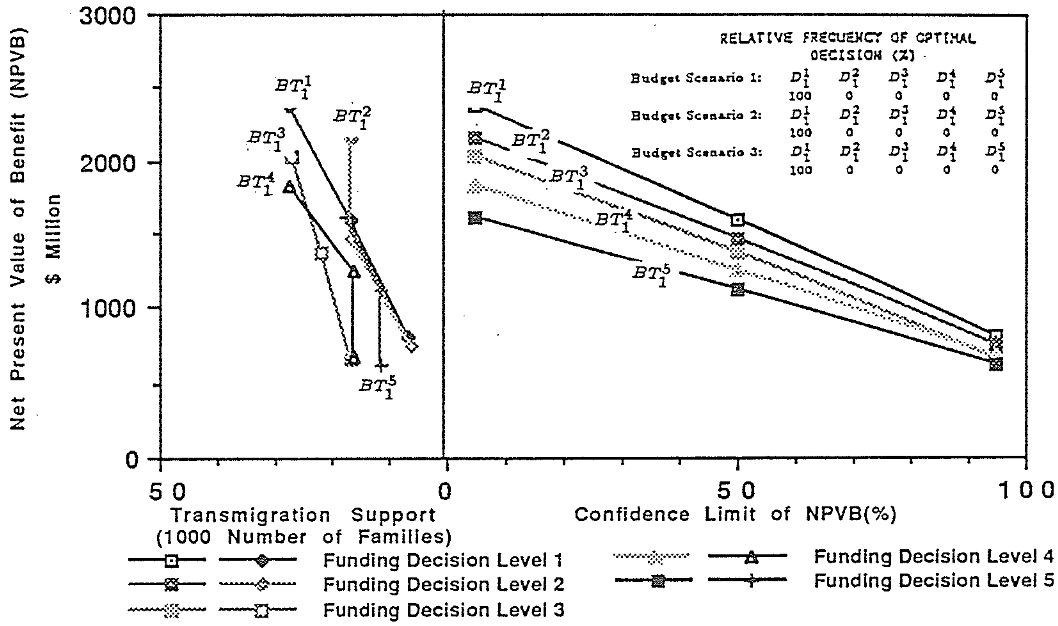


Figure 7.3: Trade-off Between NPVB Vs. Confidence Limit Vs. TS for the Five Levels of Possible Funding Allocation BT_1^1 *to* BT_1^5 When Preference is Given to the NPVB Criterion

on NPVB vs. maximizing Transmigration Support (TS) for the five levels of possible funding allocation BT_1^1 *to* BT_1^5 can be seen in Figures 7.2 and 7.3 respectively. The relative frequency of the optimal funding decision for each of the possible funding decision options associated with those levels of possible funding allocation, i.e., D_1^1 through D_1^5 for stage 1 and for each case of the three scenarios of future budget availability, i.e., Limited Non-limited, and Undetermined Budget is also shown in these two figures. These figures show that the higher the level of funding decision the steeper the slope of the trade off line between NPVB and confidence limit. At the funding allocation BT_1^1, increasing the reliability of NPVB by 10% reduces the achievement of NPVB by 17.78%. On the other hand, at level BT_1^5 increasing the reliability by 10% only reduces the attainment of NPVB by 11.11%. Furthermore, it can be seen that increasing the reliability (confidence limit) will also decrease the achievement of the other objectives such as IAD, TS and FRD (Farmer Readiness to exploit new irrigation facilities). Compromise solutions can be achieved at the reliability level of 50% (mean) that is, improving the confidence limit by 45% without excessive reduction in the achievement of NPVB, IAD, TS, and FRD.

Similar trade-offs to those discussed above but for the situation when preference is given to Irrigation Area Developed (IAD) and Transmigration Support (TS) goals are presented in Table A.25 and in Figures 7.4 and 7.5, respectively. When preference is given to the IAD goal, the choice of the confidence limit on NPVB criterion does not have any impact on the achivement of IAD (see Table A.25 and Figure 7.4). On the other hand, the variation in the level of the possible funding allocation options BT_1^1 *to* BT_1^5 significantly affects the achievements of IAD (see Figure 7.4). A similar finding also occurs when preference is given to the TS goal. In this case, the choice of the confidence limit on NPVB as well as the variation of level of the possible funding decision options do not have any impact at achievement of the TS goal (see Figure 7.5) as the TS goal is already achieved at the lowest possible funding allocation (BT_t^5).

As mentioned previously, when the same preference is given to two goals simultaneously (see Table A.26 and Figures 7.6 and 7.7), for example between NPVB-IAD (Case H), NPVB-TS (Case I), and NPVB-FRD (Case J) it is not possible to optimize one goal before the other and hence only the weighting model can be used. A set of weights that minimizes the

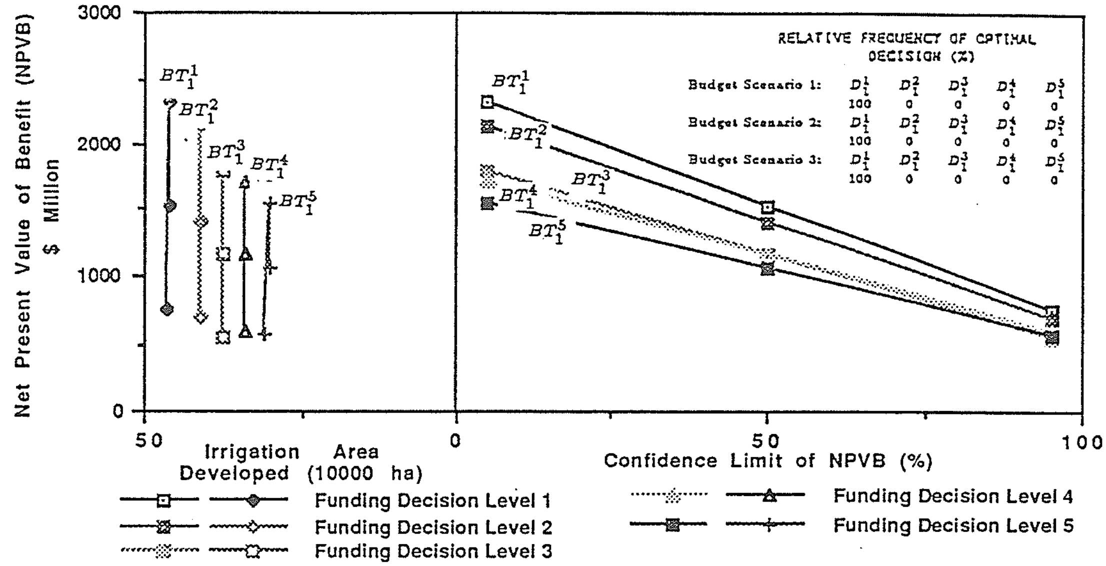


Figure 7.4: Trade-off Between NPVB Vs. Confidence Limit Vs. IAD for the Five Levels of Possible Funding Allocation BT_1^1 *to* BT_1^5 When Preference is Given to IAD Goal

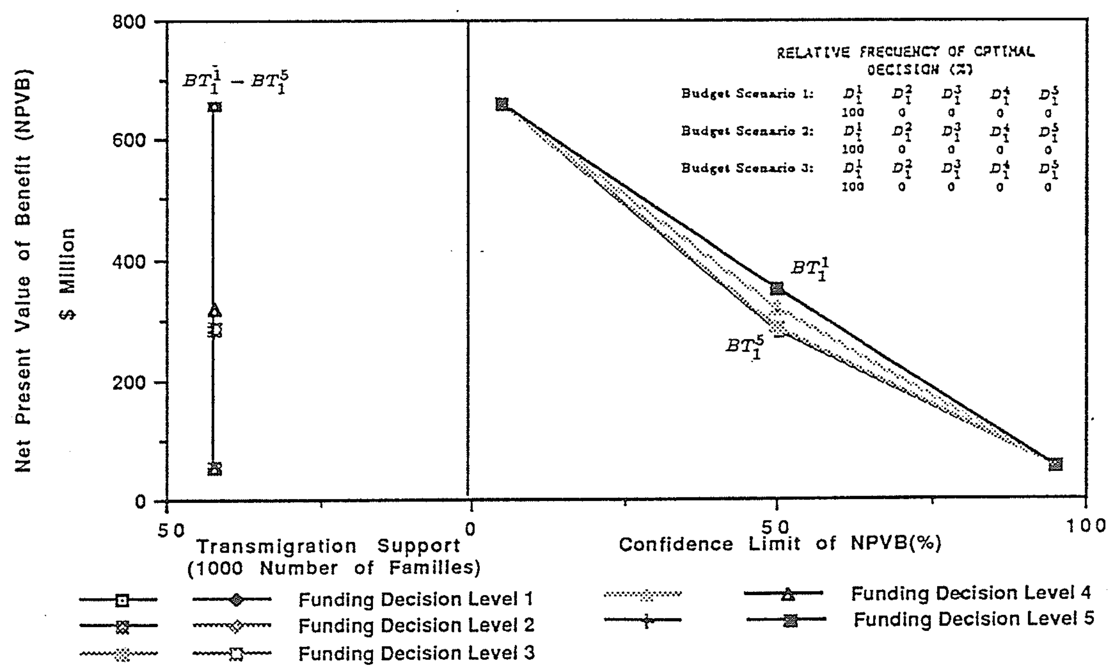


Figure 7.5: Trade-off Between NPVB Vs. Confidence Limit Vs. TS for the Five Levels of Possible Funding Allocation BT_1^1 *to* BT_1^5 When Preference is Given to TS Goal

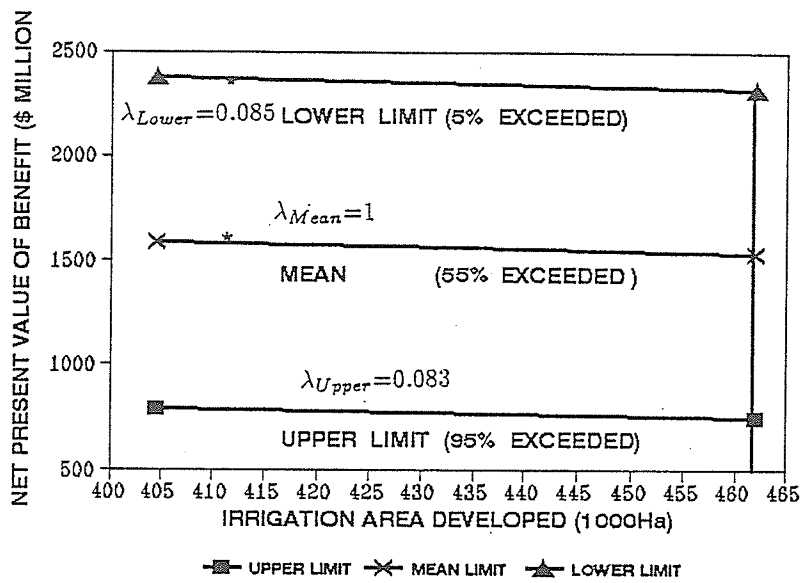


Figure 7.6: Trade-off Between NPVB Vs. IAD for the Three Critical Levels of Confidence Limit of NPVB When Preference is Given to Both Objectives

distance between each solution and the ideal solution is therefore used. In this procedure, each solution is calibrated with respect to the ideal solution and an interactive process with the DM is implemented to check his/her satisfaction relative to the ideal solution. The results shown in Table A.26 and Figure 7.6 (for NPVB-IAD) and Figure 7.7 (for NPVB-TS) indicate that the maximum possible goal achievement for the IAD and TS goals can be achieved without significant reduction in the achievement of the NPVB goal for all three levels of confidence limit on NPVB.

Similar characteristics of trade-offs between NPVB vs. confidence limit on NPVB vs. IAD and vs. TS for a range of BT_t^1 to BT_t^5 for the other stages of the SDP ($t = 2, .., 5$) can be generated using the results shown in Tables A.21, A.22, A.23, and A.24 respectively.

3) Important Features of Fuzzy Formulation (FCCIGP)

The fuzzy formulation expressed by Expressions (6.58)-(6.65) (see Chapter 6) in handling the problem of imprecision of input data inherent in NPVB parameters on the FCCIGP model can be applied in two versions: i) imprecision of input data inherent in specification

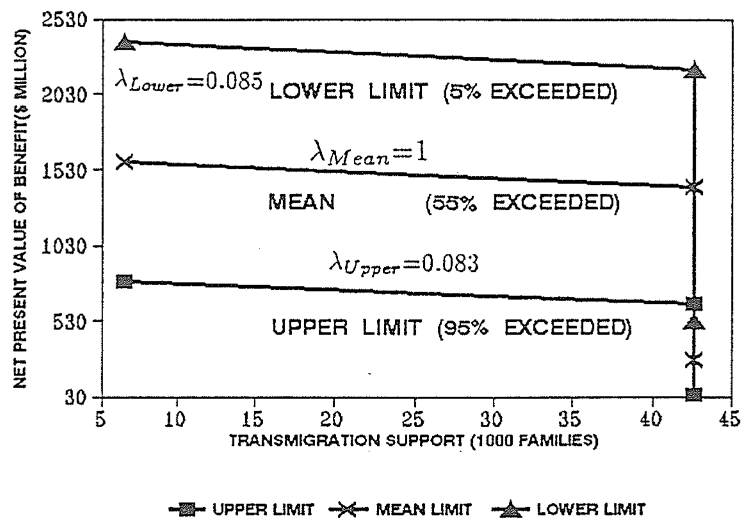


Figure 7.7: Trade-off Between NPVB Vs. TS for the Three Critical Levels of Confidence Limit of NPVB When Preference is Given to Both Objectives

of the NPVB target goal at a prespecified confidence limit and the setting of budget limit, ii) imprecision of qualitative data inherent in preference towards the confidence limit on NPVB. The more detailed discussions related to these version are given below.

i) Imprecision on the NPVB target goal and the setting of budget limit.

In this case, the grade of membership of the budgetary constraint and the NPVB goal represent the degree of the support for the model solutions. The FCCIGP (see Expressions (6.58)-(6.65)) model was run for each specified value of λ ($0 \leq \lambda \leq 1$), the lower bound of the NPVB and other goals, and the budget limit (funding allocation) with their associated tolerances, to observe the implications of the relationships between these parameters in the project portfolios.

A summary of the project selection by the FCCIGP model for the funding allocation in the range of BT_1^1 to $90\%BT_1^1$ (with tolerance interval 10% BT_t^1) for a mean confidence level at stage 1 is given in Table 7.6 and Figures 7.8 and 7.9. Observing the solutions of the FCCIGP for various membership grades of budgetary constraints and varying values of the lower bounds of NPVB target goal and under a specified budget intervals ($10\%BT_1^1$) as shown in Table 7.6 and Figures 7.8 and 7.9, the following conclusions can be drawn. The greater the grade of membership, i.e., the larger the support for the solution, the smaller the goal achievement but with the implication of a higher degree of certainty. On the other hand, the smaller the membership grade, i.e., the smaller the support for the solution, the larger the goal achievement but with the implication of a lower degree of certainty.

Note that in this formulation the membership grade λ is used to express the degree of certainty of the solution with respect to the associated fuzzy parameter(s) (Zimmermann, 1988). In this example of the model application, the levels of possible funding allocation BT_t^k planned for each stage of the SDP and the target setting of NPVB goal constraint are defined as fuzzy parameters, wherein, the closer the membership grade to unity the higher the degree of certainty. Conversely the closer λ is to zero the lower the degree of certainty. It can therefore be concluded that the FCCIGP model does not just provide "another crisp" solution; instead it produces an optimum solution together with the degree of certainty/support of the system to that solution within a prespecified tolerance interval of a binding constraint.

In this application of the model, the relationship between goal achievements and the choices of membership grade and the setting of lower bound of NPVB target goal and budget limit constraints are examined for a range of possible values of membership grade between 0 and 1. Such examination is required in order to provide the DM with sufficient information on the implication of the choice of membership grade prior to the final choice determined by the DM. Variations of the goal achievement, and hence variations in the support of the system for the solution, can be obtained by varying the value of membership grade and the value of the lower bound of NPVB target goal and of binding budgetary constraint (see Table 7.6). Depending on the choice made by the DM, membership grade can be set to 1 which indicates a maximum attainable support to this solution but yields a minimum goal achievement.

Observation of the relationship between: (i) membership grade and NPVB achievement (shown in Figure 7.8-1), (ii) membership grade of binding and non-binding constraints with tolerance level (shown in Figure 7.8-2), and (iii) NPVB and IAD achievement with tolerance level (shown in Figure 7.8-3), indicates that the changes in the tolerance interval of fuzzy constraint alters the attainment of membership grade and goal achievement only slightly. In this case, the most influential factor affecting the achievement of a membership grade is the setting of the value of the lower bound of the fuzzy constraint (see Table 7.6 and Figure 7.8-1).

ii) Imprecision of preference toward confidence limit on the NPVB criterion.
Recall that the membership grade for various level of confidence limit on NPVB are assessed by a group of DM's/assessors through a collective opinion technique, i.e., the Analytic Hierarchy Process (AHP). In this approach, it is planned that, prior to such assessments, the DMs are informed with relevant information related to the implication of any choice of confidence limit levels (see Table 6.6). [In this example application for model demonstration, the writer acted as a DM to make assessments on the choice of membership values of confidence limits.] The FCCIGP model is therefore run a number of times for the specified values of membership grade of confidence limit on NPVB between 0 and 1, shown Table 6.7 to obtain the values of all decision variables in the model formulation such as goal achievement, project portfolio and schedule, degree of constraints violation, optimal annual budget allocation, etc.

The comparison of the results of CCIGP (crisp) and FCCIGP shown in Table 7.7 and Figures 7.9 and 6.8 (Chapter 6) indicates the following features: i) both models (CCIGP and FCCIGP) are able to identify the presence of a 'risky' project relative to the 'reliable' one and to provide a means to avoid selection of those risky projects, ii) the FCCIGP model is able to explicitly handle the problem of imprecision in qualitative preference of confidence limits for NPVB criterion, i.e., the effects of such choice can be explicitly evaluated as in Figure 7.9 which shows the relationship between the NPVB attainment and the membership grade of the confidence limit for NPVB, and iii) the results of the FCCIGP enable membership grade as well as the degree of violation of NPVB constraint to be easily observed and their implications on the model solutions explicitly evaluated.

In addition to the features described above, the formulation of the model in the Fuzzy Set theory enables the membership grade to be used effectively to represent the level of the support for solutions in hierarchial manner when the modified partitioning algorithm is used to screen the projects based on the sociotechnical selection criteria preferences (Case G), e.g., the projects that are categorized in the First Priority have higher membership grade than the projects in the Second Priority, etc. (see Figure 7.10).

Table 7.6: Projects Selected by FCCIGP Under Various Membership Grade of NPVB Goal for the Possible Funding Allocation BT_1^1 and Mean Confidence Limit on NPVB

Proposed Projects		YEAR IN WHICH CONSTRUCTION STARTED										
		MEMBERSHIP GRADE OF BUDGET AND GOALS CONSTRAINTS										
Project Number & Name	Area (ha)	1	0.913	0.856	0.800	0.753	0.647	0.538	0.421	0.302	0.217	0.123
1 Krueng Baro	16772	1st	1st	0	1st	1st	1st	1st	1st	1st	1st	1st
2 North Sumatra	41000	0	0	0	0	0	0	0	0	0	0	0
3 Pasaman	4926	2nd	2nd	2nd	2nd	0	2nd	2nd	2nd	2nd	2nd	2nd
4 Batang Kumu	13800	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
5 Limun Sungkat	2500	4th	4th	4th	4th	4th	4th	4th	1st	4th	4th	1st
6 Komering	55904	0	0	0	0	0	0	0	0	0	0	0
7 Baal	5500	0	0	0	0	0	0	0	0	0	0	0
8 Way Abung	5000	2nd	0	2nd	1st	0	0	2nd	2nd	2nd	2nd	2nd
9 Way Perdada	13550	1st	0	1st	0	1st	1st	1st	1st	1st	1st	1st
10 Alas	4400	0	0	0	0	0	0	0	0	0	0	0
11 Manjuto Kanan	10000	0	0	0	0	0	0	0	0	0	0	0
12 Teluk Lada	18923	0	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
13 Jatigede	130158	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
14 Jratunseluna	74537	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
15 Dumpil	25415	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
16 Madura	2580	4th	4th	4th	4th	4th	4th	4th	4th	4th	4th	4th
17 East Java Rehab	42912	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
18 Sanggau Ledo	555	4th	4th	4th	0	0	1st	0	4th	4th	4th	4th
19 Kasau	5000	0	0	0	0	0	0	0	0	0	0	0
20 Riam Kanan	12000	0	0	0	0	0	0	0	0	0	0	0
21 Toraut Bongo	7820	0	0	0	0	0	0	0	0	0	0	0
22 Taopa	8000	0	0	0	0	0	0	0	0	1st	0	0
23 Kalong	1200	0	4th	0	4th	0	4th	0	4th	3rd	0	3rd
24 Boya	10000	0	0	0	0	0	0	0	0	0	1st	1st
25 San Rego	7500	0	0	0	0	0	0	0	0	0	0	0
26 Wawotobi	21200	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
27 Dataran Kobi	1950	4th	4th	0	0	0	0	0	4th	4th	0	2nd
28 Wimbo Erang	1963	0	0	0	0	0	0	0	0	0	0	0
29 Irigasi Bali	3425	0	0	0	0	0	0	0	0	3rd	0	0
30 Embung NTB	1520	0	0	0	0	0	0	0	0	0	0	0
31 Kalimantong	2850	0	0	0	0	0	0	0	0	0	0	0
32 Irigasi NTT	3360	0	0	0	0	0	0	0	0	0	0	0
33 Embung NTB	8276	0	0	0	0	0	0	0	0	0	0	0

PARAMETERS	GOAL ATTAINMENT										
1 Irrigation Area (ha)	377075	376698	377276	381143	383567	389048	393493	397198	400623	404048	407198
2 N.P.V. of Benefit ($10^6)	1489.7	1498.7	1500.4	1510.9	1520	1538	1550.6	1555.5	1564.6	1566.2	1571.1
3 Transmigration Support (number of families)	13000	14500	9000	14500	14500	14500	14500	15000	15000	16500	17500
4 Number Selected Projects	14	14	13	13	11	14	13	16	18	15	17.
5 Total Budget ($10^6)	832	839.97	845.2	850.4	854.76	864.41	874.48	885.24	896.21	904.03	912.68
6 Lower Bound of NPVB ($10^6)	650	750	800	850	900	1000	1100	1200	1300	1370	1450

	ANNUAL BUDGET ALLOCATION										
First Year (B1)	131.64	134.85	134.36	134.85	139.25	139.25	139.25	142.1	139.26	143.71	145.8
Second Year (B2)	254.96	259.29	260.67	261.97	265.75	267.68	270	271.95	269.95	280.24	283.53
Third Year (B3)	165.46	166.42	169.06	169.68	168.97	171.75	175	175	180.66	180.4	184.25
Fourth Year (B4)	162.86	162.58	163.87	165.38	163.47	166.43	169.23	171.4	178.75	174.69	174.13
Fifth Year (B5)	117.08	116.84	117.22	118.53	117.32	119.31	120.99	124.78	127.58	124.97	124.97

NOTE: $BT_1^1 - 90\% BT_1^1$ = REFLECTING 10% TOLERANCE INTERVAL BELOW POSSIBLE FUNDING ALLOCATION BT_1^1

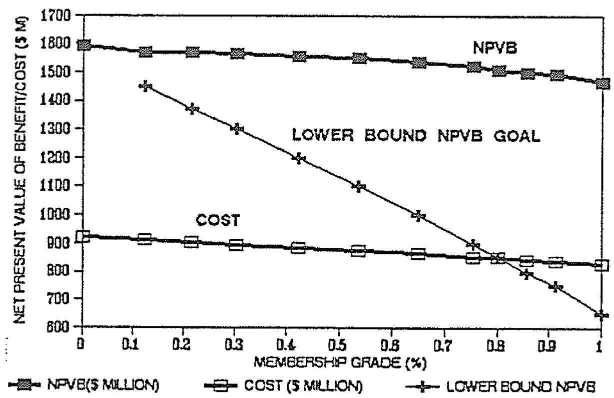


FIGURE 7.8 - 1 : RELATIONSHIP BETWEEN
GOAL ACHIEVEMENT (NPVB GOAL) Vs.
MEMBERSHIP GRADE OF GOAL CONSTRAINT

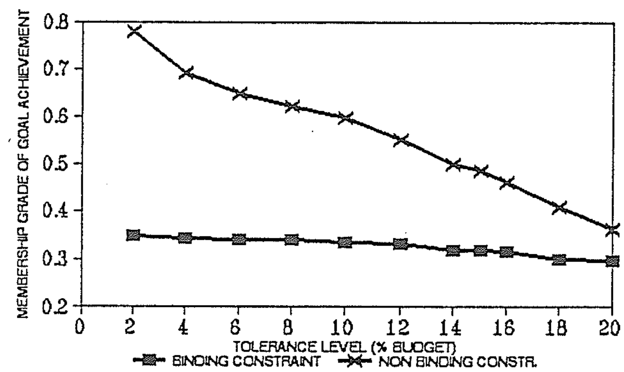


FIGURE 7.8 - 2 : RELATIONSHIP BETWEEN
MEMBERSHIP GRADE Vs. TOLERANCES
OF BUDGET CONSTRAINTS

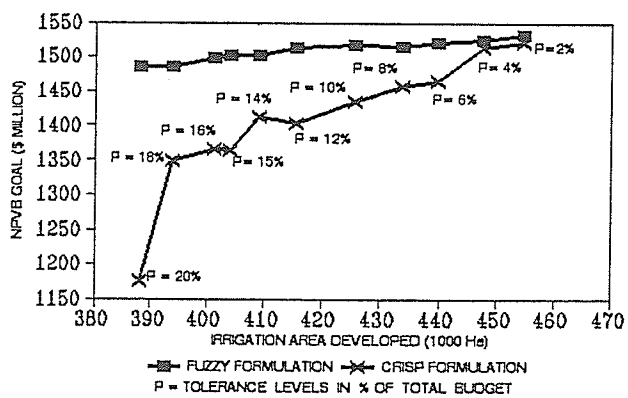


FIGURE 7.8 - 3 : RELATIONSHIP BETWEEN
GOAL ACHIEVEMENT (NPVB & IAD) FOR
VARIOUS LEVELS OF TOLERANCE

Figure 7.8: Relationship Between Membership Grade of Target Goals, Goal Achievement and Prespecified Goal Tolerance

Table 7.7: Projects Selected by FCCIGP Under Various Membership Grades of Confidence Limits on NPVB and 'Crisp' CCIGP Under Various Confidence Limits on NPVB for the Possible of Funding Allocation BT_1^1

Proposed Projects		YEAR IN WHICH CONSTRUCTION STARTED									
		CONFIDENCE LIMIT LEVELS									
Project Number & Name	Area (ha)	95% EXCEEDED		75% EXCEEDED		55% EXCEEDED		30% EXCEEDED		5% EXCEEDED	
		FUZZY	CRISP	FUZZY	CRISP	FUZZY	CRISP	FUZZY	CRISP	FUZZY	CRISP
1 Krueng Baro	16772	0	0	1st	1st	1st	1st	1st	1st	1st	1st
2 North Sumatra	41000	1st	1st	1st	1st	1st	1st	0	1st	0	0
3 Pasaman	4926	1st	2nd	2nd	2nd	2nd	2nd	2nd	2nd	2nd	2nd
4 Batang Kumu	13800	0	0	1st	1st	1st	1st	1st	1st	1st	1st
5 Limun Sungkat	2500	3rd	3rd	4th	4th	4th	4th	4th	4th	4th	4th
6 Komering	55904	0	0	0	0	0	0	1st	0	1st	1st
7 Baal	5500	0	0	0	0	0	0	0	0	0	0
8 Way Abung	5000	2nd	2nd	2nd	2nd	2nd	2nd	0	2nd	0	0
9 Way Perdada	13550	1st	1st	1st	1st	1st	1st	0	1st	0	0
10 Alas	4400	0	0	0	0	0	0	0	0	0	0
11 Manjuto Kanan	10000	0	0	0	0	0	0	0	0	0	0
12 Teluk Lada	18923	1st	1st	0	0	0	0	0	0	0	0
13 Jatigede	130158	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
14 Jratunseluna	74537	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
15 Dumpil	25415	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
16 Madura	2580	3rd	3rd	4th	4th	4th	4th	4th	4th	4th	4th
17 East Java Rehab	42912	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
18 Sanggau Ledo	555	4th	4th	0	0	0	0	4th	0	4th	4th
19 Kasau	5000	0	0	0	0	0	0	0	0	0	0
20 Riam Kanan	12000	0	0	0	0	0	0	0	0	0	0
21 Toraut Bongo	7820	0	0	0	0	0	0	0	0	0	0
22 Taopa	8000	0	0	0	0	0	0	0	0	0	0
23 Kalong	1200	0	0	0	0	0	0	4th	0	3rd	3rd
24 Boya	10000	0	0	0	0	0	0	0	0	0	0
25 San Rego	7500	0	0	0	0	0	0	0	0	0	0
26 Wawotobi	21200	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
27 Dataran Kobi	1950	0	0	0	0	0	0	4th	0	2nd	2nd
28 Wimbo Erang	1963	0	0	0	0	0	0	0	0	0	0
29 Irigasi Bali	3425	0	0	0	0	0	0	0	0	0	0
30 Embung NTB	1520	0	0	0	0	0	0	0	0	0	0
31 Kalimantong	2850	0	0	0	0	0	0	0	0	0	0
32 Irigasi NTT	3360	0	0	0	0	0	0	0	0	0	0
33 Embung NTB	8276	0	0	0	0	0	0	0	0	0	0

PARAMETERS	GOAL ATTAINMENT									
1 Irrigation Area (ha)	404476	404476	415570	415570	415570	415570	415629	415570	415629	415629
2 N.P.V. of Benefit ($10^6)	792.85	792.85	1272.9	1272.9	1590.4	1590.4	1828	1836.7	2378.8	2378.8
3 Transmigration Support (number of families)	6500	6500	26000	26000	26000	26000	14500	26000	27500	27500
4 Number Selected Projects	13	13	13	13	13	13	14	13	14	14
5 Total Budget ($10^6)	920.43	920	923.87	923.87	923.87	923.87	922.18	923.87	923.77	923.77
6 Membership Grade of Confidence Limits	0.083	-	0.17	-	1	-	0.17	-	0.085	-
7 The Degree of Violation the NPVB Constraints	0.917	-	0.83	-	0	-	0.83	-	0.915	-

	ANNUAL BUDGET ALLOCATION									
First Year (B1)	148.3	148.3	147.53	147.53	147.33	147.33	147.53	147.33	147.53	147.53
Second Year (B2)	284.29	284.29	283.49	283.49	285.51	285.51	283.49	285.38	286.16	286.16
Third Year (B3)	187.38	187.38	181.8	181.8	184.82	184.82	181.8	184.82	185.64	185.64
Fourth Year (B4)	176.78	176.78	179.69	179.69	178.59	178.59	179.69	178.59	177.26	177.26
Fifth Year (B5)	123.68	123.68	129.68	129.68	127.62	127.62	129.68	127.75	126.17	126.17

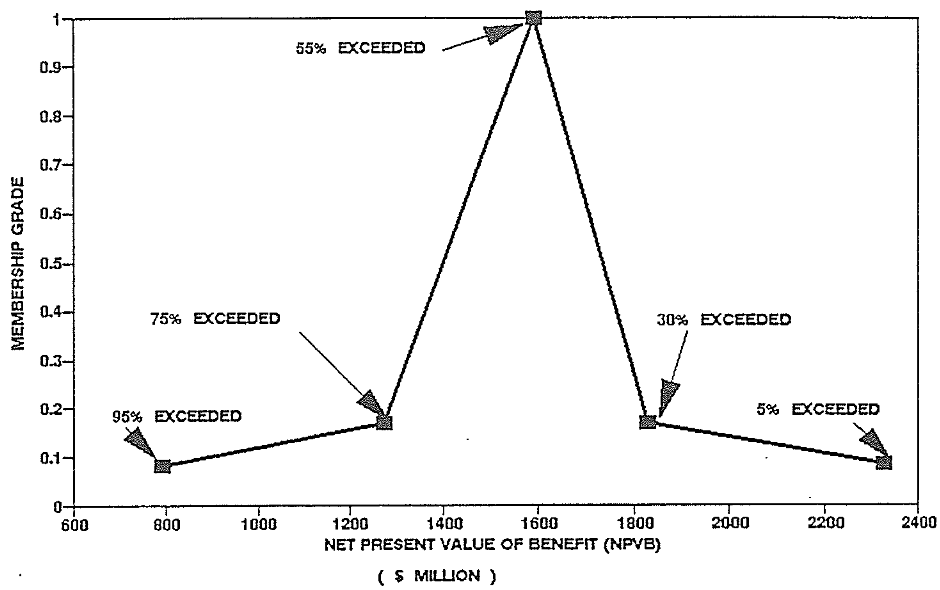


Figure 7.9: Relationship Between NPVB, Membership Grade of Confidence Limit on NPVB and Confidence Limits on NPVB

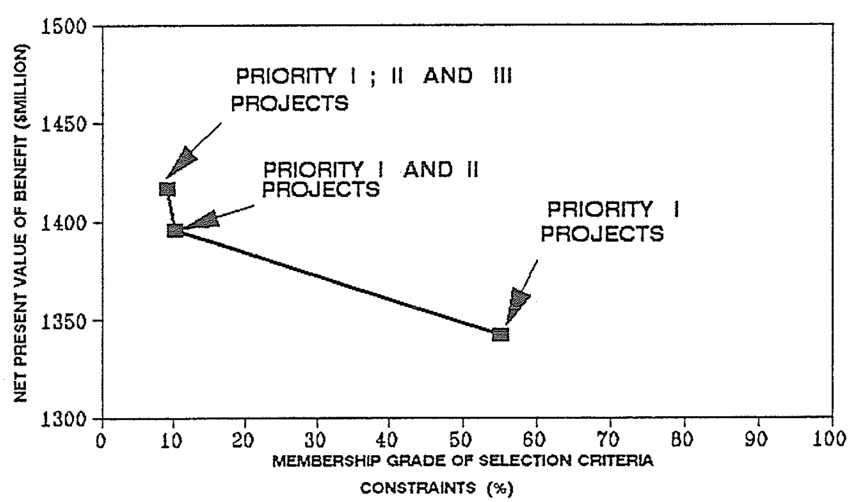


Figure 7.10: Relationship Between Membership Grade of Selection Criteria, NPVB Goal Achievement when Preferences are Given to Sociotechnical Selection Criteria for Case G

7.3.4 Discussion of FCCIGP-SDP Results

Optimal Investment Planning Decision

To this point the discussion has focussed on the project selection procedure with respect to goal and criteria preferences, economic return risk preference and imprecision of input data as well as managerial concerns for each level of possible funding decision D_t^k in each scheduling horizon (stage t) of the SDP model as provided by the FCCIGP model by running it for each value in the range of possible funding allocations as provided. However, in the integrated model of FCCIGP-SDP model, the question of which level of possible funding decision is 'optimal' with respect the associated probabilities of getting actual funding relative to various level of possible funding is handled by the SDP model. The transformation probabilities $(p(F^l_{t,i,m,k}))^\gamma$ for each of the budget scenario cases γ examined in the SDP model are taken from the analysis in Chapter 5 and information on historical data given in Tables 7.1 and 7.3. Those transformation probabilities are shown in Tables A.15, A.16, and A.17 in the Appendix for the three scenarios of future budget availability, $\gamma=$ Limited, Non-limited, and Undetermined Budget respectively. The summary of the inputs for the SDP model obtained by running the FCCIGP model a number of times taking into account the possible combinations of 5 levels of possible funding decisions $D^k_{t,i,m}$ and 5 levels of actual funding received $F^l_{t,i,m}$ with the associated cost escalation coefficient (see Section 5.4) and for three critical levels of confidence limits on NPVB with the associated membership grade are given in the Appendix. These inputs are shown in Tables A.27, A.28, A.29 for $t = 1$, J_t=26; Tables A.30, A.31, A.32 for $t = 2$, J_t=26; Tables A.33, A.34, A.35 for $t = 3$, J_t=26; Tables A.36, A.37, A.38 for $t = 4$, J_t=31; Tables A.39, A.40, A.41 for $t = 5$, J_t=31, for the Mean, Upper, and Lower Levels of confidence limit on the NPVB respectively.

The summary of the SDP results in terms of relative frequencies of the optimal investment/funding decisions with the associated information, i.e., goal achievements and optimal project portfolios for all stages t and the three scenarios of future budget availability, and for the mean confidence limit on NPVB with the associated membership grade is shown in Table 7.8. Similar results for the upper and lower confidence limits on NPVB are given in Tables A.42 and A.43 respectively in the Appendix. The other SDP results in terms of the distribution of the optimal investment /funding decision with respect to the state combina-

Table 7.8: Relative Frequency of Optimal Funding Decision for Each Stage and Each Case with Their Associated Goal Attainment for Mean Confidence Limit on NPVB and Membership Grade of Confidence Limit on NPVB, $\lambda_{Mean} = 1.0$

PARAMETERS	GOAL ATTAINMENT — OPTIMAL DECISION For Mean Confidence Level (55% exceeded)					REMARKS					
	D_t^1	D_t^2	D_t^3	D_t^4	D_t^5						
SCHEDULING HORIZON $t = 1$						RELATIVE FREQUENCY OF OPTIMAL DECISION (%)					
Irrigation Area (ha)	415570	*)	*)	*)	*)	Scenario 1:	D_1^1 100	D_1^2 0	D_1^3 0	D_1^4 0	D_1^5 0
N.P.V. Of Benefit ($ 10^6)	1590.48	*) Non optimal decision				Scenario 2:	D_1^1 100	D_1^2 0	D_1^3 0	D_1^4 0	D_1^5 0
Number of selected projects	13					Scenario 3:	D_1^1 100	D_1^2 0	D_1^3 0	D_1^4 0	D_1^5 0
Total budget used ($ 10^6)	923.87										
SCHEDULING HORIZON $t = 2$						RELATIVE FREQUENCY OF OPTIMAL DECISION (%)					
Irrigation Area (ha)	202100	194433	166433	141565	107655	Scenario 1:	D_2^1 0	D_2^2 2.30	D_2^3 11.45	D_2^4 46.15	D_2^5 40.
N.P.V. Of Benefit ($ 10^6)	891.59	880.61	855.21	808.38	735.55	Scenario 2:	D_2^1 100	D_2^2 0	D_2^3 0	D_2^4 0	D_2^5 0
Number of selected projects	24	23	20	17	9	Scenario 3:	D_2^1 0	D_2^2 0	D_2^3 4.62	D_2^4 0	D_2^5 95.38
Total budget used ($ 10^6)	710.03	684.84	578.35	477.85	368.82						
SCHEDULING HORIZON $t = 3$						RELATIVE FREQUENCY OF OPTIMAL DECISION (%)					
Irrigation Area (ha)	248618	248618	216968	177720	138190	Scenario 1:	D_3^1 0	D_3^2 0	D_3^3 1.53	D_3^4 95.40	D_3^5 3.07
N.P.V. Of Benefit ($ 10^6)	906.44	933.91	900.22	827.09	786.73	Scenario 2:	D_3^1 100	D_3^2 0	D_3^3 0	D_3^4 0	D_3^5 0
Number of selected projects	26	26	20	16	12	Scenario 3:	D_3^1 0	D_3^2 0	D_3^3 0	D_3^4 26.10	D_3^5 73.90
Total budget used ($ 10^6)	911.62	909.35	769.61	626	489.2						
SCHEDULING HORIZON $t = 4$						RELATIVE FREQUENCY OF OPTIMAL DECISION (%)					
Irrigation Area (ha)	258565	235565	195093	158890	129315	Scenario 1:	D_4^1 0	D_4^2 0	D_4^3 30.30	D_4^4 69.70	D_4^5 0
N.P.V. Of Benefit ($ 10^6)	1298.23	1233.89	1163.19	1098.7	975.16	Scenario 2:	D_4^1 100	D_4^2 0	D_4^3 0	D_4^4 0	D_4^5 0
Number of selected projects	24	19	17	16	14	Scenario 3:	D_4^1 0	D_4^2 0	D_4^3 97.4	D_4^4 2.60	D_4^5 0
Total budget used ($ 10^6)	1060.44	932.83	785.47	646.32	500.91						
SCHEDULING HORIZON $t = 5$						RELATIVE FREQUENCY OF OPTIMAL DECISION					
Irrigation Area (ha)	252403	230473	194494	164344	129116	Scenario 1:	D_5^1 0	D_5^2 0	D_5^3 28.40	D_5^4 71.60	D_5^5 0
N.P.V. Of Benefit ($ 10^6)	837.68	824.22	784.21	753.44	685.32	Scenario 2:	D_5^1 100	D_5^2 0	D_5^3 0	D_5^4 0	D_5^5 0
Number of selected projects	23	25	18	17	14	Scenario 3:	D_5^1 0	D_5^2 0	D_5^3 16.80	D_5^4 0	D_5^5 83.20
Total budget used ($ 10^6)	1137.78	1019.32	854.83	699.63	550.76						

SCENARIO 1 = LIMITED BUDGET
SCENARIO 2 = NON-LIMITED BUDGET
SCENARIO 3 = UNDETERMINED BUDGET

tion of level of development and level of previous funding $L_t^{i,m}$ for all t, i, m, for the Scenario 3 (Undetermined Budget), and for mean confidence limit on NPVB criterion with the associated membership grade are shown in Table 7.9, and Tables A.44 and A.45 for the upper and lower confidence limits on NPVB respectively. The similar results occuring for Scenario 2 (the Non-limited Budget) and Scenario 1 (Limited Budget), and for the mean, upper, and lower confidence limits on NPVB are shown in Tables A.46, A.47, A.48; and Tables A.49, A.50, A.51 respectively.

Examination of optimal investment funding decisions for: i) the three scenarios of budget availability i.e., Scenario 1 (Limited Budget), Scenario 2 (Non-limited Budget) and Scenario 3 (Undetermined Budget), ii) the three levels (mean, upper, and lower) of confidence limits on NPVB with the associated membership grade, and iii) the 5 years scheduling horizon ($NT \leq 5$ years) on each stage t of the SDP model reveals the folowing characteristics.

The results for Scenario 1 (see Tables A.49, A.50, and A.51) show that for stage $t = 1$ the optimal investment decision selected is always funding decision level one ($D^1_{1,i,m}$ $\forall$ i, m) for the lower and mean level of confidence limit and level two ($D^2_{1,i,m}$ $\forall$ i m) for the upper confidence limit. These two decisions are those associated with the first and second highest level funding decision. On the other hand, at the remaining stages ($t = 2,..,5$) and for all of the three levels of confidence limits, the level of existing development L_t^i (state i) has significant influence on the choice of optimal funding investment. For example, in stages $t = 2$ and 3 and at the states associated with lower levels of existing development ($i = 23, ..., 26$), the optimal funding decisions selected consist of two of $D^2_{t,i,m}$, representing 5% of the total optimal funding decisions selected at those stages, 27 of $D^3_{t,i,m}$, representing 68% of the total optimal funding decisions selected at those stages ($t = 2, 3$) and states combination $L_t^{i,m}$; and 11 of $D^4_{t,i,m}$ representing 27% of the total optimal funding decisions selected at those stages. At medium levels of existing development ($i = 11, .., 22$) the majority of the optimal funding decisions selected tends to be at the lower level; $D^4_{t,i,m}$ is selected 113 times representing 94% of the total funding decisions and $D^5_{t,i,m}$, 7 times representing 6% of the total optimal funding decisions. Similarly, at the states associated with higher levels of development ($i = 1, ..., 22$) the optimal funding decisions selected consist of 53 choices of $D^4_{t,i,m}$ representing 53% of all funding decisions and 47 choices of $D^5_{t,i,m}$ representing 47% of all funding decisions. A rather

Table 7.9: Distribution of Optimal Funding Decision $D^*_{t,i,m}$ with Respect to the State Combination of Level of Development and Level of Previous Funding $L_t^{i,m}$ $\forall$ t, i, m for Undetermined Budget Scenario and Mean Confidence Limit on NPVB with Membership Grade of Confidence Limit on NPVB, λ_{Mean}=1.0

SCHEDULING HORIZON ; LEVEL OF PREVIOUS FUNDING=1 ; OPTIMAL DECISION: $D^*_{1,1}=1$
$t=1$ LEVEL OF DEVELOPMENT: = 1

SCHEDULING HORIZON: $t=2$						SCHEDULING HORIZON: $t=3$						SCHEDULING HORIZON: $t=4$						SCHEDULING HORIZON: $t=5$					
LEVEL OF DEVEL-OPMENT	LEVEL OF PREVIOUS FUND m					LEVEL OF DEVEL-OPMENT	LEVEL OF PREVIOUS FUND m					LEVEL OF DEVEL-OPMENT	LEVEL OF PREVIOUS FUND m					LEVEL OF DEVEL-OPMENT	LEVEL OF PREVIOUS FUND m				
	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
i	OPTIMAL DECISION $D^*_{2,i,m}$					i	OPTIMAL DECISION $D^*_{3,i,m}$					i	OPTIMAL DECISION $D^*_{4,i,m}$					i	OPTIMAL DECISION $D^*_{5,i,m}$				
1	5	5	3	5	5	1	5	5	4	5	5	1	3	3	3	3	3	1	5	5	5	5	5
2	5	5	5	5	5	2	5	4	5	5	5	2	3	3	3	3	3	2	5	5	5	5	5
3	5	5	5	5	5	3	4	5	5	5	5	3	3	3	3	3	3	3	5	5	5	5	5
4	5	5	5	5	5	4	5	5	5	5	5	4	3	3	3	3	3	4	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	3	3	3	3	3	5	5	5	5	5	5
6	5	5	5	5	5	6	5	5	5	5	5	6	3	3	3	3	3	6	5	5	5	5	5
7	5	5	5	5	5	7	4	4	4	4	5	7	3	3	3	3	5	7	5	5	5	5	5
8	5	5	5	5	5	8	5	5	5	5	5	8	3	3	3	5	3	8	5	5	5	5	5
9	5	5	5	5	5	9	5	5	5	5	5	9	3	3	5	3	3	9	5	5	5	5	5
10	5	5	5	5	5	10	5	5	5	5	5	10	3	5	3	3	3	10	5	5	5	5	5
11	5	5	5	5	5	11	5	5	5	5	5	11	5	3	3	3	3	11	5	5	5	5	5
12	5	5	5	5	5	12	5	5	5	5	5	12	3	3	3	3	3	12	5	5	5	5	5
13	5	5	5	5	5	13	5	5	5	5	5	13	3	3	3	3	3	13	5	5	5	5	5
14	5	5	5	5	5	14	5	5	5	5	5	14	3	3	3	3	3	14	5	5	5	5	5
15	5	5	5	5	5	15	5	5	5	5	5	15	3	3	3	3	3	15	5	5	5	5	5
16	5	5	5	5	5	16	5	5	5	5	5	16	3	3	3	3	3	16	5	5	5	5	5
17	5	5	5	5	5	17	5	5	5	5	5	17	3	3	3	3	3	17	5	5	5	5	5
18	5	5	5	5	3	18	5	5	5	4	4	18	3	3	3	3	3	18	5	5	5	5	3
19	5	5	5	3	5	19	5	5	4	4	4	19	3	3	3	3	3	19	5	5	5	3	5
20	5	5	3	5	5	20	5	5	4	4	4	20	3	3	3	3	3	20	5	5	3	5	5
21	5	3	5	5	5	21	5	4	4	4	4	21	3	3	3	3	3	21	5	3	5	5	5
22	3	5	5	5	5	22	4	4	4	4	4	22	3	3	3	3	3	22	3	5	5	5	5
23	5	5	5	5	5	23	4	4	4	4	4	23	3	3	3	3	3	23	5	5	5	5	5
24	5	5	5	5	5	24	4	4	4	4	4	24	3	3	3	3	3	24	5	5	5	5	5
25	5	5	5	5	5	25	4	4	4	4	4	25	3	3	3	3	3	25	5	5	5	5	5
26	5	5	5	5	5	26	4	4	4	4	5	26	3	3	3	3	3	26	5	5	5	5	5
												27	3	3	3	3	3	27	5	5	5	5	5
												28	3	3	3	3	3	28	5	5	5	5	5
												29	3	3	3	3	3	29	5	5	5	5	5
												30	3	3	3	3	3	30	5	5	5	5	5
												31	3	3	3	3	3	31	5	5	5	5	5

moderate (less strong) influence is observed at stages t =4 and 5. At the states associated with lower levels of development ($i = 23, ..., 31$) for all confidence levels, $D^3_{t,i,m}$ is selected 100% of the time. At the states associated with the higher and medium levels of existing development ($i = 1, ..., 22$), the optimal funding $D^4_{t,i,m}$ is selected 104 times representing 95% of all decision for mean and lower confidence levels. However, a significant variation of the optimal funding decision is again observed for the upper confidence limit on NPVB at the same stages ($t = 4, 5$), i.e., $D^4_{t,i,m}$ is selected 103 times (53% of all funding decisions), and $D^5_{t,i,m}$ is selected 117 times (47% of all funding decisions).

Further examination of the results shown in Tables A.49, A.50, and A.51 for Mean, Upper, and Lower confidence limits on NPVB reveals that this confidence limit only effects the distribution of optimal funding decision slightly; the optimal funding decisions for all stages and states are almost similar for the three confidence limits, except for the highest and medium states of the stage 5 at the Upper Confidence Limit as described above. Similarly variation of level of previous funding, m, only yields a minor variation in the distribution of the optimal funding decisions at any stage and state. A small variation is observed at the highest ($i = 1, ..., 6$) and lowest ($i = 23, ..., 26$) levels of existing development for the stages t =2 and 3.

On the basis of this evidence it may be concluded that, when the likelihood of obtaining the high level of funding is low, as reflected in the transformation probabilities of Scenario 1 (Limited Budget), most of the optimal funding decisions at any stage yield the decision involving the lower levels of possible funding. It is apparent, somewhat unexpectedly, that level of previous funding and level of confidence limit on NPVB only have a minor influence on the distribution of optimal funding decision under the scenario of Limited budget. On the other hand, the level of development has a significant influence on such distribution.

The results of Scenario 2 (Non-Limited Budget) (see Tables A.46, A.47, and A.48) show that at the stage 1 the optimal investment decision selected is $D^1_{1,i,m}$ $\forall$ i, m. Similar results are obtained for the remaining stages and for all confidence limits on NPVB, and the optimal funding decisions selected are always $D^1_{t,i,m}$. These results indicate that level of development, level of previous funding, and confidence limit on NPVB do not have any impact on the optimal funding decision selected for the Non-limited Budget scenario.

On the basis this result, it may be concluded that, when the likelihood of obtaining a high level of funding is high, as reflected in transformation probabilities of Scenario 2 (Non-Limited Budget), all of the optimal funding decision at any state and stage will always yield the decision that involves the highest level of possible funding, namely $D^1_{t,i,m}$, regardless the preference toward confidence limit on NPVB.

The results for the Scenario 3 (Undetermined Budget) (see Tables 7.9, A.44, A45) show that at stage 1 the optimal decision selected is $D^1_{1,i,m}$ $\forall$ i, m for the mean and lower level of confidence limit on NPVB, and $D^2_{1,i,m}$ $\forall$ i, m for the upper confidence limit. A more variable distribution is observed at the other stages $t = 2, ..., 5$. When NPVB is evaluated at the mean confidence limit, for example, $D^3_{t,i,m}$ is selected 165 times representing 28% of all decisions, $D^4_{t,i,m}$ is selected 34 times representing 6%, and $D^5_{t,i,m}$ is selected 391 times representing 66% of all decisions (see Table 7.9). A similar pattern is observed when NPVB is evaluated at the lower confidence limit (see Table A.45), except that in this case the majority of optimal funding decision tends to shift to the higher level, i.e., $D^3_{t,i,m}$ is selected 425 times (75% of all decisions), $D^4_{t,i,m}$ is selected 41 times (7% of all decisions), and $D^5_{t,i,m}$ is selected 104 times (18% of all decisions). When NPVB is evaluated at the upper confidence limit (see Table A.44) the decisions $D^3_{t,i,m}$, $D^4_{t,i,m}$ and $D^5_{t,i,m}$ are selected 10, 10, and 550 times respectively representing 2%, 2%, and 96% of all decisions respectively.

Further examination of the results shown in Tables 7.9, A.44, and A.45 indicates that for Undetermined Budget scenario (Scenario 3), level of development (state) does not have any impact on the distribution of optimal funding decision selected for the upper and lower level of confidence limits (see Tables A.44 and A.45). However, a significant impact can be observed at stage $t = 3$ for the mean confidence limit (see Table 7.9). It can also be seen that variation in level of previous funding, m, only yields a minor variation in the distribution of optimal funding selected with the variation occuring predominated in states $i = 1, ..., 10$ associated with higher levels of development, at the stages $t = 2$ and 3 for the mean and lower confidence limit.

On the basis of these results, it may be concluded that, when the most likely available funds are somewhere in between the two extremes (maximum and minimum level), as reflected in the transformation probabilities of Scenario 3 (Undetermined Budget) most of the optimal

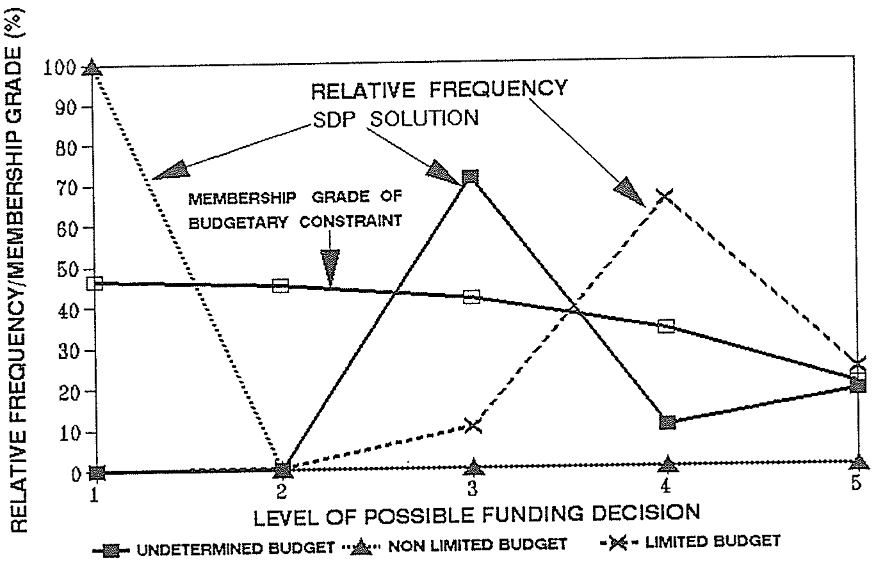


Figure 7.11: Relationship Between Relative Frequency of Possible Funding Decision and Membership Grade of Budgetary Constraint for the Three Future Budget Availability Scenarios

decisions at any stage will favour the decision involving the medium and lower levels of possible funding, namely levels three through five. It should be noted, however, that level of development and level of previous funding have a minor effect on the distribution of optimal funding decision. On the other hand, preference toward confidence limit on NPVB has a significant impact on the distribution of optimal funding decision.

Examination of the relationship between the membership grade of the budgetary constraint formulated in the FCCIGP model (at the Lower Confidence limit on the NPVB criterion) for the five possible funding decisions, $D^k_{t,i,m}$ vs. the relative frequencies of the optimal funding decisions for the three budget scenarios shown in Figure 7.11 indicates that under the Undetermined Budget scenario the optimal decision is not associated with the highest membership grade. Conversely, the possible funding decisions that are associated with the highest membership grade are not an optimal funding decisions. Similar observation can be made for Limited Budget scenario. However, under the Non-limited Budget scenario, the optimal planning decision is always associated with the highest membership grade. These results are consistent with the situation in which budget availability level is closely parallel to the level of satisfaction.

To examine how good the optimal investment policies produced by the SDP model using transformation probabilities generated from the combination of Subjective model and Direct Assessment method (see Tables A.15, A.16, and A.17) relative to the 'historical planned' funding and the 'historical actual' funding realisations extracted from the information available in Table 7.1, the relative frequencies of the SDP's optimal funding policy, for various level of confidence limits on the NPVB criterion and the distribution of the 'historical planned' funding decisions and the 'historical actual' funding realization were plotted in Figure 7.12.

Examination of Figure 7.12-1 indicates that the SDP results under Scenario 1 (Limited Budget) for all level of confidence limit on NPVB cover almost the same range as the range of levels of 'historical actual' funding realization. However there is a difference in the peaks of the SDP result and the 'historical actual' funding. Under a condition of limited budget availability the SDP results suggest that the second lowest level possible funding $D^4_{t,i,m}$ is the most 'optimal'/suitable investment decision.

On the other hand, under the Non-Limited Budget condition (see Figure 7.12-2) the SDP results suggest that the optimal investment decision is associated with the highest level of possible funding, i.e., $D^1_{t,i,m}$ (level of funding that satisfy fully projected demand). This level of decision is coincident with the historical record of levels of 'planned' funding for water resources projects in Indonesia over 17 years (see Table 7.1). However, in reality (as shown in Table 7.1) such levels of planned funding never been satisfied. There were always discrepancies between planned and actual funding received (see Table 7.1). As previously cited reflection of this situation is that many hundreds of on going water resources projects have been rescheduled, postponed and some even have been cancelled.

A more varying pattern optimal investment decisions with respect to the preferences toward confidence limit on NPVB is observed from the results of the SDP model under Undetermined Budget scenario (see Figure 7.12-3). Almost all of the optimal funding decisions selected in this case are concentrated on the medium level $D^3_{t,i,m}$ for the lower confidence limit, and on the lowest level $D^5_{t,i,m}$ for the mean and upper confidence limits. These results can be interpreted as indicating that, at the medium level of investment, the economic return of such investment can only be attained at lower confidence limits. On the other hand, at

FIGURE 7.12-1 : SDP RESULTS FOR SCENARIO 1 (LIMITED BUDGET)

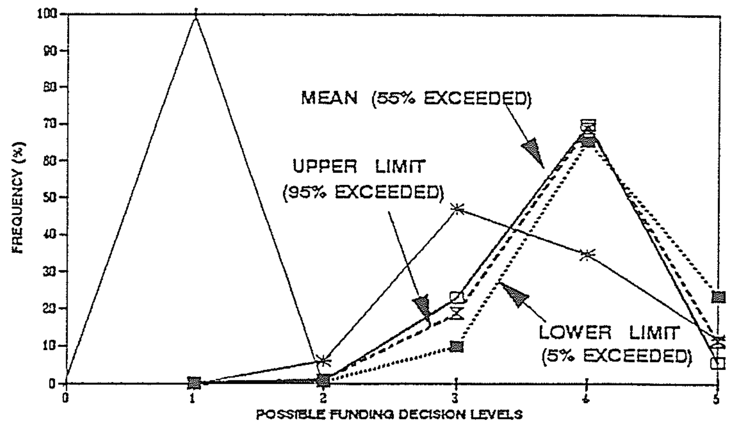


FIGURE 7.12-2 : SDP RESULTS FOR SCENARIO 2 (NON-LIMITED BUDGET)

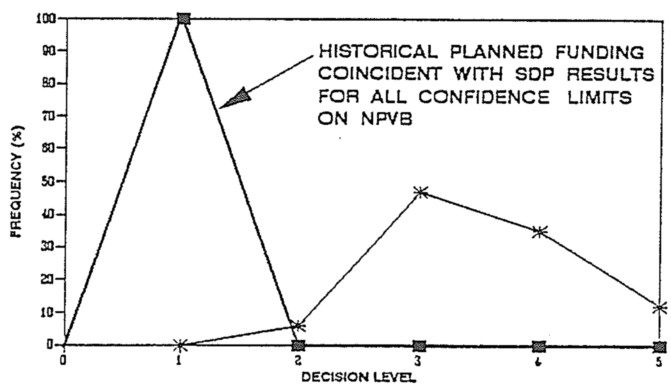


FIGURE 7.12-3 : SDP RESULTS FOR SCENARIO 3 (UNDETERMINED BUDGET)

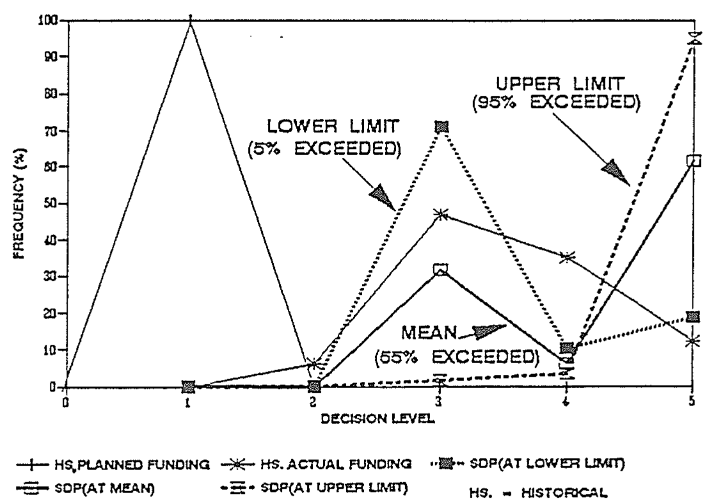


Figure 7.12: Comparison of Relative Frequency Between SDP Results vs. Historical Planned and Historical Actual Funding for the Three Scenarios of Future Budget Availability and Three Critical Confidence Limits

the lowest level of investment the economic return of such investment can be attained with higher confidence limits. Therefore, these results are consistent with the definition of Undetermined Budget, i.e., the level of actual funding is not known precisely, but it is estimated to lie somewhere in between the maximum and minimum levels. It has been noted that the relative frequency of optimal funding decision generated by the SDP model using the Direct Assessment (DA) derived transformation probability does not match perfectly with the relative frequency of 'historical actual' funding since there are significant gaps at the lowest and second lowest level funding decisions. The reason for the existence of such significant gaps is due to two factors, namely: i) the differences in characteristics between the scenario-based probability assignment of the Undetermined Budget scenario (see Figure 5.4-3) and the distribution of 'historical actual' funding realization, and ii) logical inconsistencies inherent in such probability assignments since there is no means to check the logical consistency of numerical assessment in the DA method which is employed in the Subjective model to generate transformation probabilities.

It should be noted, however, that such comparisons (comparison of the SDP results with 'historical' planned and actual funding) may contain some weaknesses since future budget availability may not be the same as past budget availability. In such situations an estimation of the likelihood of each scenario of future budget availability may be required and therefore, the result of the AHP method as shown in Table 7.4 for ratings such a likelihood may be useful. Recall that the AHP method combines and prioritizes (with subjective input from DM's/ assessors) a range of external factors governing the future budget availability (shown in Figure 7.1) into a numerical rating representing the likelihood of each scenario in the future.

A similar comparison was performed between the SDP results using transformation probabilities generated by the Subjective model with the Direct Assessment (DA) and with the AHP method relative to the 'historical' planned and actual funding levels for the three cases of budget scenario and for mean confidence limit on NPVB. The results of this comparison a summarized in Figure 7.13.

For the Limited Budget scenario, most (70%) of the optimal funding decisions produced by the SDP using the AHP are $D^5_{t,i,m}$ (see Figure 7.13-1). This result is consistent with the

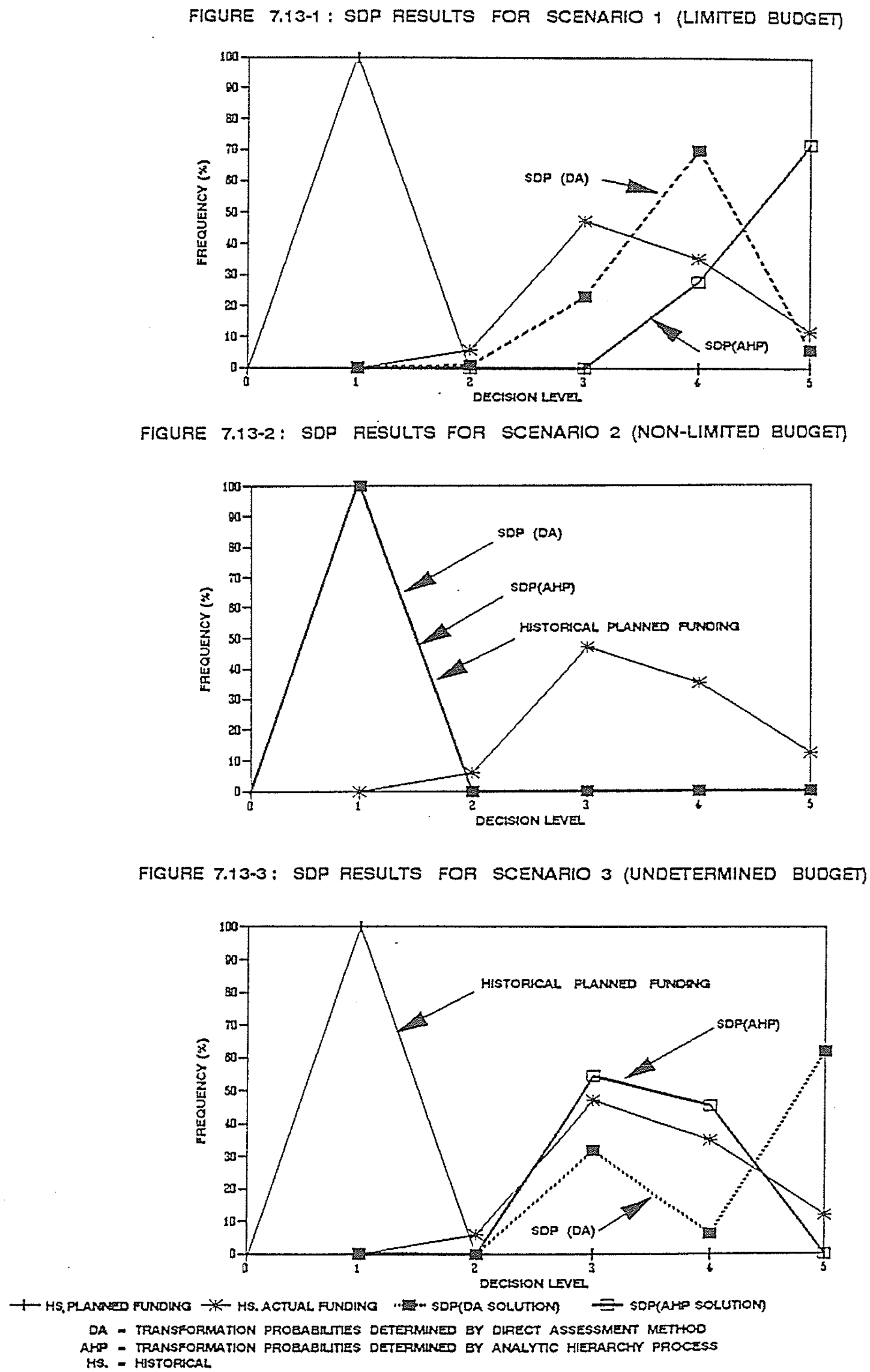


Figure 7.13: Comparison of Relative Frequency Between the SDP Results From Both Direct Assessment (DA) and AHP Vs. the Historical Planned and Historical Actual Funding for the Scenarios of Future Budget Availability at Mean Confidence Limit on NPVB

definition of that budget scenario. Application of the SDP using the DA derived transformation probability result in most of the decisions being at the second lowest level of funding, i.e., $D^4_{t,i,m}$. These results are again reasonably consistent with the definition of the budget scenario but not to the same extent as the results obtained using the AHP approach. A similar result is also observed for Non-Limited Budget scenario, in which both the SDP using the DA and the AHP method produce the same optimal funding decision, i.e., $D^1_{t,i,m}$ (see Figure 7.13-2).

Interestingly, for the Undetermined Budget scenario, the SDP using the AHP method produces a distribution of optimal funding decisions that closely matchs the distribution of level of actual funding over the last 17 years (see Figure 7.13-3). This feature is important for situations in which the DM's wish to replicate the past tendency of funding allocation in the future.

Based on these comparisons, it is reasonable to conclude that, the transformation probabilities generated by the Subjective model with the AHP method (see Subsection 5.6.6) which provides a means for checking logical consistency of qualitative assessments from assessors yields solutions that give a more realistic approach to the definition of scenario of future budget availability.

Examination of Optimal Scheduling Horizon with Respect to Discounted Cost

The SDP results also confirm that the longer scheduling horizon NT the greater optimal total return in terms of the total expected present value of net benefit at the beginning of planning horizon given the optimal funding/investment decision policy is adopted (TENB). The relationship between TENB and NT for Scenario 3 (Undetermined Budget) under the three critical (i,e., Mean, Lower, and Upper) levels of confidence limit on NPVB with the associated membership grades of confidence limit on NPVB is shown in Figure 7.14. To determine the optimal scheduling horizon with respect to the minimization of discounted costs, the FCCIGP model was run a number of times to account: i) the range of combinations of each level of possible funding decision $D^k_{t,i,m}$ and level of actual funding received, ii) the coefficient of cost escalation, and iii) the three critical levels (mean, lower, and upper) of confidence limit on NPVB with the associated membership grade, and iv) the range of scheduling horizons $NT \leq 5, 6, 7, 8, 9$ and 10 years. The results of this analyses shown in

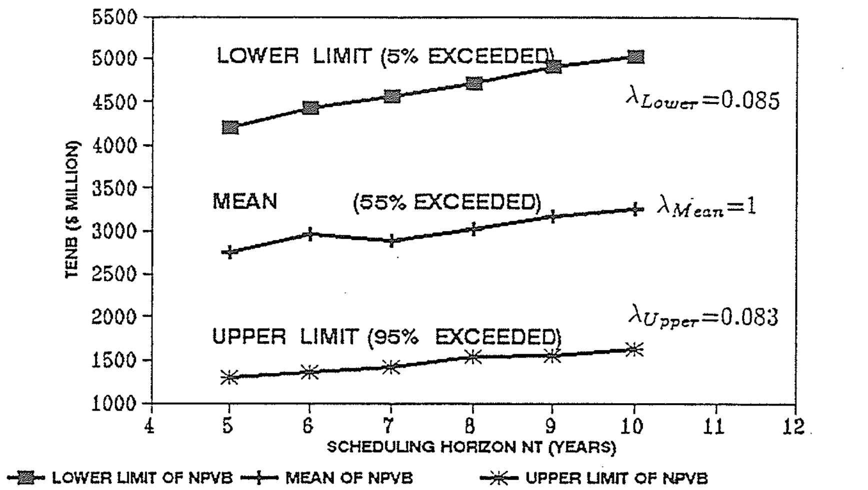


Figure 7.14: Relationship Between Total Expected Net Benefit vs. Scheduling Horizon for Undetermined Budget Scenario and the Three Critical Confidence Limit of NPVB with the Associated Membership Grades of Confidence Limit on NPVB

Figure 7.15 and Table A.52 indicate that the longer the scheduling horizon NT, the greater the achivement of NPVB and IAD goals. At the lower level of confidence limit, the increase of NPVB is steeper than at mean and lower limits. These features are due to a decreasing discount factor of construction cost as NT increases.

Based on these observations, it is reasonable to conclude that from a viewpoint of purely minimizing total discounted costs, the optimal scheduling horizon (NT) can be obtained, not unexpectedly, by scheduling the projects over a longer scheduling horizon. Furthermore, introduction of construction period constraints expressed by Equation (6.47) also reveals that the model tends to schedule the projects at the very end of the construction period (see Table A.52).

Examination of Scheduling Horizon and Risk of Interruption

To examine the risk of interruption of project implementation the SDP model is run a number of times using the results from the FCCIGP for different restrictions on NT, i.e., $NT \leq$ 5 to 10 years, the three critical levels (mean, upper, and lower) of confidence limit on NPVB with the associated membership grade, and various values of the discount factor (α)

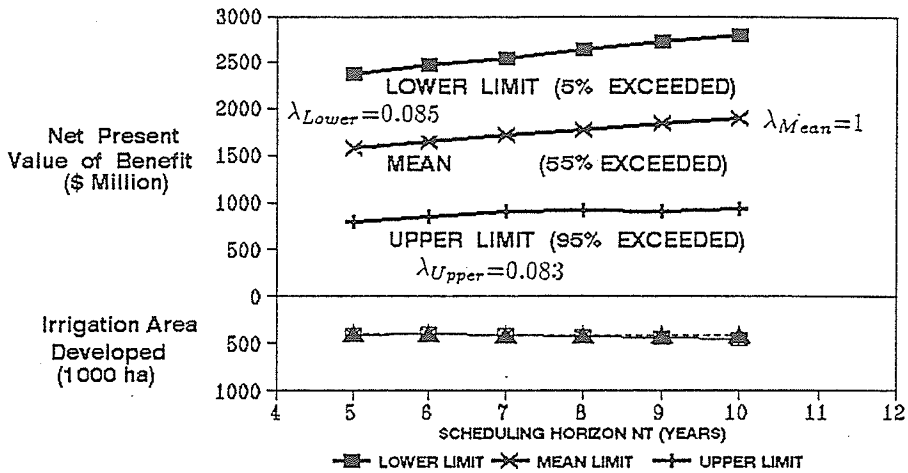
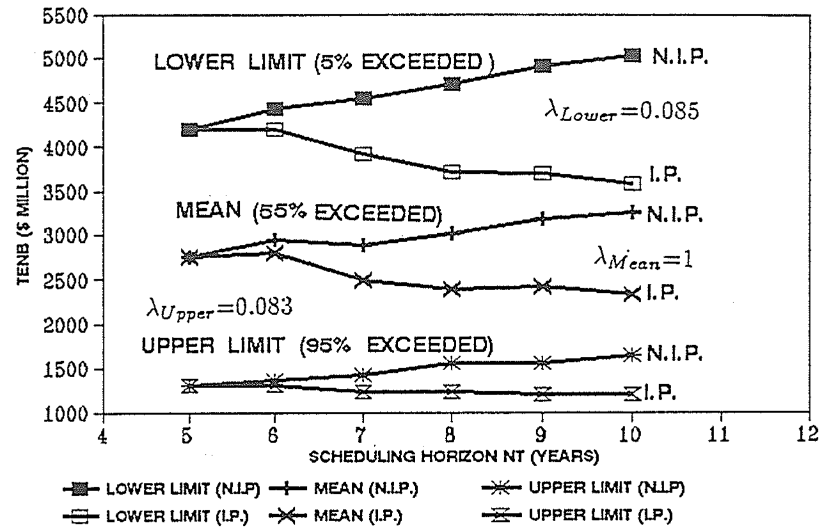


Figure 7.15: Relationship Between NPVB vs. Scheduling Horizon (NT) for the Three Critical Levels of Confidence Limit of NPVB with the Associated Confidence Limit on NPVB

reflecting features of uncertain future outcomes. In this case the long range return specified in terms of NPVB in the SDP formulation are discounted twice, in the first instant for monetary value of time with constant discount rate for various NT, and in the second instant to reflect the likelihood of the potential of interruption which varying with NT. For example in this application, discount rates of 0%; 1%; 3%; 5%; 6% and 8% are assigned for each $NT \leq 5$ to 10 years respectively. The results of the SDP model for Scenario 1 (Limited Budget) in terms of TENB for constant discount rate (reflecting non interrupted plan) and for various values of discount rate associated with the different retrictions on NT (reflecting potential interrupted plan inherent in each scheduling horizon NT) are plotted in Figure 7.16. From this figure it can be observed that there is a gain of between $124 to 237 million; $88 to 200 million; $12 to 121 million, for the lower, mean and upper level of confidence limits on NPVB respectively for extending NT by one year.

However, at the same time, there is also potential loss in between$115 to 276 million; $50 to 300 million; and $30 to 61 million, for the lower, mean and upper level of confidence limits respectively for extending NT by one year if the potential interruption occurred on the



TENB = TOTAL EXPECTED NET PRESENT VALUE OF BENEFIT AT THE BEGINNING OF PLANNING HORIZON
N.I.P. = NON INTERRUPTED PLAN (TENB DISCOUNTED AT CONSTANT RATE)
I.P. = INTERRUPTED PLAN (TENB DISCOUNTED AT VARIOUS RATES)

Figure 7.16: Trade-off Between Interrupted Plan vs. Non-interrupted Plan for the Three Critical Confidence Limits of NPVB with the Associated Membership Grade on Confidence Limit on NPVB and Various Scheduling Horizons

scheduling period in question. However, these results do not provide information about the probabilities, which represent the likelihood of the projects not being interrupted. To address this aspect of the problem, the utility function (described in Subsection 6.8.4 of Chapter 6) is used to determine the threshold probability (the cross over value p^*) between 0 to 1 such that the planner will be indifferent between choosing $NT \leq 5$ years and $NT \leq 6$ to 10 years. The results of the utility function can be summarized as follows: At the upper level of confidence limit and for $NT \leq 6$ to 10 years $p^* = 0.48$. Similarly $p^* = 0.66$ and $p^* = 0.31$ for the mean and lower level of confidence limits.

The interpretation of these results is as follows: for choosing the scheduling horizon length, when the probability, p, of not being interrupted satisfies if, i) $p \geq 0.66$, the planners can extend their scheduling horizon if necessary over the range of 6 to 10 years for any level of confidence limit, ii) $0.31 \leq p \leq 0.48$ the planners can consider extending their scheduling horizon only for the lower and upper level of confidence level, and iii) $p \leq 0.31$ the planners only have one option, namely, $NT \leq 5$ years.

7.4 Evaluation of the Model

Evalution of the proposed model is performed in two parts. The first part describes the strength and weaknesses of the FCCIGP model. Comparisons with the other investment models and the current project selection practice in Indonesia are given in the second part.

7.4.1 Strengths and Weaknesses of the Models

Strengths of the Models

Based on the theory on which the integrated (SDP-FCCIGP) was developed and on the results of the application of integrated model to the real problem of water resources planning in Indonesia, it can be concluded that the strengths of the model lie on the following factors:

1. Budgetary fluctuations problems:

The problems of budgetary fluctuations can be handled effectively in the SDP model by employing transformation probabilities reflecting the likelihood of actual funding realization levels relative to the possible funding decision levels applicable to the definitions of the s-cenarios of future budget availability considered likely to occur. [In the example problem the budget scenarios were defined in terms of Limited, Non-Limited and Undetermined.] Recognition of budgetary fluctuations, defined in terms of these three scenarios, enables the implications of budget different then that planned for, e.g., possibility of project delays, rescheduling, postponement, and cancellation, to be recognized, incorporated and therefore 'minimized' (reduced) in the decision making process of project selection.

2. Flexible Optimal Investment Planning Decision Policies:

The SDP approach provides the DM with flexible optimal investment policies that enable he or she to account for the possibility that the actual funding received in the previous scheduling horizons (and the associated level of development expected from that investment) may be substantially less or greater than that asked for and to value the 'correct' optimal decision in the light of these variations.

3. Collective Opinion Technique:

The use of the AHP in the integrated SDP-FCCIGP can be summarized as follows: i) generation of the subjective probabilities for the transformation probabilities in the SDP model, ii) determination of the membership grades of the range of confidence limits, and iii) rating of the likelihood (possibility) of each scenario of future budget availability. The use of such a collective opinion technique enables the prediction of future government funding availability and the preference toward risk inherent in the investment outcome to be based not just simply on a single individual judgment but also on group judgments elicited from a large number of assessors through political processes. This ability is very relevant for the problems of public investment planning. Recall that in such situations, the best way to handle such problems of uncertainty has been identified as eliciting judgments from the well informed assessors/public (Major, 1977).

4. Multiobjective-Multicriteria Portfolio Optimization:

The use of goal programming, and its extension integer programming, to determine the return for each level of possible funding decision in the SDP model enables the following characteristics of the problem associated with the portfolio approach to selection of water resources projects to be handled more adequately:

- Multiobjective-multicriteria optimization involving multiple conflicting and incommensurate objectives are able to be performed efficiently. It produces an efficient solution that directly refers to the over or underachievement of sectorial objectives such that relationships between goal achievement level and resource capacities can be easily observed,

- Managerial concerns with respect to: i) ensuring that there is always a feasible solution, ii) satisfying the requirement for "go no go" status to avoid fragmented project completion and intermittent implementation, and iii) accomodating other constraints such as scheduling, budgeting, and political as well as project dependencies, can be achieved satisfactorily,

- It is suitable for accomodating sociotechnical criteria which are incommensurate in reality.

5. Scoring-Criterion-Based-Optimization:

Modification and application of the Partitioning Algorithm enables the sociotechnical criteria to be optimized in a hierarchial manner, i.e., the projects that have a higher score in a particular criterion have to be satisfied to maximum possible level before the projects with a lower score are even considered. Inclusion of the sociotechnical factors which underlie the agricultural production and marketing subsystems which contribute to project success in this multiobjective-multicriteria portfolio model makes the model more effective as a screening model than the traditional Benefit-Cost analysis in the following ways:

- Recognization and quantification of non-economic objectives in the model formulation permits the projects dominated by non-economic concerns to "compete" more effectively for selection with those projects which are dominated by favourable benefit cost conditions but which do not match the non-economic goals, and

- Recognization and quantification of socio-economic factors measuring social end effects of projects enables the DM/planner to identify those projects that have favourable scores in the Benefit-Cost analysis but whose predicted scores for social responses (support and participation of farmers or water users) following the completion of irrigation schemes are low.

The second ability ensure that the potential delays in project utilization due to lack of consideration of the users support, participation, and ability to exploit the newly completed irrigation projects can be detected in the earlier stage of decision processes. Such model ability contributes to relieve the current deficiency of water resources management agencies in developing countries who generally fail to seek and obtain the understanding, support, and participation of the water users (Chaturvedi, 1992).

6. Measures for Handling Uncertain Investment Outcome:

Various type of uncertainties which may affect investment outcome and whose implication can be measured in monetary units can be aggregated into an uncertainty measure associated with benefit cost measures by assuming the NPVB criterion to be a random variable. Such probabilistic Benefit-Cost analysis provides a more thorough evaluation than the traditional Benefit-Cost procedure, especially with respect to the following issues : 1) the FCCIGP model is able to identify the existence of "risky" projects and thereby provide a means for avoiding them, and 2) consideration of the Benefit-Cost issue in a probabilistic constraint enables the dispersion of random variable to be explored such that the risk aversion attitude of the DM can explicitly be incorporated in the decision making process.

7. Measures for Handling Imprecise Input Data:

The 'real life' problems of imprecise input data in the form of imprecise goals and target setting, imprecise specification of budget limits, and imprecise choice of level of confidence limit for NPVB criterion generally cannot be properly articulated in a traditional "crisp" formulation. Formulation of the Chance Constrained Integer Programming (CCIGP) in a fuzzy linear environment is therefore more appropriate. Such fuzzy formulations offer more flexibility than traditional (crisp) IGP in the sense of providing optimum solutions lying between a lower and an upper bound of a budgetary interval. Thus, in this fuzzy formulation the DM is not forced into a precise formulation. Moreover, the FCCIGP admits imprecise goals and criterion setting on constraints in more realistic manner, i.e., by assigning membership grades of the fuzzy parameter as a decision variable in the model formulation.

In addition to those advantages, the FCCIGP formulation offers the following other improvements over the traditional (crisp) CCP method:

- Unlike the traditional chance constraint (CCP) method in which levels of confidence limit are determined arbritarily, in this FCCIGP model levels of confidence limit are decision variables represented by a membership grade which is itself defined based on qualitative judgments of the relative importance of different confidence levels extracted from a DM or a group of DM. A consistency measure is also available (Saaty, 1977) to evaluate the consistency of the DM's input and thereby ensure a reasonable solution.

- In a FCCIGP model the effect of the extent of constraint violation is explicitly considered in a decision variable representing the degree of violation of binding constraints such that its implication on model solutions can be easily observed and evaluated. This feature is in contrast with the CCP method in which there is no explicit consideration made either of penalties or reward involved if the chance constraints are violated or made less restrictive thereby making it difficult to quantify the effects of constraints violations.

Weaknesses of the Models

A number of shortcomings exist within this integrated model:

1. Sociotechnical criteria developed for the demonstration example are strongly related to the nature of the problems of water resources development in Indonesia and can therefore be quite "problem specific". These criteria would require a significant modification if the model would be applied in a different country with a different financial and/or social environment.

2. It should be noted that while the incorporation of social and political factors into the water resources planning process in the manner described in this study is an important step towards more comprehensive and informed decision making, there is no guarantee all or even at least most of relevant social and political factors have been or can be addressed even for the particular case of irrigation planning in Indonesia used to demonstrate the model. Furthermore the problems of quantification of these social and political factors which involve both specification and measurement are not insignificant. Such problems can become an even greater concern when the factors are extrapolated into the future for prediction purposes and used in preparing for potential future

outcomes and associated decisions. While such problems associated with extrapolation also occur with more easily quantifiable variables related to engineering and economics, they are more serious in relation to the social and political variable because of the nature of those factors.

3. The introduction of social and political factors in the manner proposed in this thesis also introduces normative elements into what is meant to be an engineering or scientific analysis. The implications of introducing such value judgements in the process require considerable review. These shortcoming require further study before the model can be used with absolute confidence and as such represent an area for further research.

4. It is assumed that the shape of the probability distribution for NPVB criterion (random variable) follows the normal distribution curve. Such assumption might not be totally true. However, the recent study of probabilistic Benefit-Cost analysis by Tung (1992) indicates that the normal distribution provides a satisfactory result for describing the randomness of net benefit criterion.

5. It is also assumed that in defining the deterministic equivalent of chance constraints there is no significant correlation between the pairs of random variables. In this integrated model the relation between projects are articulated by project dependency constraints. This assumption may also be inappropriate. The theoretical and practical consequences of this assumption being inappropriate is an area in which further study should be undertaken.

6. The use of the AHP method for generation of subjective probabilities is not free from imperfection. The background knowledge and personal preferences of the analysts and the degree of understanding of the systems can have a strong effect on the elements in the judgment matrix and hence the results of weights/probabilities. Advisory experts can mitigate the problems to some extent. It should be noted, however, that the AHP method is considered by many reserchers (Zahedi, 1986) as an elegant and effective approach to a complex public decision making problem in which a large number of opinions and interests have to be accomodated.

7. The use of a point allocation and unit weighting scheme for predicting the farmer readiness to utilize a newly completed irrigation scheme in the case when the number of completed schemes are not sufficient to perform regression analysis is not free from problems. The applications suffer from uncertainty resulting from the particular scale chosen. Furthermore, they do not provide an internal check on the consistency of the weights generated (Palmer and Lund, 1985).

8. The use of multiple variable regression model is also not free from difficulty since no one subset of independent variables is usually 'best' for all descriptive or predictive uses and regions (Neter et al., 1983).

7.4.2 Comparison with Target Motad and IGP model

The solutions of FCCIGP model for the three confidence limits on NPVB (mean, lower, and upper) with the associated membership grade for confidence limits on NPVB and the prespecified value of upper bound of budget allocation equal to $100\%BT_t^1$ are compared to the solutions of the IGP (preference given to NPVB goal), and the Target Motad of Tauer (1983) model which is concerned with maximisation of expected gross margin and minimisation of the aggregated deviations. The comparison of the solutions for these three models is shown in Table 7.10. From this table it can be seen that the solution by IGP model is comparable to the solution of the FCCIGP under the lower level of confidence limit on NPVB (5% of time exceeded with $\lambda_{Lower} = 0.085$). On the other hand, the solution generated by the Target Motad procedure is the same as the solution of FCCIGP under the mean of confidence limit on NPVB (55% time exceeded with $\lambda_{Mean} = 1.00$). However, the FCCIGP model is superior to both these models (IGP and Target MOTAD) in terms of:

1. It is able to accomodate problems of imprecise input data and imprecision of criteria preferences inherent in a real life investment planning problem.

2. Formulation in the fuzzy form enables preference toward confidence limit on economic criterion to be explicitly specified.

Table 7.10: Comparison of IGP, FCCIGP and Target MOTAD for Possible Funding Decision/Allocation D_1^t/BT_t^1 at stage $t = 1$

PROPOSED PROJECTS		YEAR IN WHICH CONSTRUCTION STARTED				
		IGP	FCCIGP			TARGET
PROJECT NUMBER & NAME	AREA (ha)	MODEL	CONFIDENCE LEVELS			MOTAD MODEL
			MEAN	LOWER LIMIT	UPPER LIMIT	
1 Krueng Baro	16772	1st	1st	1st	0	1st
2 North Sumatra	41000	1st	1st	0	1st	1st
3 Pasaman	4926	2nd	2nd	2nd	1st	2nd
4 Batang Kumu	13800	1st	1st	1st	0	1st
5 Limun Sungkat	2500	4th	4th	4th	3rd	4th
6 Komering	55904	0	0	1st	0	0
7 Baal	5500	1st	0	0	0	0
8 Way Abung	5000	0	2nd	0	2nd	2nd
9 Way Perdada	13550	1st	1st	0	1st	1st
10 Alas	4400	0	0	0	0	0
11 Manjuto Kanan	10000	0	0	0	0	0
12 Teluk Lada	18923	0	0	0	1st	0
13 Jatigede	130158	1st	1st	1st	1st	1st
14 Jratunseluna	74537	1st	1st	1st	1st	1st
15 Dumpil	25415	1st	1st	1st	1st	1st
16 Madura	2580	4th	4th	4th	4th	4th
17 East Java Rehab	42912	1st	1st	1st	1st	1st
18 Sanggau Ledo	555	4th	0	4th	0	0
19 Kasau	5000	0	0	0	0	0
20 Riam Kanan	12000	0	0	0	0	0
21 Toraut Bongo	7820	0	0	0	0	0
22 Taopa	8000	0	0	0	0	0
23 Kalong	1200	0	0	2nd	0	0
24 Boya	10000	0	0	0	0	0
25 San Rego	7500	0	0	0	0	0
26 Wawotobi	21200	1st	1st	1st	1st	1st
27 Dataran Kobi	1950	0	0	2nd	0	0
28 Wimbo Erang	1963	0	0	0	0	0
29 Irigasi Bali	3425	0	0	0	0	0
30 Embung NTB	1520	0	0	0	0	0
31 Kalimantong	2850	1st	0	0	0	0
32 Irigasi NTT	3360	0	0	0	0	0
33 Embung NTB	8276	0	0	0	0	0

PARAMETERS					
1 Irrigation Area (ha)	392841	415570	415629	404476	415570
2 N.P.V. of Benefit ($10^6)	1957.4	1590.5	2379.5	796.6	1590.5
3 Transmigration Support (number of families)	11500	16500	27500	6500	16500
4 Number Selected Projects	15	13	14	12	13
5 Total Budget ($10^6)	922.99	923.87	923.77	920.43	923.87
6 Membership Grade of Budgetary Constraints	-	-	-	-	-
7 Membership Grade of Confidence Limits	-	1	0.085	0.083	-
8 Degree of Constraint Violation	-	0	0.915	0.917	-

3. FCCIGP model has features that enable the implication of various type of uncertainties inherent in economic criterion enable to be addressed on multiobjective-multicriteria based model, such that the existence of "risky" projects can be identified and avoided.

4. The formulation of a probabilistic constraint enables the dispersion of the NPVB criterion to be explored more thoroughly, not only at the mean level but also at any desired level in between a lower and an upper bound of confidence limit such that the trade off between goal achievements vs. confidence limit preferences can be performed more adequately.

7.5 Comparison with Current Planning Decision Practice

Comparison between the projects selected by the FCCIGP model for the possible funding decision/allocation D_1^4/BT_1^4 under various goal and selection criteria preferences with the projects selected by GOI under current project selection practice as shown in Table 7.11 reveals the following characteristics:

1. Goal achievement:

The FCCIGP model ensures the attainment of the optimal projects portfolio that optimized the achievement of preferred objectives, whether those objectives can be measured in monetary units (tangible) or non monetary units (intangible). For example, when preference is given to the NPVB objective at mean confidence limit (λ_{Mean}=1), the projects in the portfolio selected by the FCCIGP yield returns 21.73% greater than returns of projects ranked by a traditional B-C method. Similar tendencies are also observed when NPVB is evaluated at lower (5% of the time exceeded with λ_{Lower}=0.085) and upper (95% of time exceeded with λ_{Upper}=0.083) limits of confidence level. Furthermore, the FCCIGP model is also able to provide an optimal portfolio of projects on the basis of objectives other than monetary objectives, for example on the basis of socio-political goals and criteria related to self-sufficiency in rice production, farmer readiness criterion and transmigration. On the other hand, the traditional B-C method used previously in Indonesia is only capable to handle monetary objectives directly.

2. Means of articulating preference toward risk and uncertainty:

Inclusion of statistical analysis and chance constraints enables the risk aversion attitude of a DM or a planner to be incorporated explicitly in order to identify the existence of "risky" projects and therefore to avoid non optimal investment decisions. Without such recognition the problem of inflated benefits may rise. For example, the original returns (NPVB) resulting from a traditional B-C method have been historically overestimated by 19.3% and 178.49% when NPVB is evaluated at the mean and lower confidence limits respectively.

3. Trade-off between commensurate and non-commensurate objectives:

Inclusion of sociotechnical selection criteria constraints embracing not only technical and economic features but also socio-technical and political aspects such as the farmers' readiness to utilize completed schemes, the extent of existing rice field and the transmigration support enable the implications of such goal preferences to be evaluated explicitly. For example, there are potential losses of returns (NPVB) at about 5.94%; 21.81%; and 17.20% (relative to the return when NPVB goal is preferred) when preferences are given to the extension of irrigation area, the transmigration support and the farmer readiness goals in isolation respectively. Satisficing solutions for such conflicting goals can be obtained by proper setting of weights (refer to column 7 and 9 of Table 7.11). On the other hand, such abilities can not be found in the current traditional B-C method. For example, there is no satisfactory means of evaluating the implication of policies other than those involving monetary objectives. Such application of a B-C method has the potential to overlook the socio-technical factors underlie the agricultural production and marketing subsystems which contribute to the success of the utilization of completed irrigation schemes resulting in the delays in achieving a full development stage experienced in Indonesia (Sutardi, 1988).

4. Means of handling managerial needs:

The FCCIGP model provides an effective and explicit means of handling managerial needs related to: i) an optimal project scheduling within a given scheduling horizon, ii) the requirement for a "go or no go" status for each project or subproject to avoid fragmented project completion and intermittent implementation, and iii) an optimal annual budget allocation within a given scheduling horizon.

Table 7.11: Comparison Between Projects Selected by FCCIGP and Current Planning Decision Practice

PROPOSED PROJECTS		YEAR IN WHICH CONSTRUCTION STARTED												
PROJECT NUMBER & NAME	Area (ha)	FCCIGP RESULTS										CURRENT *) PLANNING DECISION PRACTICES		
		GOAL AND SELECTION CRITERIA PREFERENCES												
			NPVB		IAD	NPVB=	TS	NPVB=TS	FRD	PPT	ERF	NPVB(B/C)		
		MEAN	LOWER	UPPER		IAD						ORIGINAL	MEAN	LOWER
1 Krueng Baro	16772	1st	1st	0	1st	1st	1st	1st	0	1st	0	1	1	1
2 North Sumatra	41000	1st	0	1st	1st	1st	0	0	0	0	0	0	0	0
3 Pasaman	4926	2nd	2nd	2nd	1st	2nd	0	0	1st	2nd	0	0	0	0
4 Batang Kumu	13800	1st	1st	1st	1st	1st	1st	1st	0	0	0	0	0	0
5 Limun Sungkat	2500	4th	4th	2nd	4th	4th	4th	4th	0	0	0	0	0	0
6 Komering	55904	0	1st	0	1st	1st	1st	1st	0	0	0	0	0	0
7 Baal	5500	0	0	0	0	0	0	0	2nd	2nd	2nd	0	0	0
8 Way Abung	5000	2nd	0	2nd	2nd	2nd	0	0	3rd	0	2nd	0	0	0
9 Way Perdada	13550	0	1st	1st	1st	1st	0	1st	1st	0	1st	0	0	0
10 Alas	4400	0	0	0	0	0	0	0	2nd	0	1st	0	0	0
11 Manjuto Kanan	10000	0	0	0	0	0	1st	1st	0	0	0	1	1	1
12 Teluk Lada	18923	1st	0	1st	1st	1st	0	0	0	1st	1st	1	1	1
13 Jatigede	130158	0	0	0	0	0	0	0	0	0	0	0	0	0
14 Jratunseluna	74537	1st	1st	1st	1st	1st	0	1st	1st	1st	1st	1	1	1
15 Dumpil	25415	1th	1st	1st	1st	1st	0	1st	1st	1st	1st	1	1	1
16 Madura	2580	4th	4th	4th	3rd	4th	0	4th	4th	4th	4th	1	1	1
17 East Java Rehab	42912	1st	1st	1st	0	0	0	0	1st	1st	1st	1	1	1
18 Sanggau Ledo	555	2nd	4th	3rd	3rd	3rd	0	4th	0	0	4th	0	0	0
19 Kasau	5000	0	0	0	0	0	1st	1st	0	0	0	0	0	0
20 Riam Kanan	12000	0	0	0	0	0	1st	1st	0	0	0	0	0	0
21 Toraut Bongo	7820	0	0	0	0	0	1st	1st	0	0	0	0	0	0
22 Taopa	8000	0	0	0	0	0	1st	1st	0	0	0	0	0	0
23 Kalong	1200	0	0	0	4th	4th	1st	4th	0	0	4th	0	0	0
24 Boya	10000	0	0	0	1st	1st	1st	1st	1st	0	1st	0	0	0
25 San Rego	7500	0	0	0	0	0	1st	1st	1st	1st	1st	0	0	0
26 Wawotobi	21200	1st	1st	1st	1st	1st	1st	1st	1st	1st	0	1	1	1
27 Dataran Kobi	1950	0	0	0	4th	4th	2nd	4th	4th	1st	0	0	0	0
28 Wimbo Erang	1963	0	0	0	4th	4th	4th	3rd	0	4th	0	0	0	0
29 Irigasi Bali	3425	0	0	0	0	0	0	0	3rd	3rd	3rd	1	1	1
30 Embung NTB	1520	0	0	0	0	0	0	0	4th	3rd	4th	1	1	1
31 Kalimantong	2850	0	0	0	4th	4th	0	0	4th	4th	0	0	0	0
32 Irigasi NTT	3360	0	0	0	3rd	1st	0	0	3rd	3rd	1st	0	0	0
33 Embung NTT	8276	0	0	0	0	0	0	0	1th	2nd	1st	1	1	1

PARAMETERS										ORIGINAL	MEAN	UPPER
1 N.P.V. of Benefit ($10^6)	1225.7	1802.1	669.84	1152.9	1152.9	189.56	958.32	1014.9	1064.4	996.08	1201.19	1006.9	1568.9
2 Irrigation Area (ha)	291340	297821	288118	339205	339205	196809	313466	260121	264829	228673	325690	325690	325690
3 Transmigration Support (number of families)	16500	15500	11500	26500	26500	42500	42500	10500	9500	500	15000	15000	15000
4 Number Selected Projects	13	12	13	20	20	15	20	18	17	16	11	11	11
5 Total Budget ($10^6)	563.04	563.96	563.78	563.98	563.96	437.84	563.72	563.63	562.93	563.65	563.43	563.43	563.43

	SATISFACTION OF SELECTION CRITERIA Number of Projects									
1 Physical Potential										
Range: > 85%	7	6	7	10	10	3	7	13	15	10
80% - 85%	5	5	5	9	9	6	7	5	2	7
< 80%	1	1	1	1	1	6	6	0	0	0
2 Existing Rice Fields										
Range: > 85%	6	5	6	6	6	1	5	9	10	11
60% - 80%	1	1	2	4	4	2	3	5	1	6
50% - 60%	3	2	3	4	4	4	4	3	3	0
< 50%	3	4	2	5	5	8	8	1	3	0
3 Farmer Readiness										
Range: > 80%	5	4	5	6	0	0	3	9	11	9
60% - 80%	5	5	5	9	6	6	7	9	6	8
< 60%	3	3	3	5	9	9	10	0	0	0

NOTE: NPVB=IAD : PREFERENCE IS GIVEN TO BOTH NPVB AND IAD GOALS
NPVB=TR : PREFERENCE IS GIVEN TO BOTH NPVB AND TS GOALS
*) SOURCE BCEOM (1989) IRRIGATION INVESTMENT STUDY

Comparison of the results of the SDP (with transformation probabilities generated by the AHP) in terms of the optimal investment policies relative to the planned and actual funding realization for water resources projects in Indonesia over the last 17 years (see Figure 7.13) indicates that the SDP results under Case 3 (Undetermined Budget Scenario) for the mean confidence limit of NPVB closely match the actual funding realizations derived from the historical data over the last 17 years (Table 7.1). This result confirms the validity of the model (and input data) to a large extent as the undetermined budget scenario and average level of performance of projects is a fair representation of a planning process.

The results of the possibility rating of the three scenarios of future budget availability in term of a numerical rating representing the likelihood of the occurence of each of these scenarios as shown in Table 7.4 also confirm that the Undetermined Budget scenario represent the most likely to prevail in the future. The concern for providing the DM with realistic optimal investment decision policy is very relevant to the situation in Indonesia where the GOI's investment policy over the last 17 years was governed by a 'target oriented' policy which is only comparable with the Non-limited budget scenario. Recall that as a reflection of such discrepancies (between planned and actual funding levels) resulting in many hundreds of medium and large scale water resources projects being rescheduled and postponed, and even cancelled. Recognization or anticipation of such situation enables the DM to reduce the problems of such projects rescheduling, postponement and cancellation due to budgetary fluctuations beyond the control of the DM.

In summary, the results of the integration of FCCIGP-SDP model indicate that the approach provides more useful guidance for investment planning under various type of uncertainties and a more satisfying approach in fulfilling the needs of managerial concerns than the traditional B-C method currently applied for investment planning in water resources investment in Indonesia. Similar results can be expected from planning decision in other countries as long as the parameters in the model are adjusted adequately to reflect the financial, social and political climate of those countries.

Chapter 8

SUMMARY AND CONCLUSION

In general, a water resources system is planned, designed, built, operated and controlled for the purpose of fulfilling specified future demands. However, these water resources development activities are subject to uncertainties inherent in both resource availabilities as well as in demands. By definition, planning itself is the process of forecasting the future developments. Therefore, ideally planning activities have to incorporate these uncertainties. Uncertainties related to natural resources and future demands are generally handled in the technical level of planning. However, uncertainties inherent in economic resources, e.g., the level of future budget availability for investment and the uncertainties inherent in socio-political factors contributing to the success of water resources management are ideally handled by the high level decision making process (investment planning).

The implications of these types of uncertainties are quite severe. Current water resources investment plannings in Indonesia provide illustrative cases. Hundreds of medium and large scale irrigation projects have been postponed due to year-to-year budgetary fluctuations originating from fluctuations of the world oil price during the last twenty years (Sutardi et al., 1991a). In addition to this problem, uncertainty inherent in the investment outcome has also caused problems. Examination and evaluation of economic performance of completed schemes reveal that most of project benefits have been overestimated due to insufficient information on complex inter-related socio-economic factors and to a lesser extent the randomness of natural phenomena. The importance of sociotechnical and political factors to the success of completed irrigation schemes is further indicated by the fact that many hundred thousand hectares of completed facilities have not been utilized to the maximum potential level because of the inability of existing approaches to recognize socio-technical and political factors contributing to the success of the agricultural production and marketing subsystems which control the rate of utilization and productivity of these schemes (Sutardi, 1988).

Two issues of investment planning, i.e., sequential decision making and the flexibility aspect (ability to adjust the outcomes of previous decisions) are addressed in the model proposed in this thesis. Some planning problems are sequential in nature, in that the latter decisions can be influenced both by earlier decisions and by outcomes of the stochastic parameters whose values only become known to the decision maker after the earlier decisions have been taken. In this sequntial decision making environment, an 'optimal' investment/funding decision has to be made based on the consideration of the existence of these various types of uncertainties.

The term 'optimal' associated with the most desired investment decision has two meanings. The first meaning relates to the fact that investment decisions have to recognize the possibility that actual funding is significantly different, and normally less, than anticipated, or more precisely, desired for that scheduling horizon. This approach is in direct contrast to the "target oriented" planning approach which has been applied in countries like Indonesia with the direct consequences that the projects selected in the planning process are currently being rescheduled and even cancelled as development budget and priorities vary. The second meaning is related to the need to obtain the best portfolio projects that yield the maximum 'return' with respect to preferred objectives and criteria.

The second issue of flexibility in planning relates to the fact that the components of the system, e.g., the scale of the system, can be adjusted in accordance with changing conditions. Two aspects of flexibility in planning are required to operationalize this 'flexible' plan, i.e., *staged development* and *trade-offs between alternatives.* Staged development in this case is to address questions as to which part of the plan should be implemented immediately, what portions are to be staged for future consideration, and when they might be constructed under various definitions of the scenario of future budget availability. Trade-offs between alternatives, e.g., goal achievement vs. confidence limit of preferred goal, shorter vs. longer scheduling horizon, taking into consideration this budgetary uncertainty problem, are often required.

This thesis identifies and examines the implications of various types of uncertainties generally inherent in practical problems of water resources investment planning. Such uncertainties and risks can be categorized as follows: i) external uncertainties; the parameters which contribute to this uncertainty cannot be statistically defined and originate from a process beyond the control of the Decision Maker (DM) , e.g., budgetary uncertainty/fluctuations, ii) internal uncertainties; the parameters which contribute to this uncertainty cannot be statistically defined and originate from imperfect knowledge which is partly under 'control' of the DM through the specification of tolerance intervals. These types of uncertainties arise from imperfect knowledge of what is acceptable or should be the target level, and imprecision (fuzziness) of qualitative data, and iii) external risks; These uncertainties are characterized by conditions in which the uncertain parameters can be statistically defined but are beyond the control of the DM, e.g., uncertainties inherent in the Net Present Value of Benefit (N-PVB) criterion, and uncertainties inherent in sociotechnical and political factors underlying the agricultural production and marketing subsystems.

The nature of the problems illustrated above suggest that any approach proposed to address the investment planning problem should consist of the integration of both mathematical and subjective models within a structured framework to enable both quantitative and qualitative parameters to be formulated to model the actual real world problems as adequately as possible.

A frame work and methodological approach embracing formal mathematical optimization and intuitively-based (subjective) models for rationally interpreting these uncertainties and subsequently incorporating them, in the planning process in a formal manner has been proposed. An integration of a Stochastic Dynamic Programming (SDP) for optimisation and a subjective model in combination with the Analytic Hierarchy Process (AHP) to provide quantitative statements of the uncertainties is employed to handle the problems inherent in the first type of uncertainty. An integration of statistical analyses, e.g., First Order and Second Moment (FOSM), Contingency Index, Point Allocation and a multiple variable regression with a multiobjective optimisation technique, i.e., Chance Constraint Integer Goal

Programming (CCIGP) is used to handle the problems associated with the third type of risk. Fuzzy set theory is incorporated in the proposed CCIGP model to accomodate the problems of the second type of uncertainty. Hence the the multiobjective-multicriteria optimization component of the approach becomes Fuzzy Chance Constrained Integer Goal Programming (FCCIGP). The overall approach proposed to handle simultaneously the three types of uncertainties, therefore, is in the form of an integrated SDP-FCCIGP model.

A case study from water resources development in Indonesia, where such uncertainties are serious problems, was examined to demonstrate the capabilities of the model.

8.1 Important Features of the SDP Model

The SDP model proposed in this thesis has scheduling horizons (time periods) as the stages and the level of funding/investment for which to plan as the decision. The state variables are the level of development stated in physical terms, i.e., hectares of irrigation area developed at the beginning of scheduling horizon, and the level of funding actually received in the previous scheduling horizon. The objective of the SDP model is the development of an investment planning policy for the DM's which permits them to define and select the optimal investment planning decision in terms of an optimal portfolio of projects to pursue during any scheduling horizon under conditions of current and future budgetary fluctuations.

To incorporate the problem of budgetary uncertainty within the SDP, a transformation probability matrix which defines the likelihood of a range of levels of funding actually being received is introduced. The probabilities in this matrix in turn define the likelihood of a particular state transformation occuring. These probabilities within the transformation probability matrices are specified in terms of the level of funding being planned for a given time period, the existing level of development, and level of funding received in the previous time period.

However, unlike traditional engineering problems in general, the transformation probabilities of the SDP for such investment planning cannot be determined objectively in the sense that the relative frequencies in past observations cannot be used in isolation to estimate the likelihood of funding outcomes. In this case, a "subjective probability" is derived from the combination of a subjective model, specification of scenarios of future budget availability in a broader manner, i.e., Limited, Non-limited, and Undetermined, and the AHP method.

The return for each level of possible funding outcome at each stage of the SDP , specified as a NPVB, is obtained by the FCCIGP. This return considers three critical levels of confidence limit of NPVB, in this case the lower, mean, and upper limit. The optimal investment/funding decision in any scheduling horizon, with its associated expected optimal return for a given combination of existing level of development and funding from the previous period, can then be based on these probabilities while accounting for the preferred confidence limit on the value of the NPVB and the projected scenario of future budget availability. The likelihood of each budget scenario with its associated subjective probabilities can be estimated in a possibilistic manner in the form of a possibility rating using the AHP method.

The optimal investment policy generated by the SDP in its stochastic framework explicitly recognizes the possibility that the level of funding actually being received may be different from (normally less) that anticipated for that planning period. The adoption of an optimal investment planning policy generated using the proposed SDP approach enables the DM to recognize and minimize the problems of project rescheduling, postponement and cancellation due to budgetary fluctuations.

The other important feature of the SDP approach is that, as long as the budget changes remain within the range of projected levels, it will provide a guide or answer if, for any reason, the actual funding received at a particular time period is different, either greater or smaller, than that projected.

8.2 Important Features of the FCCIGP Model

The objective of the FCCIGP model in this integrated model is to determine the optimal return for each possible level of funding decision along with the associated optimal portfolio of projects taking into account preferences toward goals, criteria, and uncertainties inherent in investment outcome and other socio-political factors affecting the return of investment in a particular scheduling horizon within a specified of planning horizon of the SDP model.

In its general formulation the objective function of the FCCIGP model is to minimize the underachievements from specified target goals and criteria subject to various selection criteria, budgetary constraints, and managerial constraints.

For the specific application for irrigation investment planning in Indonesia the goals, criteria, budgetary, and managerial constraints can be delineated as follows:

Goal constraints:

a) Economic objective specified in terms of satisficing the achievement of the economic returns reflected in terms of probabilistic form of NPVB criterion. This constraint is formulated in the form of a linear deterministic equivalent of a non-linear chance constraint. b) Socio-political objectives; i) Maintaining self-sufficiency of rice production by expanding irrigated rice fields to fulfill the demand; ii) Supporting the transmigration (inter island migration within Indonesia) program by quantifying the number of transmigrant families supported by irrigation facilities on newly opened transmigration areas.

Selection Criteria constraints:

The first criteria are related to the physical potential that are used to define technical and environmental eligibility of the projects. The other two criteria, namely, the Readiness of Farmers to exploit newly completed irrigation facilities, and the Extent of Existing Rice Field are applied to enforce socio-technical criteria related to the agricultural production and marketing subsystems in order to minimize their degree of uncertainties in these subsystems.

Budgetary constraints:

Two budgetary constraints are incorporated in the model. The first constraint is the annual budget constraint, which states that funds committed to projects to be implemented in a particular year cannot exceed the funds allocated in that year. The second constraint defines that total funds expended in any scheduling horizon or stage of the SDP must be less than or equal to the total funds available for that time period.

Managerial constraints:

Three sets of managerial constraints are formulated in the model. The first set of constraints are integer constraints to satisfy the requirement of "go" or "no go" status to avoid fragmented project completion. The second set of constraints construction period constraints. These constraints are needed to ensure that a project is selected for a sufficient number of years to avoid intermittent implementation and that it is started at the 'optimum' position of construction period in a given scheduling horizon. The third set of constraints are socio-political constraints which are defined as those which influence or require project acceptance regardless of the economic desirability of a project.

The multiobjective-multicriteria optimization formulation designed to handle these issues incorporates three distinct features which enable it to address a number of problems inherent in this optimization model for investment planning of water resources projects or more specifically irrigation projects. These features are:

1. Scoring-Criterion-Based-Optimization

The modified Partitioning Algorithm is used to rank the projects in hierarchial manner when a particular criteria, e.g., the socio-technical environmental and political criteria related to the agricultural production and marketing subsystems, are important for project selection. In this case, the projects that have the higher score for these parameters have to be satisfied to the maximum possible level subject to budgetary constraint before the projects with a lower score are even considered. This ability to include non-monetary selection criteria makes the FCCIGP model a more appropriate and powerful tool than the traditional Benefit-Cost analysis for screening and identifying the potential projects for implementation.

2. Fuzzy Set Theory

The most important aspect of the application of fuzzy set theory for the investment planning problem in uncertain environment being examined in this thesis is that it provides a means of representing imprecise or ill-defined information, such as subjective judgments, semantic data, and qualitative information. In this thesis the fuzzy set theory is applied to handle the problems of imprecision in data such as inability to set goals and targets precisely, imprecise specification of budget limits, and imprecise preference for choice of level of confidence limit of NPVB criterion. In general none of these feature can be properly articulated in traditional "crisp" formulations.

3. Integration of Fuzzy Set Theory, Chance Constraints and IGP

The main role of the FCCIGP model in the integration with the SDP model is to determine the optimal return for each possible level of funding outcome to plan for within each scheduling horizon (stage) within the SDP model taking into consideration:

- Goal preferences and trade-offs among the various economic, environmental , and socio-political objectives of water resources planning.

- Socio-economic, political and environmental selection criteria preferences and concerns with respect to socio-economic, political and environmental issues.

- The trade-off between goal achievements vs. the various levels of confidence limit of NPVB criterion to enable the attitude toward risk of the DM, e.g., "risk taker" or "risk averter," to be incorporated explicitly in the decision process.

- Imprecise input data, specification of targets and preferences inherent and characteristic of practical water resources planning problems.

- Managerial concerns with respect to the optimal project scheduling in the sense of defining in which year a project should be started within a specified scheduling horizon, project unity to avoid intermittent implementation and incomplete projects, project dependencies, and optimal annual budget allocation within a specified scheduling horizon. The optimal project scheduling is also required to reduce implications of budgetary uncertainty /fluctuations.

The other important features of the intregation of the CCIGP model with Fuzzy Set Theory can be outlined as follows:

- Qualitative preferences from an assessor or a group of assessors toward uncertainty specified in terms of confidence limits on the economic criterion can be incorporated explicitly in the FCCIGP model through an appropriate collective opinion technique, i.e., the AHP, method and by introducing membership grade into the model formulation.

- The impacts of constraint 'violation' can also be quantified explicitly by introducing a decision variable representing the degree of constraint violation in the FCCIGP formulation

The advantages of such fuzzy formulation contribute to improve traditional chance constrained programming in which the choice of level of confidence limit is determined rather arbitrarily and the effect of constraint violations are unsatisfactorily or inadequately quantified.

8.3 Summary of the Results of the Demonstration of the SDP-FCCIGP Model

The results of the application of the integrated model SDP-FCCIGP to the problems of water resources investment planning in terms of its ability to handle four types of uncertainties, namely budgetary and investment outcome uncertainties, socio-technical and political factor uncertainties inherent in the agricultural production and marketing subsystems, and imprecision of input data, with particular reference to the situation in Indonesia are summarized as the followings

8.3.1 The Results of the SDP model

Budgetary Uncertainty:

The use of the integrated SDP-FCCIGP model enables the DM to select the 'optimal' investment decision which satisfies two requirements simultaneously, i.e., the need to recognize the possibility of budgetary fluctuation and the need to obtain the best portfolio of projects that yield the maximum 'return' with respect to preferences toward goals, criteria and risks associated with each level of possible funding decision. In the demonstration example, the results of the SDP model under the 'Undetermined Budget' scenario at the mean confidence limit on NPVB criterion provide the most comparable results relative to the actual funding realisation based on the historical data for the last 20 years. On the other hand, the current GOI's investment policy is only suitable for the current Non-limited budget scenario. As a reflection of this situation, many hundred of on going water resources projects have been rescheduled, postponed and some even have been cancelled. The results of possibility ratings of the scenarios of future budget availability also confirm that the Undetermined Budget scenario represents the most likely scenario to prevail in the future.

In addition to these results, implications of budgetary uncertainty are also further examined by determination of the optimal project scheduling horizon with respect to discounted cost and risk of interruption of project implementation arising from budgetary fluctuations beyond the control of DM. The information generated by this approach provides a guidance for the DM or the planners for choosing the most suitable scheduling horizon for the anticipated budget availability scenario.

The important features of the SDP model for investment planning decision process can be summarized as follows:

1. The combination of a subjective model, and the AHP which generates scenario based transformation probabilities, provides a means of recognizing, synthesizing, and prioritizing quantitative and qualitative socio-economic and political factors which govern the future budget availability for investment into a numerical scale, such that they can be incorporated explicitly into an optimization procedure.

2. The use of scenario based transformation probabilities enables the problems of budgetary fluctuations to be anticipated and quantified such that they can be incorporated in the decision making process. In this case, the optimal investment policies are not only to be governed by a 'target oriented' policy but also by a policy that recognizes and quantifies the anticipated budgetary fluctuations arising from socio-economic and political factors beyond the control of the DM. The adoption of such an optimization investment policy generated by the SDP approach enables the DM to recognize and minimize the problems of project rescheduling, postponement and cancellation due to budgetary fluctuations.

8.3.2 The Results of the FCCIGP Model

The results of the FCCIGP ensure that the economic return of each possible level of funding decision, with its associated portfolio of projects is satisfied with respect to goals, criteria and risks preferences. In terms of goal achievement, when preference is given NPVB objective the projects in the portfolio selected by the FCCIGP yield returns 21.73% greater than the return of projects ranked by a traditional B-C method. Furthermore, the results of the application show that the FCCIGP model is also able to identify any over-and under-estimations of components of benefits and costs inherent in a traditional B-C method.

Similarly, in terms of articulating preference toward risk and uncertainty and trade-off between commensurate and non-commensurate objective, the FCCIGP model is superior to these traditional B-C method, IGP model, and Target MOTAD. Other managerial requirements such as the optimal project scheduling, project unity, and the optimal annual budget are also satisfactorily obtained using the proposed FCCIGP model.

The other important features of the FCCIGP model in handling the risks inherent in the determination of NPVB criterion, the uncertainty inherent in socio-technical and political factors related to selection criteria, and problems of imprecision of input data can be summarized as the follows.

Investment Outcome Uncertainty:

1. The combination of the Contingency Index and FOSM analysis provides a means of recognizing and quantifying various types of uncertainties inherent in the Benefit-Cost analysis which are different from traditional engineering risks.

2. The use of the Contingency Index and benefit-cost historical data of similar completed projects provides a basis by which to correct any over-and under- estimation of the lower and upper bounds of benefit and cost components inherent in the original data for potential projects. Such approach provides more reliable, and somewhat less biased values than the purely subjective estimates of experts or DM's currently being used in existing approaches.

3. The integration of the probability analysis of economic criterion within the multiobjective-multicriteria portfolio optimization model provides a means of identifying the existence of 'risky' projects and to articulate risk preferences in the project selection process. This ability enables the proposed FCCIGP model to be used as an approach for choosing between a number of projects, each with an uncertain economic indicator.

4. The ability to perform trade-off analyses both between preferences for risks and uncertainties and goals and criteria achievement and resources capacities, and between commensurate and non-commensurate objectives with somewhat less complex interaction with the DM relative to other multiobjective techniques makes the proposed FCCIGP model attractive for the practitioner in water recources planning and management.

Socio-technical and Political Factor Uncertainties

1. The integration of Point Allocation and Multiple Variable Regression models in the form of scoring prediction regression model enables non-quantitative socio-political and technical factors inherent in the agricultural production and marketing subsystems to be recognized, combined, and quantified explicitly. This ability is required to improve current practice in water resources planning that merely has been focussed only on engineering and economic data in the processes of obtaining project approval (Chaturvedi, 1992).

2. The combination of the Scoring Prediction Regression model and the Scoring Criterion-Based Optimization enables the socio-technical and political factors uncertainties inherent in the agricultural production and marketing subsystem to be incorporated into the optimization model for project selection. Recognition and incorporation of such socio-technical and political factors uncertainties on an investment planning is required to reduce excessive delays in utilization of newly completed projects due to lack of recognition of such factors.

Imprecision of Input Data:

The use of Fuzzy Set theory in the model enables uncertainty arising from imprecision of qualitative data and incomplete knowledge of quantitative data inherent in the setting of target goals, in the specification of budget limits, and in the preferences toward uncertainty, to be evaluated and incorporated in the decision making process.

8.4 Conclusion

Experience with the integrated SDP-FCCIGP model on the basis of its application to the problems of water resources investment planning in an uncertain budgetary and outcome environment, with particular reference to the situation in Indonesia, suggests that it is a useful technique for examining such types of uncertainties. It provides operational guidance for almost all critical issues in public investment planning such as:

1. budgetary uncertainty in that it provides the optimal planning / funding decision representing the best combination of projects to be implemented at any stage of the planning horizon given an existing level of development and the extent of the funding received in the previous scheduling horizon : the goal and selection criteria preferences, and an anticipated budget scenario,
2. uncertainty in investment outcomes in that it provides means of identifying "risky" projects and displaying the trade-off between goal achievements and the various levels of confidence limit on the NPVB criterion thereby enabling the attitude toward risk, i.e., "risk taker" or "risk averter,"to be incorporated in the model formulation,
3. providing a means of obtaining and measuring the social end effects of projects in such a way that they can be directly incorporated into the optimization
4. imprecise input data by applying fuzzy set theory in the model formulation,
5. managerial concerns related to optimal project scheduling, project unity, project depedencies, and optimal annual budget allocation by performing these tasks within the determination of the best portfolio of projects for each time period,
6. determination of optimal scheduling horizons with respect to potential interruptions due to external factors beyond the control of DM.

In addition to providing an operational framework for handling the various types of uncertainties inherent in public investment analysis, the procedures developed in this study may contribute to enriching the existing "hard" purely mechanistic mathematical models by providing a means of incorporating a subjective or intuitively-based approach which has the specific ability to handle 'soft (subjective) data' into a formal model. Such "softening"is required to handle real world problems that are, in fact, neither purely analytic nor purely intuitive; rather, they combine both components in an intricate interaction. This integration in the so-called "meta-modelling" enables subjective information, judgments and insight reflected in the qualitative data to be directly incorporated in the optimization models through the following approaches:

1. Collective Opinion Techniques:

The AHP which actually combines the four existing collective opinion techniques: 1) Delphi method, 2) Market research, 3) Panel consensus, and 4) Visionary forecast (Saaty and Vargas, 1991) is applied in this thesis to improve elicitation of individual or group judgment(s) related to two types of uncertainties being addressed in this study. For budgetary uncertainty, the AHP method, in combination with a scenario-based model, is applied to generate transformation probabilities in the SDP and to estimate the possibility ratings of each scenario of future budget availability for investment. Similarly, for the second type of uncertainty, i.e., investment outcome uncertainty, the AHP method is applied to elicit preferences toward risk represented in various levels of confidence limits on the economic criterion. In summary, such improvements are as follows:

- It provides a means of enabling the preferences toward uncertainty to be determined by a political process in which a large number of assessor might participate. This feature is in contrast with existing procedures in which such preferences tend to be determined individually and rather abritrarily without rational explanation for such assessment.

- It provides a means of checking the consistency of each assessment from each assessor. If the calculated consistency ratio is less than a minimum acceptable ratio, the assessment is returned to the assessor for reassessment.

2. Quantification of Non-quantitative Social Factors:

The combination of the scoring prediction regression model (integration of point allocation and multiple variable regression models) and the modified partitioning algorithm enables non-quantitative social factors to be incorporated in the optimization model and decision process for determining the funding levels to anticipate and the projects to implement with each possible funding level. Such ability is required for approaches which are used as a tool in a public investment planning decision making process. However it is particularly important in addressing deficiencies of water resources investment planning analysis in developing countries which are focussed on using only engineering , economic and financial data analysis in the project planning without giving adequate attention to the social-technical and economic factors as agricultural production and marketing subsystems relevant for such objectives.

In addition of such contributions, the following improvements in the probabilistic analysis of economic criterion using the FOSM analysis and existing chance constrained programming are worthy of note:

1. **Improvement in Estimation of Uncertain Parameters in the FOSM analysis:** The use of the modified contingency index and historical data of the similar completed schemes provides a means of correcting any under and over estimation of costs and benefits of the original data of the project under consideration. These upper and lower bounds are employed to estimate 'probabilistic' economic performance expressed in terms of the mean, upper, and lower values of NPVB criterion of potential projects. Such estimation provides a more reliable result, and somewhat less biased estimate, than the subjective estimation of experts or decision makers as is currently still being used in the existing approaches which applies FOSM analysis, e.g., Goicochea et al., (1982), Dandy (1985), and Tung (1992).

2. **Improvement of existing Chance Constrained Programming:** The use of Fuzzy Set Theory alleviates some of the limitations inherent in the existing Chance Constrained Programming, such as arbitrary choice of level of confidence limits and unsatisfactory quantification of the effects of constraint violations. The other advantage, compared to the crisp problem formulation, is that it does not force DM to specify the problem being addressed into a precise formulation because of mathematical programming reasons when he or she might only be able, or willing to describe his/her problem in fuzzy terms.

8.5 Recommendation for Future Work

Although the procedure for incorporating social and political factors into the planning model for resources development represents an important step towards more informed and comprehensive decision making for water resources investment, there are a number of elements in the process of incorporating the social political factors that need further research. In particular at present the methodology does not guarantee that all or at least most of the important social and political factors are in fact included in the analysis. Furthermore, there are problems in quantifying (specifying and measuring) these social and political factors in appropriate manner. These problems are exacerbated when the social and political factors are extrapolated into the future. Such problems exist for the engineering/scientific factors which impact on the decision making process but are more acute for social and political issues. The development of process for quantifying these social economic parameters appropriately is an area requiring additional research.

Similarly, the introduction of normative elements into what is essentially meant to be an engineering or scientific process and the associated implications of using the value judgements that accompany those elements needs further detailed research before the level of confidence desired in the outcomes of the process can be achieved.

The other areas within this study that need further investigation are: 1) it is necessary to extend the formulation to address the existence of interrelated projects. This extension need a substantial modification of the formulation of the deterministic equivalent of chance constraint; 2) development of an exact deterministic equivalent of the probabilistic constraint instead of the approximation (linearization) of the non-linear deterministic equivalent currently adopted; 3) formulation of an exact analytic probability distribution of the economic criterion rather than the current approximate approach under the normality assumption used for the FOSM analysis; 4) extension of the definition of scenario of future budget availability, especially for the undetermined budget scenario. At present the range associated with this scenario seems too large. Refinement or extrapolation may be needed; and 5) at present the cost escalation coefficient to penalize any discrepancies between planned and actual funding is expressed in the form of linear scale of judgment. A more accurate function such as a non-linear utility function may be required.

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Appendix A

Results of Application of the Integrated Model for Water Resources Investment Planning in Indonesia

Table A.1: Physical Potential Scoring Data of the Completed Irrigation Projects to Determine the Regression Parameters of the Scoring Prediction Model for the Physical Potential and Environmental Criteria of the Potential Projects

PROJECT NUMBER AND NAME	LOCATION (PROVINCE)	PHYSICAL POTENTIAL SCORE(%)	CONSTITUENTS CRITERION (%)*)						
			WATER AVAILABILITY	LAND FERTILITY	TOPOGRAPHY CONDITION	LAND USE	DRAINAGE CONDITION	LAND DISTRIBUTION	SITE LOCATION
1 RAMA AGUNG	BENGKULU	90	90	88	70	90	100	80	90
2 SELUMA	BENGKULU	65	90	65	70	60	60	50	70
3 LAIS	BENGKULU	76	70	80	70	68	100	60	80
4 JATILUHUR	WEST JAVA	90	95	95	100	75	80	80	100
5 MANJUTO	BENGKULU	70	80	65	75	70	62	56	70
6 BENGKENANG	BENGKULU	76	68	78	80	80	100	85	85
7 PENAGO	BENGKULU	74	75	70	74	75	68	67	82
8 WAWOTOBI	S.E. SULAWESI	76	75	72	70	75	80	70	80
9 NOKAN SENALI	BENGKKULU	78	67	80	85	65	95	68	70
10 BELITI	BENGKULU	75	85	78	67	60	100	61	81
11 GUMBASA	N. SULAWESI	80	78	80	82	74	85	62	85
12 SITIUNG	W. SUMATRA	83	72	78	70	85	95	78	86
13 BATU LICIN	S. SUMATRA	78	80	78	80	70	85	67	80
14 SANGGAU	W. KALIMANTAN	75	78	70	74	70	78	61	75
15 TALOHEN	S. KALIMANTAN	77	80	72	78	70	80	65	82
16 PUNGGUR	LAMPUNG	80	78	80	85	87	88	62	85
17 TELUK LADA	WEST JAVA	87	82	87	90	95	85	85	92
18 KEDU SELATAN	CTRL. JAVA	90	88	89	90	95	85	100	90
19 DUMPIL	CTRL. JAVA	88	82	87	90	90	80	100	90
20 LODOYO	EAST JAVA	87	78	86	90	90	90	100	92
21 WIDAS	EAST JAVA	87	85	85	90	90	90	100	95
22 KETRO	CTRL. JAVA	78	76	78	89	90	92	95	92
23 RENTANG	WEST JAVA	89	87	88	90	90	88	100	90
24 NANTO	BENGKULU	70	80	76	65	70	80	62	62
25 SADANG	S. SULAWESI	88	86	89	90	90	90	83	90
26 PAMUKULU	N. SULAWESI	80	82	78	85	78	85	95	80
27 AIR NIPIS	BENGKULU	80	76	78	90	84	90	72	85
28 MEROWI	C. KALIMANTAN	78	80	74	85	80	86	65	81
29 MADURA	EAST JAVA	78	65	70	80	90	90	100	85
30 WARU TURI	EAST JAVA	88	86	90	90	90	86	100	90
31 SEMPOR	CTRL. JAVA	90	89	90	89	92	87	100	93
32 AIR RAMAN	S. SUMATRA	84	82	78	90	83	90	80	86
33 POLEANG	KALIMANTAN	77	78	72	86	78	80	70	82
34 BAPANG	CTRL. JAVA	86	79	82	90	90	90	100	90
35 INDRAPURA	W. SUMATRA	80	78	79	80	80	85	85	86
36 MARISA	N. SULAWESI	76	78	75	80	75	80	80	80

NOTE: *) SOURCE: DGWRD PELITA I-IV REPORTS (1989).
BCEOM (1989) and Personal observations (1988-1989)

REGRESSION RESULTS:

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	7	1367.81239	195.40177	49.654	0.0001
Error	28	110.18761	3.93527		
C Total	35	1478.00000			

Root MSE	1.98375	R-square	0.9254
Dep Mean	80.66667	Adj R-sq	0.9068
C.V.	2.45920		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	5.669417	6.92486079	0.819	0.4199
WATAVL	1	0.076775	0.07831768	0.980	0.3353
LANDFRT	1	0.441309	0.09753527	4.525	0.0001
TOPHC	1	0.038149	0.06069122	0.629	0.5347
LANDUSE	1	0.201792	0.06479572	3.114	0.0042
DRAIN	1	0.035268	0.05748794	0.613	0.5445
SITELOC	1	0.131541	0.07152973	1.839	0.0765
LANDDIST	1	0.004119	0.04062992	0.101	0.9200

Table A.2: Agricultural Production Scoring Data of the Completed Irrigation Projects to Determine the Regression Parameters of the Scoring Prediction Model for the Agricultural Production Factors Related to the Farmer Readiness Criteria of the Potential Projects

PROJECT NUMBER AND NAME	AGRICULTURAL PRODUCTION CRITERIA SCORE (%)	CONSTITUENTS CRITERION (%)*)							
		UTILIZATION OF EXISTING SCHEMES	NUMBER OF FARMERS	PRODUCTION OF EXISTING SCHEME	USE OF NEW INPUT	IRRIGATION EFFICIENCY OF EXISTING SCHEME	AGRICULTURAL SUPPORT SERVICE	OPERATION AND MAINTENANCE	LAND OWNERSHIP
1 RAMA AGUNG	85	75	100	80	70	75	75	76	56
2 SELUMA	40	68	70	65	60	57	65	63	35
3 LAIS	60	70	100	78	65	64	70	68	40
4 JATILUHUR	95	90	100	96	100	79	90	78	68
5 MANJUTO	30	40	47	54	48	53	58	54	30
6 BENGKENANG	78	69	95	69	65	57	64	61	38
7 PENAGO	58	65	86	67	61	58	65	58	35
8 WAWOTOBI	61	67	80	68	67	56	67	62	32
9 NOKAN SENALI	35	65	97	71	68	57	68	57	28
10 BELITI	36	62	87	69	62	52	61	58	25
11 GUMBASA	47	68	89	68	67	51	68	67	40
12 SITIUNG	70	78	96	77	74	61	75	65	65
13 KALAENA KANAN	65	74	85	75	68	58	72	62	37
14 BATU LICIN	35	40	68	65	61	56	54	52	25
15 SANGGAU	28	35	57	67	59	52	52	57	23
16 TALOHEN	36	28	78	59	62	51	63	52	31
17 PUNGGUR	71	75	100	75	71	61	76	78	53
18 TELUK LADA	81	95	100	87	75	62	78	76	72
19 KEDU SELATAN	96	92	100	89	82	68	85	80	75
20 DUMPIL	94	90	100	88	85	67	83	71	65
21 LODOYO	89	91	100	87	87	65	79	78	67
22 WIDAS	95	93	100	86	88	68	81	79	70
23 KETRO	92	96	100	85	86	64	82	72	78
24 RENTANG	94	91	100	84	88	65	79	76	78
25 NANTO	30	45	78	67	58	53	59	56	26
26 SADANG	87	83	100	87	79	68	76	78	68
27 PAMUKULU	57	78	93	78	76	63	78	75	48
28 AIR NIPIS	86	73	100	76	58	55	65	63	49
29 MEROWI	75	49	87	73	64	58	62	61	27
30 MADURA	89	91	100	86	81	61	82	85	56
31 WARU TURI	92	89	100	88	82	72	85	86	78
32 SEMPOR	98	91	100	89	86	76	83	87	80
33 AIR RAMAN	70	85	100	78	72	68	73	71	30
34 POLEANG	68	75	90	68	62	58	67	59	28
35 BAPANG	96	92	100	89	87	75	78	71	78
36 INDRAPURA	67	78	100	77	70	61	75	65	40
37 MARISA	65	75	87	67	65	56	71	59	30

NOTE: SOURCE: *) DGWRD PELITA I-IV REPORTS (1989)

REGRESSION RESULTS:

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	8	15844.66026	1980.58253	18.271	0.0001
Error	28	3035.23163	108.40113		
C Total	36	18879.89189			

Root MSE	10.41159	R-square	0.8392
Dep Mean	68.94595	Adj R-sq	0.7933
C.V.	15.10109		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	-43.204522	26.35395551	-1.639	0.1123
UTEXSYS	1	0.362016	0.24979934	1.449	0.1584
NOFARM	1	0.391673	0.25347243	1.545	0.1335
PRODEX	1	0.367447	0.64869192	0.566	0.5756
USEINPUT	1	-0.135183	0.46530609	-0.291	0.7736
IRREFF	1	0.567728	0.46906995	1.210	0.2363
AGRSUPP	1	-0.276896	0.66566646	-0.416	0.6806
OM	1	-0.057593	0.42128440	-0.137	0.8922
LANDOWN	1	0.416294	0.20315449	2.049	0.0499

Table A.3: Score of Selection Criteria (PPE, ERF, and FRD) and Number of Transmigrant and Irrigation Area for Each Potential Project on Stage 1

NO	PROJECTS NAME	PROVINCE	AREA (HA)	PROJECT TYPE	PHYSICAL POTENTIAL SCORE (%)	EXISTING RICE FIELDS SCORE(%)	FARMER READINESS SCORE (%)	TRANSMIGRATION SUPPORT (NUMBER OF FAMILIES)
1	KRUENG BARO	ACEH	16772	NEW	82.53	46.86	60.35	5000
2	NORTH SUMATRA	N. SUMATRA	41000	NEW	83.80	53.12	67.89	0
3	PASAMAN	WEST SUMATRA	4926	NEW	85.83	52.21	76.91	0
4	BATANG KUMU	RIAU	13800	NEW	79.91	28.10	49.24	5000
5	LIMUN SUNGKAT	JAMBI	2500	NEW	80.14	51.60	48.67	500
6	KOMERING	S. SUMATRA	55904	NEW	83.74	42.15	63.97	10000
7	BAAL	S. SUMATRA	5500	NEW	84.91	62.73	64.27	0
8	WAY ABUNG	LAMPUNG	5000	NEW	84.79	73.60	73.92	0
9	WAY PEDADA	LAMPUNG	13550	NEW	85.20	69.14	72.07	0
10	ALAS	BENGKULU	4400	NEW	83.07	76.14	70.89	0
11	MANJUTO KANAN	BENGKULU	10000	NEW	76.24	12.00	42.35	4000
12	TELUK LADA	WEST JAVA	18923	NEW	87.47	80.64	76.99	0
13	JATIGEDE	WEST JAVA	130158	NEW	88.72	99.54	81.95	0
14	JRATUNSELUNA	CENTRAL JAVA	74537	NEW	88.01	95.59	83.21	0
15	DUMPIL	CENTRAL JAVA	25415	NEW	88.60	92.82	82.26	0
16	MADURA	EAST JAVA	2580	NEW	85.86	84.03	73.10	0
17	EAST JAVA IMP.	EAST JAVA	143042	REHAB.	89.86	99.31	84.64	0
18	SANGGAU LEDO	W. KALIMANTAN	555	NEW	80.43	90.09	50.99	0
19	KASAU	C. KALIMANTAN	5000	NEW	79.41	35.60	46.30	1000
20	RIAM KANAN	S. KALIMANTAN	12000	NEW	81.54	56.21	55.56	1500
21	TORAUT BONGO	N. SULAWESI	7820	NEW	83.45	58.62	58.78	1000
22	TAOPA	C. SULAWESI	8000	NEW	84.34	47.31	51.17	3000
23	KALONG	C. SULAWESI	1200	NEW	84.11	68.58	53.51	500
24	BOYA	S. SULAWESI	10000	NEW	83.77	65.86	72.02	2500
25	SAN REGO	S. SULAWESI	7500	NEW	87.01	81.65	67.95	1500
26	WAWOTOBI	S.E. SULAWESI	21200	NEW	87.49	41.27	67.88	6000
27	DATARAN KOBI	MALUKU	1950	NEW	87.48	50.26	65.12	500
28	WIMBO ERANG	IRIAN JAYA	1963	NEW	86.29	18.14	25.82	500
29	IRIGASI BALI	BALI	3425	NEW	89.04	93.43	90.45	0
30	EMBUNG NTB	WEST NUSA TG.	1520	NEW	88.01	93.42	88.38	0
31	KALIMANTONG	WEST NUSA TG.	2850	NEW	88.60	50.88	85.81	0
32	IRIGASI NTT	EAST NUSA TG.	3360	GROUND WT	89.19	88.69	84.94	0
33	EMBUNG NTT	EAST NUSA TG.	8276	NEW	88.45	87.36	83.61	0

NOTE : REHAB. = REHABILITATION PROJECT
GROUND WT = GROUND WATER PROJECT

Table A.4: Score of Selection Criteria (PPE, ERF, and FRD) and Number of Transmigrant and Irrigation Area for Each Potential Project on Stage 2

PROJECT NUMBER AND NAME	LOCATION (PROVINCE)	AREA (HA)	PROJECT TYPE	PHYSICAL POTENTIAL SCORE (%)	EXISTING RICE FIELDS SCORE (%)	FARMER READINESS SCORE (%)	TRANSMIGRATION SUPPORT (NUMBER OF FAMILIES)
1 KRUENG ACEH	ACEH	24000	NEW	86.60	52.50	66.55	5000
2 IRIGASI ACEH	ACEH	30000	REHAB.	85.89	98.50	70.64	0
3 IRIGASI NIAS	N. SUMATRA	8000	NEW	85.84	70.88	59.53	0
4 IRIGASI SUMUT	N. SUMATRA	50000	REHAB.	89.04	97.92	76.80	0
5 BT. KALULUTAN	W. SUMATRA	4600	NEW	88.15	73.91	80.85	0
6 IRIGASI SUMBAR	W. SUMATRA	20000	REHAB.	89.49	99.00	84.86	0
7 BATANG TESO	RIAU	2960	NEW	84.90	43.24	54.09	500
8 PEMATANG LIMIT	JAMBI	2200	NEW	85.08	67.55	57.00	700
9 MUSI RAWAS	S. SUMATRA	15800	NEW	86.71	61.27	73.04	3000
10 MUNCAK KABAU	S. SUMATRA	10700	NEW	88.34	63.36	72.19	2000
11 IRG. KECIL LPG.	LAMPUNG	5000	NEW	88.63	70.00	77.70	0
12 IRIGASI LAMPUNG	LAMPUNG	40000	REHAB.	90.16	99.18	84.25	0
13 NOKAN KANAN	BENGKULU	1500	NEW	87.64	65.73	70.36	0
14 PENAGO	BENGKULU	10000	NEW	81.86	45.82	64.02	2500
15 IRIGASI BENGKUL	BENGKULU	15000	REHAB.	84.22	90.67	69.37	0
16 TANJUNG	WEST JAVA	5568	NEW	88.31	81.18	81.64	0
17 KARIAN	WEST JAVA	10300	NEW	88.03	87.77	81.77	0
18 IRG. WEST JAVA	WEST JAVA	24200	REHAB.	90.52	98.64	84.01	0
19 IRG. CTRL JAVA	CENTRAL JAVA	82942	REHAB.	90.96	95.66	82.50	0
20 LOSARI	EAST JAVA	4180	NEW	90.88	95.22	85.49	0
21 MEROWI	W. KALIMANTAN	2077	NEW	83.31	43.14	55.91	700
22 IRG. KALTENG	C. KALIMANTAN	4000	NEW	83.20	59.00	51.73	1000
23 IRG. KALSEL	S. KALIMANTAN	17682	NEW	85.68	59.10	58.03	3000
24 TANGKUP	N. SULAWESI	3400	NEW	85.79	55.59	62.16	1000
25 TAOPA LAMBUN	C. SULAWESI	7100	NEW	84.67	51.76	63.31	3000
26 BONTA MANAI	S. SULAWESI	7800	NEW	87.56	58.85	70.74	700
27 BILI-BILI	S. SULAWESI	26050	NEW	88.40	76.05	71.41	5000
28 POLEANG	S.E. SULAWESI	2530	NEW	88.31	61.66	68.62	700
29 ARSO	IRIAN JAYA	3638	NEW	86.02	29.96	49.20	1500
30 IRIGASI BALI	BALI	1000	GROUND WT	90.04	98.00	95.92	0
31 IRIGASI W. NTB	WEST NTB	7667	NEW	89.47	60.00	83.81	0
32 IRIGASI NTT	E. NUSA TGR.	8531	NEW	88.99	70.57	84.16	0

NOTE: REHAB. = REHABILITATION PROJECT
GROUND WT = GROUND WATER PROJECT

Table A.5: Score of Selection Criteria (PPE, ERF, and FRD) and Number of Transmigrant and Irrigation Area for Each Potential Project on Stage 3

NO	PROJECTS NAME	PROVINCE	AREA (HA)	PROJECT TYPE	PHYSICAL POTENTIAL SCORE (%)	EXISTING RICE FIELDS SCORE(%)	FARMER READINESS SCORE (%)	TRANSMIGRATION SUPPORT (NUMBER OF FAMILIES)
1	KRUENG JRUE	ACEH	2365	NEW	87.51	58.27	64.86	0
2	BT. INDRAPURA	WEST JAVA	2678	NEW	89.31	70.58	72.04	0
3	SUNGAI MURAI	RIAU	12000	NEW	85.71	30.67	53.94	4000
4	BATANG ULOH	JAMBI	500	NEW	84.06	73.80	59.02	0
5	BELITANG	S. SUMATRA	20600	NEW	86.51	62.18	71.95	3500
6	LEMPOING	S. SUMATRA	13100	NEW	88.08	77.86	74.89	2000
7	TULANG BAWANG	S. SUMATRA	44500	NEW	88.77	67.12	70.12	8000
8	BUMI AGUNG	LAMPUNG	3150	NEW	88.29	74.60	77.70	0
9	MESUJI II	LAMPUNG	20980	NEW	88.77	74.69	76.82	1000
10	BENGKENANG	BENGKULU	5000	NEW	88.22	79.80	75.58	0
11	SADAWARNA	WEST JAVA	6277	NEW	89.48	90.01	83.44	0
12	CIBEBER	WEST JAVA	8900	NEW	89.04	87.64	85.18	0
13	IRG. WEST JAVA	WEST JAVA	50000	REHAB.	91.24	96.60	89.68	0
14	KEDU SELATAN	CENTRAL JAVA	24000	NEW	90.75	94.94	91.31	0
15	BANJAREJO	CENTRAL JAVA	7750	NEW	91.51	87.10	90.42	0
16	IRG. CTRL JAVA	CENTRAL JAVA	50000	REHAB.	92.17	146.56	91.77	0
17	LESTI LEFT	EAST JAVA	2300	NEW	93.83	95.87	98.26	0
18	WIDAS	EAST JAVA	7750	NEW	92.10	95.32	93.54	0
19	IRG. EAST JAVA	EAST JAVA	75000	REHAB	93.74	99.44	99.41	0
20	SEBANGUN	C. KALIMANTAN	15000	NEW	78.32	37.85	53.36	5000
21	BATU LICIN	S. KALIMANTAN	4640	NEW	87.10	45.69	68.35	1500
22	IRIGASI SULUT	N. SULAWESI	8000	NEW	88.64	47.25	74.29	1500
23	PARIGI POSO	C. SULAWESI	14056	NEW	86.91	64.88	71.71	2500
24	SIDRANG	C. SULAWESI	3500	NEW	87.77	79.00	74.10	0
25	CENRANAE	S. SULAWESI	4100	NEW	88.90	72.85	78.37	0
26	KALAENA KANAN	S. SULAWESI	4748	NEW	88.16	60.97	76.28	1000
27	MAPPI	IRIAN JAYA	59800	NEW	84.47	5.35	43.30	20000
28	IRG. NTB	W. NUSA TGR.	2720	GROUND WT	90.12	95.22	84.79	0
29	PELORA	W. NUSA TGR.	9054	NEW	89.28	88.14	86.23	0
30	IRG. NTT.	E. NUSA TGR.	8530	NEW	87.56	82.39	83.43	0

NOTE : REHAB. = REHABILITATION PROJECT
GROUND WT = GROUND WATER PROJECT

Table A.6: Score of Selection Criteria (PPE, ERF, and FRD) and Number of Transmigrant and Irrigation Area for Each Potential Project on Stage 4

PROJECT NUMBER AND NAME	LOCATION (PROVINCE)	AREA (HA)	PROJECT TYPE	PHYSICAL POTENTIAL SCORE (%)	EXISTING RICE FIELDS SCORE(%)	FARMER READINESS SCORE (%)	TRANSMIGRATION SUPPORT (NUMBER OF FAMILIES)
1 IRIGASI ACEH	ACEH	20000	REHAB.	89.03	93.75	77.10	0
2 IRIGASI SUMUT	N. SUMATRA	30000	REHAB.	89.79	95.95	82.99	0
3 IRG.KECIL SUMBAR	W. SUMATRA	19512	NEW	89.22	64.73	81.92	0
4 IRIGASI SUMBAR	W. SUMATRA	20000	REHAB.	90.10	93.82	85.06	0
5 IRG. KECIL RIAU	RIAU	1165	NEW	86.18	84.55	70.62	0
6 IRG. ULAK BERAS	JAMBI	500	NEW	86.30	95.00	72.63	0
7 IRG.KECIL SUMSEL	S. SUMATRA	17100	NEW	87.28	61.75	77.95	0
8 RUPIT	S. SUMATRA	11000	NEW	88.52	45.32	78.36	2000
9 IRG. SUMSEL	S. SUMATRA	20000	REHAB.	90.02	93.75	81.62	0
10 AIR MALUS	S. SUMATRA	8800	NEW	88.66	52.84	78.48	1500
11 AIR TALANG NIUR	S. SUMATRA	4500	NEW	88.28	59.33	79.75	500
12 AIR LIMAU	S. SUMATRA	7000	NEW	88.79	78.00	78.33	2000
13 LOWER KOMERING	S. SUMATRA	22174	NEW	88.93	61.18	78.64	5000
14 LOWER LEMATANG	S. SUMATRA	11070	NEW	88.56	56.33	77.92	2000
15 WAY TAHMI	LAMPUNG	5550	NEW	89.64	66.31	82.35	0
16 WAY MESUJI II	LAMPUNG	18750	NEW	88.08	48.67	82.29	0
17 WAY BUAYA	LAMPUNG	4880	NEW	89.55	54.92	81.41	0
18 AIR SELAGAN	BENGKULU	11000	NEW	84.94	34.36	58.36	3500
19 IRG. WEST JAVA	W. JAVA	65000	REHAB.	91.04	97.62	87.56	0
20 JRAGUNG	CTRL. JAVA	12200	NEW	89.34	85.72	81.31	0
21 KEDUNGWARU	CTRL. JAVA	1330	NEW	89.50	92.48	83.69	0
22 IRG. AIR TANAH	CTRL. JAVA	2320	NEW	91.01	90.52	87.04	0
23 IRG. CTRL. JAVA	CTRL. JAVA	80000	REHAB.	92.16	99.00	90.52	0
24 BENG	EAST JAVA	3200	NEW	90.17	80.00	89.39	0
25 IRG. EAST JAVA	EAST JAVA	75000	REHAB.	91.20	97.60	93.41	0
26 BATANG ALAI	S. KALIMANTAN	6220	NEW	88.05	50.16	78.70	1500
27 BARABAI	S. KALIMANTAN	2280	NEW	85.27	44.74	79.51	500
28 IRG. KECIL NTB	WEST NUSA TGR	11518	NEW	89.04	54.09	82.04	0
29 BATU BULAN	WEST NUSA TGR	7000	NEW	89.72	62.54	83.67	0
30 IRG. C.SULAWESI	C. SULAWESI	6410	NEW	87.78	45.09	69.49	2000
31 BILA	S. SULAWESI	24040	NEW	88.76	45.63	72.90	4500
32 KUTI	IRIAN JAYA	74000	NEW	87.39	6.08	58.70	35000

NOTE : REHAB. = REHABILITATION

Table A.7: Score of Selection Criteria (PPE, ERF, and FRD) and Number of Transmigrant and Irrigation Area for Each Potential Project on Stage 5

PROJECT NUMBER AND NAME	LOCATION (PROVINCE)	AREA (HA)	PROJECT TYPE	PHYSICAL POTENTIAL SCORE (%)	EXISTING RICE FIELDS (%)	FARMER READINESS SCORE (%)	TRANSMIGRATION SUPPORT (MUNBER OF FAMILIES)
1 IRG. ACEH	ACEH	15000	REHAB.	89.99	93.23	79.54	0
2 IRG. SUMUT	N. SUMATRA	15000	REHAB.	91.38	97.17	84.69	0
3 AMPIK PAREK	W. SUMATRA	2365	NEW	88.21	88.79	85.09	0
4 PERJAYA	S. SUMATRA	21555	NEW	89.47	53.12	79.75	3000
5 LEMATANG	S. SUMATRA	11070	NEW	89.05	51.22	82.82	2000
6 LAKITAN	S. SUMATRA	11600	NEW	88.37	56.03	82.53	1000
7 BATANGHARI	S. SUMATRA	13000	NEW	88.50	67.31	81.57	2500
8 SEKAYU LUPATAN	S. SUMATRA	8600	NEW	86.96	73.84	83.75	1000
9 AIR LEBAK BUNGUR	S. SUMATRA	8344	NEW	87.92	47.76	83.56	1000
10 AIR RATAN	S. SUMATRA	13830	NEW	88.51	56.96	81.22	3000
11 WAY HITAM	S. SUMATRA	5705	NEW	88.73	67.92	84.86	1000
12 BELITANG	S. SUMATRA	8750	NEW	87.59	67.37	86.12	500
13 WAY SAKA	LAMPUNG	12600	NEW	88.64	66.19	86.37	0
14 WAY MESUJI III	LAMPUNG	15820	NEW	87.47	57.07	86.83	0
15 BUNGIN TAMBUN	BENGKULU	8000	NEW	85.23	40.98	72.33	1000
16 MAYA	WEST JAVA	2900	NEW	90.23	96.38	88.42	0
17 TELAGA HERANG	WEST JAVA	7700	NEW	91.04	93.64	88.99	0
18 CIMULYA	WEST JAVA	8350	NEW	91.65	93.72	87.60	0
19 CINIRU	WEST JAVA	2976	NEW	90.35	90.22	88.99	0
20 GUNUNG WULAN	CTRL. JAVA	21838	NEW	90.75	90.58	88.44	0
21 GLAPAN	CTRL. JAVA	19050	NEW	90.69	98.22	88.43	0
22 IRG. AIR TANAH	EAST JAVA	4300	NEW	91.48	93.26	90.74	0
23 IRG. EAST JAVA	EAST JAVA	30000	REHAB	92.41	99.66	91.04	0
24 AMANDIT	S. KALIMANTAN	6430	NEW	85.10	77.45	80.84	1500
25 TAPIN	S. KALIMANTAN	5330	NEW	83.54	75.23	80.70	1000
26 CTRL. SULAWESI	CTRL SULAWESI	6087	NEW	82.92	66.17	78.02	3000
27 MALUSO	S. SULAWESI	11106	NEW	84.59	54.28	78.24	2000
28 LANGKONE	S. SULAWESI	16398	NEW	86.69	78.06	79.38	3000
29 WALANE	S. SULAWESI	26000	NEW	86.91	76.50	79.72	5000
30 PADANGENG	S. SULAWESI	4200	NEW	85.94	70.95	80.45	1000
31 KIAS	IRIAN JAYA	66000	NEW	85.54	5.89	68.79	30000
32 IRG.KECIL NTB	WEST NUSA TGR	12040	NEW	86.60	89.70	82.92	0
33 PELA PERADO	WEST NUSA TGR	7000	NEW	86.66	86.00	82.32	0

NOTE : REHAB. = REHABILITATION PROJECT

Table A.8: Benefit and Cost Data of the Completed Irrigation Projects Located in Developed Regions In Java for Determining the Contingency Index of the Potential Projects

PROJECT NUMBER AND NAME	BENEFIT*)		COST**)	
	ESTIMATED BENEFIT (Ha)	ACTUAL BENEFIT (Ha)	ESTIMATED COST ($ 10^6)	ACTUAL COST ($ 10^6)
1 Jatiluhur	110000.00	130000.00	330.00	363.00
2 Ciujung-Cisadane	29500.00	24200.00	53.10	58.41
3 Rentang	91200.00	97800.00	186.96	209.40
4 Cirebon	89800.00	82160.00	152.66	160.29
5 Cidurian	16000.00	11200.00	30.53	33.58
6 Telagaherang	8900.00	7700.00	16.64	15.81
7 Manenteng	10500.00	8350.00	21.63	24.87
8 Jengkelok	9400.00	8275.00	19.93	22.52
9 Cilutung	6500.00	5870.00	14.37	12.93
10 Telagaherang	7700.00	6700.00	17.71	16.29
11 Cibeber area	8900.00	7800.00	20.65	18.79
12 Bodas	5400.00	3400.00	11.50	13.23
13 Glapan Sedadi	39500.00	37200.00	94.80	113.76
14 Jragung	35000.00	36000.00	112.00	128.80
15 Klambu	38500.00	37000.00	112.81	124.09
16 Cacaban	15000.00	14000.00	40.50	51.84
17 Sempor	35000.00	39300.00	98.00	127.40
18 Semarang Barat	12800.00	13960.00	36.48	37.21
19 Jawa Tengah	12500.00	13100.00	27.50	30.80
20 Gambarsari	28000.00	26000.00	82.04	91.06
21 Lodoyo	30000.00	28000.00	86.40	96.77
22 Ketro	1000.00	1200.00	2.70	3.11
23 Bapang	1600.00	1800.00	4.48	4.93
24 Kedu Selatan	11000.00	12000.00	29.15	33.52
25 Dumpil	24500.00	25000.00	72.28	80.23
26 Widas	5500.00	5800.00	15.90	17.96
27 Warujayeng	24000.00	26500.00	65.04	74.80
28 Turi-Tunggorono	18800.00	19500.00	52.64	54.75
29 Brantas Delta	19000.00	21500.00	40.09	41.29
30 Madura	6500.00	5800.00	18.59	22.31
31 Jatim	23000.00	24000.00	62.56	70.69
32 Nganjuk	18000.00	20000.00	46.80	53.82
33 Teluk lada	9500.00	8500.00	25.94	28.53

NOTE: *) Benefit accrued from the completed projects is estimated in proportion with the irrigation areas developed during 5 years after projects completion.

**) Estimated Cost = Cost estimated during design stage.
Actual Cost = Actual cost reported after projects completion.

Source: DGWRD Pelita I-IV Reports (1989).

RESULT: Average of Actual Benefit = 0.965 Average of Estimated Benefit
Average of Actual Cost = 1.104 Average of Estimated Cost

Table A.9: Benefit and Cost Data of the Completed Irrigation Projects Located in Underdeveloped Regions Off Java for Determining the Contingency Index of the Potential Projects

PROJECT NUMBER AND NAME	BENEFIT*)		COST**)	
	ESTIMATED BENEFIT (Ha)	ACTUAL BENEFIT (Ha)	ESTIMATED COST ($ 10^6)	ACTUAL COST ($ 10^6)
1 Sitiung	8000.00	7000.00	8000.00	7000.00
2 Gumbasa	6030.00	5600.00	6030.00	5600.00
3 Luwu	14000.00	15500.00	14000.00	15500.00
4 Sadang	21000.00	20000.00	21000.00	20000.00
5 OKU	4500.00	3935.00	4500.00	3935.00
6 OKI	9000.00	7600.00	9000.00	7600.00
7 Lahat	12900.00	11400.00	12900.00	11400.00
8 Mura	8700.00	7600.00	8700.00	7600.00
9 Way Rarem	25000.00	22000.00	25000.00	22000.00
10 Tulung Mas	12000.00	10500.00	12000.00	10500.00
11 Way Umpu	8900.00	7560.00	8900.00	7560.00
12 Klingi	8100.00	9700.00	8100.00	9700.00
13 Punggur	28500.00	30800.00	28500.00	30800.00
14 Air Raman	6300.00	5800.00	6300.00	5800.00
15 Gegas	2700.00	2200.00	2700.00	2200.00
16 Tulung Mas	3200.00	2950.00	3200.00	2950.00
17 Way Curup	2220.00	2600.00	2220.00	2600.00
18 Way Ketibung	1600.00	1750.00	1600.00	1750.00

NOTE: *) Benefit accrued from the completed projects is estimated in proportion with the irrigation areas developed during 5 years after projects completion.
**) Estimated Cost = Cost estimated during design stage.
Actual Cost = Actual cost reported after projects completion

Source: DGWRD Pelita I-IV Reports (1989).

RESULT: Average of Actual Benefit = 0.945 Average of Estimated Benefit
Average of Actual Cost = 1.170 Average of Estimated Cost

Table A.10: Benefit and Cost Data of the Completed Irrigation Projects Located in Developed Regions Off Java for Determining the Contingency Index of the Potential Projects

PROJECT NUMBER AND NAME	BENEFIT*)		COST**)	
	ESTIMATED BENEFIT (Ha)	ACTUAL BENEFIT (Ha)	ESTIMATED COST ($ 10^6)	ACTUAL COST ($ 10^6)
1 Alabio	6000.00	5200.00	22.80	29.64
2 Rama Agung	2800.00	2500.00	8.96	8.06
3 Seluma	8000.00	6500.00	30.80	39.42
4 Lais	6000.00	6650.00	22.20	18.87
5 Musi Kejalo	1040.00	1140.00	3.64	4.37
6 Manjuto	7300.00	5800.00	28.47	38.43
7 Bengkenang	4500.00	5500.00	15.75	18.90
8 Penago	10000.00	6500.00	36.00	46.80
9 Wawotobi	12000.00	10500.00	45.00	57.60
10 Nokan Senali	750.00	450.00	2.70	2.65
11 Beliti	850.00	620.00	3.15	3.96
12 Kalaena Kanan	12300.00	11400.00	44.28	57.12
13 Batu Licin	1400.00	1200.00	5.25	7.09
14 Sanggau	2800.00	2450.00	10.22	13.90
15 Talohen	680.00	830.00	2.57	3.52
16 Air Nanto	690.00	540.00	2.55	3.57
17 Pamukulu	4550.00	4050.00	17.11	23.10
18 Nipis	2850.00	3120.00	10.20	9.39
19 Merowi	3200.00	2830.00	12.16	16.42
20 Poleang	3500.00	2500.00	13.30	17.02
21 Indrapura	3050.00	3300.00	10.98	13.83
22 Merisa	3080.00	2500.00	11.70	15.45
23 Latula	1360.00	1120.00	5.03	6.64
24 Bunta	5300.00	4890.00	19.35	24.76
25 Lakejo	1260.00	1100.00	4.79	6.22
26 Padang Sappa	8500.00	7600.00	32.30	41.99
27 Alue Ubai	3050.00	2640.00	11.29	14.90
28 Trieng Gading	2100.00	1910.00	7.60	9.81
29 Pendrah	1200.00	1000.00	4.56	5.93
30 Bolonga	3150.00	2800.00	11.43	15.78
31 Pohu	1500.00	1200.00	5.70	7.92
32 Ajo	1600.00	1270.00	6.08	8.39
33 Ayong Bolangat	2280.00	2300.00	8.66	10.92
34 Lambunu	6200.00	6000.00	23.13	29.83
35 Sausu	8190.00	8000.00	30.88	37.05
36 Puna	2100.00	1950.00	7.98	9.66
37 Sanggauledo	2100.00	1520.00	7.98	9.74
38 Pamukulu	4500.00	3900.00	16.43	20.20
39 Sanrego	10200.00	9500.00	38.35	46.79
40 Talohen	1100.00	980.00	4.18	5.23
41 Lomaya	2600.00	3100.00	9.88	12.84
42 Tambarana	1100.00	1300.00	4.18	5.48
43 Tidari	790.00	915.00	3.00	3.84
44 Kilo	680.00	780.00	2.58	3.41

NOTE: *) Benefit accrued from the completed projects is estimated in proportion with the irrigation areas developed during 5 years after projects completion.
**) Estimated Cost = Cost estimated during design stage.
Actual Cost = Actual cost reported after projects completion.
Source: DGWRD Pelita I-IV Reports (1989).
RESULT: Average of Actual Benefit = 0.905 Average of Estimated Benefit
Average of Actual Cost = 1.255 Average of Estimated Cost

Table A.11: Summary of the Probabilistic Information of NPVB Criterion for the Potential Projects at Stage 2

PROJECTS NUMBER AND NAME	LOCATION (PROVINCE)	AREA (HA)	ORIGINAL*) NET BENEFIT ($ 10^6)	VARIANCE OF NET BENEFIT	STANDARD DEVIATION OF NET BENEFIT	MEAN OF NET BENEFIT ($ 10^6)	UPPER LIMIT [95% EXCEEDED] ($ 10^6)	LOWER LIMIT [5% EXCEEDED] ($ 10^6)
1 KRUENG ACEH	ACEH	24000	25.1	332.83	18.24	-18.90	-49.00	11.20
2 IRIGASI ACEH	ACEH	30000	91.35	57.84	7.61	76.59	64.04	89.14
3 IRIGASI NIAS	N. SUMATRA	8000	17.35	18.59	4.31	4.15	-2.96	11.26
4 IRIGASI SUMUT	N. SUMATRA	50000	46.1	55.26	7.43	36.08	23.82	48.35
5 BT. KALULUTAN	W. SUMATRA	4600	14.66	12.49	3.53	8.37	2.54	14.20
6 IRIGASI SUMBAR	W. SUMATRA	20000	56.6	39.72	6.30	48.95	38.55	59.35
7 BATANG TESO	RIAU	2960	8.76	3.81	1.95	4.50	1.28	7.72
8 PEMATANG LIMIT	JAMBI	2200	6.3	1.23	1.11	3.08	1.26	4.91
9 MUSI RAWAS	S. SUMATRA	15800	33.29	65.97	8.12	10.31	-3.10	23.71
10 MUNCAK KABAU	S. SUMATRA	10700	22.25	75.23	8.67	3.40	-10.91	17.71
11 IRG. KECIL LPG	LAMPUNG	5000	14.35	11.86	3.44	8.58	2.90	14.26
12 IRIGASI LAMPUN	LAMPUNG	40000	130.5	130.45	11.42	117.68	98.83	136.52
13 NOKAN KANAN	BENGKULU	1500	3.84	0.81	0.90	1.95	0.47	3.44
14 PENAGO	BENGKULU	10000	14.5	37.93	6.16	-2.26	-12.42	7.91
15 IRIGASI BENGKU	BENGKULU	15000	42.04	19.02	4.36	34.96	27.77	42.16
16 TANJUNG	WEST JAVA	5568	14.24	16.07	4.01	8.60	1.98	15.21
17 KARIAN	WEST JAVA	10300	27.3	54.11	7.36	17.00	4.87	29.14
18 IRG. WEST JAVA	WEST JAVA	24200	82.12	47.88	6.92	75.54	64.12	86.95
19 IRG. CTRL JAVA	CENTRAL JAVA	82942	169.56	542.29	23.29	144.78	106.36	183.21
20 LOSARI	EAST JAVA	4180	15.04	8.72	2.95	11.08	6.21	15.95
21 MEROWI	W. KALIMANTAN	2077	1.64	2.09	1.45	-1.79	-4.18	0.60
22 IRG. KALTENG	C. KALIMANTAN	4000	3.17	7.77	2.79	-3.44	-8.04	1.16
23 IRG. KALSEL	S. KALIMANTAN	17682	27.67	186.15	13.64	-1.62	-24.14	20.89
24 TANGKUP	N. SULAWESI	3400	5.28	6.13	2.48	-0.42	-4.51	3.67
25 TAOPA LAMBUN	C. SULAWESI	7100	18.89	21.28	4.61	9.16	1.55	16.77
26 BONTA MANAI	S. SULAWESI	7800	21.22	20.62	4.54	11.59	4.10	19.08
27 BILI-BILI	S. SULAWESI	26050	201.07	950.02	30.82	144.86	94.00	195.72
28 POLEANG	S.E. SULAWESI	2530	6.33	2.66	1.63	2.83	0.14	5.52
29 ARSO	IRIAN JAYA	3638	3.2	5.59	2.36	-3.98	-7.88	-0.08
30 IRIGASI BALI	BALI	1000	1.55	0.84	0.91	0.45	-1.05	1.95
31 IRIGASI W. NTB	WEST NTB	7667	10.58	29.12	5.40	1.54	-7.37	10.44
32 IRIGASI NTT	E. NUSA TGR.	8531	7.8	38.37	6.19	-2.30	-12.52	7.92

NOTE : *) SOURCE BCEOM (1989) IRRIGATION INVESTMENT STUDY

Table A.12: Summary of the Probabilistic Information of NPVB Criterion for the Potential Projects at Stage 3

PROJECTS NUMBER AND NAME	LOCATION (PROVINCE)	AREA (HA)	ORIGINAL*) NET BENEFIT ($ 10^6)	VARIANCE OF NET BENEFIT	STANDARD DEVIATION OF NET BENEFIT	MEAN OF NET BENEFIT ($ 10^6)	UPPER LIMIT [95% EXCEEDED] ($ 10^6)	LOWER LIMIT [5% EXCEEDED] ($ 10^6)
1 KRUENG JRUE	ACEH	2365	11.16	7.97	2.82	9.08	4.43	13.74
2 BT. INDRAPURA	WEST SUMATRA	2678	8.05	13.04	3.61	4.94	-1.02	10.90
3 SUNGAI MURAI	RIAU	12000	24.18	488.15	22.09	2.73	-33.73	39.18
4 BATANG ULOH	JAMBI	500	1.16	0.78	0.89	0.31	-1.15	1.77
5 BELITANG	S. SUMATRA	20600	43.7	1284.37	35.84	7.68	-51.45	66.82
6 LEMPOING	S. SUMATRA	13100	40.71	436.27	20.89	24.93	-9.53	59.40
7 TULANG BAWANG	S. SUMATRA	44500	74.92	6580.39	81.12	-4.13	-137.98	129.71
8 BUMI AGUNG	LAMPUNG	3150	5.71	19.90	4.46	0.71	-6.65	8.08
9 MESUJI II	LAMPUNG	20980	33.29	371.46	19.27	12.18	-19.62	43.98
10 BENGKENANG	BENGKULU	5000	10.64	81.39	9.02	2.28	-12.60	17.17
11 SADAWARNA	WEST JAVA	6277	22.84	83.23	9.12	15.96	0.91	31.01
12 CIBEBER	WEST JAVA	8900	25.73	212.01	14.56	16.58	-7.45	40.60
13 IRG. WEST JAVA	WEST JAVA	75000	245.4	3473.77	58.94	218.96	121.71	316.21
14 KEDU SELATAN	CENTRAL JAVA	24000	92.8	1499.46	38.72	68.39	4.50	132.29
15 BANJAREJO	CENTRAL JAVA	7750	12.88	201.72	14.20	1.05	-22.38	24.49
16 IRG. CTRL JAVA	CENTRAL JAVA	50000	165	1711.29	41.32	147.48	79.31	215.65
17 LESTI LEFT	EAST JAVA	2300	3.88	15.43	3.93	1.38	-5.10	7.87
18 WIDAS	EAST JAVA	7750	14.77	163.75	12.80	6.63	-14.48	27.74
19 IRG.EAST JAVA	EAST JAVA	75000	197.63	3025.31	55.00	172.29	81.53	263.04
20 SEBANGUN	C. KALIMANTAN	15000	9.9	749.75	27.38	-18.18	-63.36	27.00
21 BATU LICIN	S. KALIMANTAN	4640	12.4	53.89	7.34	7.75	-4.37	19.86
22 IRIGASI SULUT	N. SULAWESI	8000	7.64	184.86	13.60	-1.92	-24.35	20.52
23 PARIGI POSO	C. SULAWESI	14056	40.7	520.17	22.81	19.33	-18.30	56.96
24 SIDRANG	C. SULAWESI	3500	7.95	26.24	5.12	3.09	-5.36	11.55
25 CENRANAE	S. SULAWESI	4100	7.57	50.99	7.14	0.60	-11.18	12.38
26 KALAENA KANAN	S. SULAWESI	4748	8.7	53.04	7.28	2.12	-9.90	14.13
27 MAPPI	IRIAN JAYA	59800	43.05	9877.24	99.38	-56.78	-220.77	107.20
28 IRG. NTB	W. NUSA TGR.	2720	25.42	98.44	9.92	17.06	0.69	33.43
29 PELORA	W. NUSA TGR.	9054	33.29	283.72	16.84	18.20	-9.59	45.99
30 IRG. NTT.	E. NUSA TGR.	8530	23	214.09	14.63	11.57	-12.57	35.71

NOTE : *) SOURCE BCEOM (1989) IRRIGATION INVESTMENT STUDY

Table A.13: Summary of the Probabilistic Information of NPVB Criterion for the Potential Projects at Stage 4

PROJECTS NUMBER AND NAME	LOCATION (PROVINCE)	AREA (HA)	ORIGINAL*) NET BENEFIT ($ 10^6)	VARIANCE OF NET BENEFIT	STANDARD DEVIATION OF NET BENEFIT	MEAN OF NET BENEFIT ($ 10^6)	UPPER LIMIT [95% EXCEEDED] ($ 10^6)	LOWER LIMIT [5% EXCEEDED] ($ 10^6)
1 IRIGASI ACEH	ACEH	20000	59.8	266.77	16.33	51.59	24.64	78.54
2 IRIGASI SUMUT	N. SUMATRA	30000	94.87	480.35	21.92	85.63	49.46	121.79
3 IRG.KECIL SUMBA	W. SUMATRA	19512	51.22	860.10	29.33	20.31	-28.08	68.70
4 IRIGASI SUMBAR	W. SUMATRA	20000	62.7	240.21	15.50	56.87	31.30	82.44
5 IRG. KECIL RIAU	RIAU	1165	3.65	3.71	1.93	2.22	-0.96	5.40
6 IRG. ULAK BERAS	JAMBI	500	0.17	1.48	1.22	-0.76	-2.77	1.25
7 IRG.KECIL SUMSE	S. SUMATRA	17100	47.79	794.59	28.19	22.88	-23.64	69.39
8 RUPIT	S. SUMATRA	11000	27	235.79	15.36	10.68	-14.65	36.02
9 IRG. SUMSEL	S. SUMATRA	20000	62.14	209.41	14.47	56.16	32.28	80.04
10 AIR MALUS	S. SUMATRA	8800	20.63	204.30	14.29	5.44	-18.14	29.03
11 AIR TALANG NIU	S. SUMATRA	4500	10.6	39.05	6.25	3.97	-6.34	14.29
12 AIR LIMAU	S. SUMATRA	7000	13.8	120.56	10.98	3.77	-14.35	21.89
13 LOWER KOMERING	S. SUMATRA	22174	45.5	1270.25	35.64	9.45	-49.35	68.26
14 LOWER LEMATANG	S. SUMATRA	11070	24.88	298.41	17.27	8.46	-20.05	36.96
15 WAY TAHMI	LAMPUNG	5550	17.5	55.39	7.44	10.74	-1.54	23.02
16 WAY MESUJI II	LAMPUNG	18750	45	816.81	28.58	16.98	-30.17	64.14
17 WAY BUAYA	LAMPUNG	4880	11.2	56.42	7.51	4.77	-7.62	17.16
18 AIR SELAGAN	BENGKULU	11000	15.4	355.27	18.85	-5.63	-36.73	25.47
19 IRG. WEST JAVA	W. JAVA	65000	170.3	2408.76	49.08	151.06	70.08	232.04
20 JRAGUNG	CTRL. JAVA	12200	62	301.39	17.36	48.50	19.86	77.15
21 KEDUNGWARU	CTRL. JAVA	1330	5.2	64.17	8.01	0.68	-12.54	13.90
22 IRG. AIR TANAH	CTRL. JAVA	2320	7.1	13.27	3.64	3.79	-2.22	9.80
23 IRG. CTRL. JAV	CTRL. JAVA	80000	255	3702.22	60.85	233.33	132.94	333.73
24 BENG	EAST JAVA	3200	9.09	27.81	5.27	6.32	-2.38	15.02
25 IRG. EAST JAVA	EAST JAVA	75000	235.1	3107.04	55.74	217.12	125.15	309.10
26 BATANG ALAI	S. KALIMANTAN	6220	7.3	126.96	11.27	-3.13	-21.72	15.46
27 BARABAI	S. KALIMANTAN	2280	2.85	17.21	4.15	-1.27	-8.12	5.57
28 IRG. KECIL NTB	WEST NUSA TGR	11518	47.72	639.71	25.29	20.40	-21.33	62.14
29 BATU BULAN	WEST NUSA TGR	7000	41.5	140.73	11.86	41.50	21.93	61.07
30 IRG. C.SULAWES	C. SULAWESI	6410	12.12	144.64	12.03	0.88	-18.96	20.73
31 BILA	S. SULAWESI	24040	140.6	5621.61	74.98	78.31	-45.40	202.02
32 KUTI	IRIAN JAYA	74000	8.5	17280.24	131.45	-118.79	-335.69	98.11

NOTE : *) SOURCE BCEOM (1989) IRRIGATION INVESTMENT STUDY

Table A.14: Summary of the Probabilistic Information of NPVB Criterion for the Potential Projects at Stage 5

PROJECTS NUMBER AND NAME	LOCATION (PROVINCE)	AREA (HA)	ORIGINAL*) OF NET BENEFIT ($ 10^6)	VARIANCE OF NET BENEFIT	STANDARD DEVIATION OF NET BENEFIT	MEAN OF NET BENEFIT ($ 10^6)	UPPER LIMIT [95% EXCEEDED] ($ 10^6)	LOWER LIMIT [5% EXCEEDED] ($ 10^6)
1 IRG. ACEH	ACEH	15000	46.8	133.45	11.55	41.05	21.99	60.12
2 IRG. SUMUT	N. SUMATRA	15000	46.8	141.04	11.88	41.50	21.91	61.10
3 AMPIK PAREK	W. SUMATRA	2365	8.01	12.47	3.53	5.38	-0.45	11.20
4 PERJAYA	S. SUMATRA	21555	37	1887.62	43.45	-0.19	-71.88	71.50
5 LEMATANG	S. SUMATRA	11070	14.7	543.72	23.32	-5.97	-44.45	32.50
6 LAKITAN	S. SUMATRA	11600	19.55	508.37	22.55	1.11	-36.09	38.31
7 BATANGHARI	S. SUMATRA	13000	38.54	746.02	27.31	13.99	-31.07	59.06
8 SEKAYU LUPATAN	S. SUMATRA	8600	18.06	315.85	17.77	2.90	-26.42	32.22
9 AIR LEBAK BUNGU	S. SUMATRA	8344	18.38	287.05	16.94	4.33	-23.63	32.28
10 AIR RATAN	S. SUMATRA	13830	27.36	783.37	27.99	1.67	-44.51	47.85
11 WAY HITAM	S. SUMATRA	5705	10.39	116.20	10.78	0.95	-16.84	18.74
12 BELITANG	S. SUMATRA	8750	12.98	285.68	16.90	-0.93	-28.82	26.96
13 WAY SAKA	LAMPUNG	12600	66.44	1000.96	31.64	37.78	-14.42	89.99
14 WAY MESUJI III	LAMPUNG	15820	89.74	6900.39	83.07	14.61	-122.45	151.68
15 BUNGIN TAMBUN	BENGKULU	8000	17.53	207.18	14.39	3.95	-19.80	27.70
16 MAYA	WEST JAVA	2900	10.1	835.66	28.91	-13.52	-61.21	34.18
17 TELAGA HERANG	WEST JAVA	7700	8.8	452.07	21.26	-6.61	-41.69	28.48
18 CIMULYA	WEST JAVA	8350	27.4	183.74	13.56	18.63	-3.74	41.00
19 CINIRU	WEST JAVA	2976	7.46	23.32	4.83	4.87	-3.10	12.84
20 GUNUNG WULAN	CTRL. JAVA	21838	213.15	5127.16	71.60	164.39	46.24	282.54
21 GLAPAN	CTRL. JAVA	19050	38.1	1112.89	33.36	19.85	-35.19	74.89
22 IRG. AIR TANAH	EAST JAVA	4300	11.71	58.87	7.67	7.92	-4.74	20.58
23 IRG. EAST JAVA	EAST JAVA	30000	103.65	554.70	23.55	95.53	56.67	134.39
24 AMANDIT	S. KALIMANTAN	6430	17.2	91.43	9.56	8.72	-7.05	24.50
25 TAPIN	S. KALIMANTAN	5330	10	79.10	8.89	1.64	-13.04	16.31
26 CTRL. SULAWESI	CTRL SULAWESI	6087	14.78	90.21	9.50	7.14	-8.53	22.81
27 MALUSO	S. SULAWESI	11106	23.72	371.51	19.27	7.32	-24.49	39.12
28 LANGKONE	S. SULAWESI	16398	40.74	765.25	27.66	18.36	-27.28	64.01
29 WALANE	S. SULAWESI	26000	145.08	3142.72	56.06	106.60	14.10	199.10
30 PADANGENG	S. SULAWESI	4200	10.61	49.28	7.02	4.93	-6.65	16.51
31 KIAS	IRIAN JAYA	66000	47.38	9914.66	99.57	-53.46	-217.75	110.84
32 IRG.KECIL NTB	WEST NUSA TGR	12040	102.19	426.87	20.66	92.87	58.78	126.96
33 PELA PERADO	WEST NUSA TGR	7000	18.7	160.84	12.68	9.01	-11.92	29.94

NOTE : *) SOURCE BCEOM (1989) IRRIGATION INVESTMENT STUDY

Table A.15: Transformation Probabilities of the SDP Model for Scenario 1 (Limited Budget)

$(p_k(F_t^l))^\gamma = \mathcal{F}(t, L_t^i, PF_t^m, D_t^k) \Rightarrow p(F_{t,i,m,k}^l)^\gamma = \mathcal{F}(t, L_t^i, PF_t^m, D_t^k)$ γ=Limited Budget Scenario

For: $t = 2$; $i = 1, 2$; $m = 1, .., N_{PF_{2,i}}$ for $N_{PF_{2,i}} = 5$ $k = 1, .., N_{D_{2,i,m}}$ for $N_{D_{2,i,m}} = 5$; and $l = 1, .., N_{F_{2,i,m}}$ for $N_{F_{2,i,m}} = 5$

$L_2^{i,m}$ $(i = 1)$						$L_2^{i,m}$ $(i = 2)$					
	$l = 1, ..., N_{F_{2,i,m}} = 5$						$l = 1, ..., N_{F_{2,i,m}} = 5$				
$p(F_{t,i,m,k}^l)$	$l = 1$	$l = 2$	$l = 3$	$l = 4$	$l = 5$	$p(F_{t,i,m,k}^l)$	$l = 1$	$l = 2$	$l = 3$	$l = 4$	$l = 5$
$p(F_{2,1,1,1}^l) =$	0.01	0.01	0.15	0.33	0.50	$p(F_{2,2,1,1}^l) =$	0.01	0.01	0.15	0.34	0.49
$p(F_{2,1,1,2}^l) =$	0.01	0.01	0.15	0.34	0.49	$p(F_{2,2,1,2}^l) =$	0.01	0.01	0.15	0.35	0.48
$p(F_{2,1,1,3}^l) =$	0.01	0.01	0.15	0.35	0.48	$p(F_{2,2,1,3}^l) =$	0.01	0.01	0.15	0.36	0.47
$p(F_{2,1,1,4}^l) =$	0.01	0.01	0.15	0.36	0.47	$p(F_{2,2,1,4}^l) =$	0.01	0.01	0.15	0.37	0.46
$p(F_{2,1,1,5}^l) =$	0.01	0.01	0.15	0.37	0.46	$p(F_{2,2,1,5}^l) =$	0.01	0.01	0.15	0.38	0.45
$p(F_{2,1,2,1}^l) =$	0.01	0.01	0.15	0.34	0.49	$p(F_{2,2,1,1}^l) =$	0.01	0.01	0.15	0.35	0.48
$p(F_{2,1,2,2}^l) =$	0.01	0.01	0.15	0.35	0.48	$p(F_{2,2,1,2}^l) =$	0.01	0.01	0.15	0.36	0.47
$p(F_{2,1,2,3}^l) =$	0.01	0.01	0.15	0.36	0.47	$p(F_{2,2,1,3}^l) =$	0.01	0.01	0.15	0.37	0.46
$p(F_{2,1,2,4}^l) =$	0.01	0.01	0.15	0.37	0.46	$p(F_{2,2,1,4}^l) =$	0.01	0.01	0.15	0.38	0.45
$p(F_{2,1,2,5}^l) =$	0.01	0.01	0.15	0.37	0.46	$p(F_{2,2,1,5}^l) =$	0.01	0.01	0.15	0.39	0.44
$p(F_{2,1,3,1}^l) =$	0.01	0.01	0.15	0.35	0.48	$p(F_{2,2,1,1}^l) =$	0.01	0.01	0.15	0.36	0.47
$p(F_{2,1,3,2}^l) =$	0.01	0.01	0.15	0.36	0.47	$p(F_{2,2,1,2}^l) =$	0.01	0.01	0.15	0.37	0.46
$p(F_{2,1,3,3}^l) =$	0.01	0.01	0.15	0.37	0.46	$p(F_{2,2,1,3}^l) =$	0.01	0.01	0.15	0.38	0.45
$p(F_{2,1,3,4}^l) =$	0.01	0.01	0.15	0.38	0.45	$p(F_{2,2,1,4}^l) =$	0.01	0.01	0.15	0.39	0.44
$p(F_{2,1,3,5}^l) =$	0.01	0.01	0.15	0.39	0.44	$p(F_{2,2,1,5}^l) =$	0.01	0.01	0.15	0.40	0.43
$p(F_{2,1,4,1}^l) =$	0.01	0.01	0.15	0.36	0.47	$p(F_{2,2,1,1}^l) =$	0.01	0.01	0.15	0.37	0.46
$p(F_{2,1,4,2}^l) =$	0.01	0.01	0.15	0.37	0.46	$p(F_{2,2,1,2}^l) =$	0.01	0.01	0.15	0.38	0.45
$p(F_{2,1,4,3}^l) =$	0.01	0.01	0.15	0.38	0.45	$p(F_{2,2,1,3}^l) =$	0.01	0.01	0.15	0.39	0.44
$p(F_{2,1,4,4}^l) =$	0.01	0.01	0.15	0.39	0.44	$p(F_{2,2,1,4}^l) =$	0.01	0.01	0.15	0.40	0.43
$p(F_{2,1,4,5}^l) =$	0.01	0.01	0.15	0.40	0.43	$p(F_{2,2,1,5}^l) =$	0.01	0.01	0.15	0.41	0.42
$p(F_{2,1,5,1}^l) =$	0.01	0.01	0.15	0.37	0.46	$p(F_{2,2,1,1}^l) =$	0.01	0.01	0.15	0.38	0.45
$p(F_{2,1,5,2}^l) =$	0.01	0.01	0.15	0.38	0.45	$p(F_{2,2,1,2}^l) =$	0.01	0.01	0.15	0.39	0.44
$p(F_{2,1,5,3}^l) =$	0.01	0.01	0.15	0.39	0.44	$p(F_{2,2,1,3}^l) =$	0.01	0.01	0.15	0.40	0.43
$p(F_{2,1,5,4}^l) =$	0.01	0.01	0.15	0.40	0.43	$p(F_{2,2,1,4}^l) =$	0.01	0.01	0.15	0.41	0.42
$p(F_{2,1,5,5}^l) =$	0.01	0.01	0.15	0.41	0.42	$p(F_{2,2,1,5}^l) =$	0.01	0.01	0.15	0.42	0.41

Table A.16: Transformation Probabilities of SDP Model for Scenario 2 (Non-Limited Budget)

$(p_k(F_t^l))^\gamma = \mathcal{F}(t, L_t^i, PF_t^m, D_t^k) \Rightarrow p(F^l_{t,i,m,k})^\gamma = \mathcal{F}(t, L_t^i, PF_t^m, D_t^k)$ γ=Non-Limited Budget Scenario											
For: $t = 2$; $i = 1, 2$; $m = 1, .., N_{PF_{2,i}}$ for $N_{PF_{2,i}} = 5$ $k = 1, .., N_{D_{2,i,m}}$ for $N_{D_{2,i,m}} = 5$; and $l = 1, .., N_{F_{2,i,m}}$ for $N_{F_{2,i,m}} = 5$											
$L_2^{i,m}$ $(i = 1)$						$L_2^{i,m}$ $(i = 2)$					
	$l = 1, ..., N_{F_{t,i,m}} = 5$						$l = 1, ..., N_{Ft,i,m} = 5$				
$p(F^l_{t,i,m,k})$	$l = 1$	$l = 2$	$l = 3$	$l = 4$	$l = 5$	$p(F^l_{t,i,m,k})$	$l = 1$	$l = 2$	$l = 3$	$l = 4$	$l = 5$
$p(F^l_{2,1,1,1}) =$	0.40	0.30	0.15	0.10	0.05	$p(F^l_{2,2,1,1}) =$	0.41	0.29	0.15	0.10	0.05
$p(F^l_{2,1,1,2}) =$	0.41	0.29	0.15	0.10	0.05	$p(F^l_{2,2,1,2}) =$	0.42	0.28	0.15	0.10	0.05
$p(F^l_{2,1,1,3}) =$	0.42	0.28	0.15	0.10	0.05	$p(F^l_{2,2,1,3}) =$	0.43	0.27	0.15	0.10	0.05
$p(F^l_{2,1,1,4}) =$	0.43	0.27	0.15	0.10	0.05	$p(F^l_{2,2,1,4}) =$	0.44	0.26	0.15	0.10	0.05
$p(F^l_{2,1,1,5}) =$	0.44	0.26	0.15	0.10	0.05	$p(F^l_{2,2,1,5}) =$	0.45	0.25	0.15	0.10	0.05
$p(F^l_{2,1,2,1}) =$	0.41	0.29	0.15	0.10	0.05	$p(F^l_{2,2,1,1}) =$	0.42	0.28	0.15	0.10	0.05
$p(F^l_{2,1,2,2}) =$	0.42	0.28	0.15	0.10	0.05	$p(F^l_{2,2,1,2}) =$	0.43	0.27	0.15	0.10	0.05
$p(F^l_{2,1,2,3}) =$	0.43	0.27	0.15	0.10	0.05	$p(F^l_{2,2,1,3}) =$	0.44	0.26	0.15	0.10	0.05
$p(F^l_{2,1,2,4}) =$	0.44	0.26	0.15	0.10	0.05	$p(F^l_{2,2,1,4}) =$	0.45	0.25	0.15	0.10	0.05
$p(F^l_{2,1,2,5}) =$	0.45	0.25	0.15	0.10	0.05	$p(F^l_{2,2,1,5}) =$	0.46	0.24	0.15	0.10	0.05
$p(F^l_{2,1,3,1}) =$	0.42	0.28	0.15	0.10	0.05	$p(F^l_{2,2,1,1}) =$	0.43	0.27	0.15	0.10	0.05
$p(F^l_{2,1,3,2}) =$	0.43	0.27	0.15	0.10	0.05	$p(F^l_{2,2,1,2}) =$	0.44	0.26	0.15	0.10	0.05
$p(F^l_{2,1,3,3}) =$	0.44	0.26	0.15	0.10	0.05	$p(F^l_{2,2,1,3}) =$	0.45	0.25	0.15	0.10	0.05
$p(F^l_{2,1,3,4}) =$	0.45	0.25	0.15	0.10	0.05	$p(F^l_{2,2,1,4}) =$	0.46	0.24	0.15	0.10	0.05
$p(F^l_{2,1,3,5}) =$	0.46	0.24	0.15	0.10	0.05	$p(F^l_{2,2,1,5}) =$	0.47	0.23	0.15	0.10	0.05
$p(F^l_{2,1,4,1}) =$	0.43	0.27	0.15	0.10	0.05	$p(F^l_{2,2,1,1}) =$	0.44	0.26	0.15	0.10	0.05
$p(F^l_{2,1,4,2}) =$	0.44	0.26	0.15	0.10	0.05	$p(F^l_{2,2,1,2}) =$	0.45	0.25	0.15	0.10	0.05
$p(F^l_{2,1,4,3}) =$	0.45	0.25	0.15	0.10	0.05	$p(F^l_{2,2,1,3}) =$	0.46	0.24	0.15	0.10	0.05
$p(F^l_{2,1,4,4}) =$	0.46	0.24	0.15	0.10	0.05	$p(F^l_{2,2,1,4}) =$	0.47	0.23	0.15	0.10	0.05
$p(F^l_{2,1,4,5}) =$	0.47	0.23	0.15	0.10	0.05	$p(F^l_{2,2,1,5}) =$	0.48	0.22	0.15	0.10	0.05
$p(F^l_{2,1,5,1}) =$	0.44	0.26	0.15	0.10	0.05	$p(F^l_{2,2,1,1}) =$	0.45	0.25	0.15	0.10	0.05
$p(F^l_{2,1,5,2}) =$	0.45	0.25	0.15	0.10	0.05	$p(F^l_{2,2,1,2}) =$	0.46	0.24	0.15	0.10	0.05
$p(F^l_{2,1,5,3}) =$	0.46	0.24	0.15	0.10	0.05	$p(F^l_{2,2,1,3}) =$	0.47	0.23	0.15	0.10	0.05
$p(F^l_{2,1,5,4}) =$	0.47	0.23	0.15	0.10	0.05	$p(F^l_{2,2,1,4}) =$	0.48	0.22	0.15	0.10	0.05
$p(F^l_{2,1,5,5}) =$	0.48	0.22	0.15	0.10	0.05	$p(F^l_{2,2,1,5}) =$	0.49	0.21	0.15	0.10	0.05

Table A.17: Transformation Probabilities of SDP Model for Scenario 3 (Undetermined Budget)

$(p_k(F^l_t))^\gamma = \mathcal{F}(t, L^i_t, PF^m_t, D^k_t) \Rightarrow p(F^l_{t,i,m,k})^\gamma = \mathcal{F}(t, L^i_t, PF^m_t, D^k_t)$ γ= Undetermined Budget Scenario

For: $n = 2$; $i = 1, 2$; $m = 1, .., N_{PF_{2,i}}$ for $N_{PF_{2,i}} = 5$ $k = 1, .., N_{D_{2,i,m}}$ for $N_{D_{2,i,m}} = 5$; and $l = 1, .., N_{F_{2,i,m}}$ for $N_{F_{2,i,m}} = 5$

$L_2^{i,m}$ $(i = 1)$						$L_2^{i,m}$ $(i = 2)$					
	$l = 1, ..., N_{F_{2,i,m}} = 5$						$l = 1, ..., N_{F_{2,i,m}} = 5$				
$p(F^l_{t,i,m,k})$	$l = 1$	$l = 2$	$l = 3$	$l = 4$	$l = 5$	$p(F^l_{t,i,m,k})$	$l = 1$	$l = 2$	$l = 3$	$l = 4$	$l = 5$
$p(F^l_{2,1,1,1}) =$	0.01	0.01	0.15	0.33	0.50	$p(F^l_{2,2,1,1}) =$	0.01	0.01	0.15	0.34	0.49
$p(F^l_{2,1,1,2}) =$	0.01	0.20	0.25	0.20	0.34	$p(F^l_{2,2,1,2}) =$	0.01	0.20	0.25	0.21	0.33
$p(F^l_{2,1,1,3}) =$	0.01	0.20	0.25	0.20	0.34	$p(F^l_{2,2,1,3}) =$	0.01	0.20	0.25	0.21	0.33
$p(F^l_{2,1,1,4}) =$	0.01	0.20	0.25	0.20	0.34	$p(F^l_{2,2,1,4}) =$	0.01	0.20	0.25	0.21	0.33
$p(F^l_{2,1,1,5}) =$	0.01	0.01	0.15	0.37	0.46	$p(F^l_{2,2,1,5}) =$	0.01	0.01	0.15	0.38	0.45
$p(F^l_{2,1,2,1}) =$	0.01	0.01	0.15	0.34	0.49	$p(F^l_{2,2,1,1}) =$	0.01	0.01	0.15	0.35	0.48
$p(F^l_{2,1,2,2}) =$	0.01	0.20	0.25	0.21	0.33	$p(F^l_{2,2,1,2}) =$	0.01	0.20	0.25	0.22	0.32
$p(F^l_{2,1,2,3}) =$	0.01	0.20	0.25	0.21	0.33	$p(F^l_{2,2,1,3}) =$	0.01	0.20	0.25	0.22	0.32
$p(F^l_{2,1,2,4}) =$	0.01	0.20	0.25	0.21	0.33	$p(F^l_{2,2,1,4}) =$	0.01	0.20	0.25	0.22	0.32
$p(F^l_{2,1,2,5}) =$	0.01	0.01	0.15	0.38	0.45	$p(F^l_{2,2,1,5}) =$	0.01	0.01	0.15	0.39	0.44
$p(F^l_{2,1,3,1}) =$	0.01	0.01	0.15	0.35	0.48	$p(F^l_{2,2,1,1}) =$	0.01	0.01	0.15	0.36	0.47
$p(F^l_{2,1,3,2}) =$	0.01	0.20	0.25	0.22	0.32	$p(F^l_{2,2,1,2}) =$	0.01	0.20	0.25	0.23	0.31
$p(F^l_{2,1,3,3}) =$	0.01	0.20	0.25	0.22	0.32	$p(F^l_{2,2,1,3}) =$	0.01	0.20	0.25	0.23	0.31
$p(F^l_{2,1,3,4}) =$	0.01	0.20	0.25	0.22	0.32	$p(F^l_{2,2,1,4}) =$	0.01	0.20	0.25	0.23	0.31
$p(F^l_{2,1,4,5}) =$	0.01	0.01	0.15	0.39	0.44	$p(F^l_{2,2,1,5}) =$	0.01	0.01	0.15	0.40	0.43
$p(F^l_{2,1,4,1}) =$	0.01	0.01	0.15	0.36	0.47	$p(F^l_{2,2,1,1}) =$	0.01	0.01	0.15	0.37	0.46
$p(F^l_{2,1,4,2}) =$	0.01	0.20	0.25	0.23	0.31	$p(F^l_{2,2,1,2}) =$	0.01	0.20	0.25	0.24	0.30
$p(F^l_{2,1,4,3}) =$	0.01	0.20	0.25	0.23	0.31	$p(F^l_{2,2,1,3}) =$	0.01	0.20	0.25	0.24	0.30
$p(F^l_{2,1,4,4}) =$	0.01	0.20	0.25	0.23	0.31	$p(F^l_{2,2,1,4}) =$	0.01	0.20	0.25	0.24	0.30
$p(F^l_{2,1,4,5}) =$	0.01	0.01	0.15	0.40	0.43	$p(F^l_{2,2,1,5}) =$	0.01	0.01	0.15	0.41	0.42
$p(F^l_{2,1,5,1}) =$	0.01	0.01	0.15	0.37	0.46	$p(F^l_{2,2,1,1}) =$	0.01	0.01	0.15	0.38	0.45
$p(F^l_{2,1,5,2}) =$	0.01	0.20	0.25	0.24	0.30	$p(F^l_{2,2,1,2}) =$	0.01	0.20	0.25	0.25	0.29
$p(F^l_{2,1,5,3}) =$	0.01	0.20	0.25	0.24	0.30	$p(F^l_{2,2,1,3}) =$	0.01	0.20	0.25	0.25	0.29
$p(F^l_{2,1,5,4}) =$	0.01	0.20	0.25	0.24	0.30	$p(F^l_{2,2,1,4}) =$	0.01	0.20	0.25	0.25	0.29
$p(F^l_{2,1,5,5}) =$	0.01	0.01	0.15	0.41	0.42	$p(F^l_{2,2,1,5}) =$	0.01	0.01	0.15	0.42	0.41

Table A.18: Results of the Calculation of Each Step of the AHP Method for the Determination of the Likelihood of Future Budget Availability

TABLE A.18-1 PAIRWISE COMPARISON MATRIX FOR CONTRIBUTION OF PRIMARY FACTORS THAT AFFECT FUTURE BUDGET AVAILABILITY

Future Budget	F1	F2	F3	Weight
F1 = World Oil Price	1	3/2	5	0.540
F2 = Non-oil Revenue	2/3	1	3	0.350
F3 = External Funding	1/5	1/3	1	0.110

Max eigenvalue = 3.001
Consistency Index=0.0006
Consistency Ratio=0.001

TABLE A.18-2 PAIRWISE COMPARISON MATRIX FOR CONTRIBUTION OF WORLD OIL PRICE SUBFACTORS WITH RESPECT TO WORLD OIL PRICE

World Oil Price	W1	W2	W3	W4	Weight
W1 = World Oil Consumption	1	5	5	1	0.414
W2 = Alternative Fuels	1/5	1	3	1/5	0.109
W3 = Influence of Financial Institution	1/5	1/3	1	1/5	0.063
W4 = Political Factors	1	5	5	1	0.414

Max eigenvalue = 4.15
Consistency Index=0.051
Consistency Ratio=0.057

TABLE A.18-3 PAIRWISE COMPARISON MATRIX FOR LEVEL OF INTENSITY OF EACH SUBFACTOR WITH RESPECT TO ITS ASSOCIATED SUBFACTORS

SUB-FACTORS	LEVEL OF INTENSITY	LEVEL OF INTENSITY L(W1)	M(W1)	H(W1)	WEIGHT	CONSISTENCY CHECKING
W1	L = Low	1	1/7	1/7	0.066	Max eigenvalue= 3
	M = Medium	7	1	1	0.467	CI = 0
	H = High	7	1	1	0.467	CR = 0
		L(W2)	M(W2)	H(W2)		
W2	L = Low	1	1/7	1/7	0.067	Max eigenvalue= 3
	M = Medium	7	1	1	0.466	CI = 0
	H = High	7	1	1	0.467	CR = 0
		LF(W2)	SQ(W2)	MF(W2)		
W3	LF = Less Favorable	1	1/3	1	0.200	Max eigenvalue= 3
	SQ = Status Quo	3	1	1	0.600	CI = 0
	MF = Most Favorable	1	1	1	0.200	CR = 0

Note:
W1 = World Oil Consumption Growth
W2 = Intensity of Development Alternative Fuels
W3 = Inlfuence of International Instutions

TABLE A.18-4 PAIRWISE COMPARISON MATRIX FOR CONTRIBUTION OF EACH SUB-SUBFACTOR OF POLITICAL SUBFACTOR OF WORLD OIL PRICE

SUB-FACTORS	SUB-SUBFACTOR	SUB-SUBFACTOR L(W1)	M(W1)	WEIGHT	CONSISTENCY CHECKING
W4	P1 = Opec Pricing Behaviour	1	3/2	0.60	Max eigenvalue= 2 CI = 0
	P2 = Tension Between Individual State	2/3	1	0.40	CR = 0

Note:
W4 = Political Factors

TABLE A.18-5 PAIRWISE COMPARISON MATRIX FOR LEVEL OF INTENSITY OF EACH SUB-SUBFACTOR WITH RESPECT TO ITS ASSOCIATED POLITICAL SUB-SUBFACTORS

SUB-SUB FACTORS	LEVEL OF INTENSITY	LEVEL OF INTENSITY D(P1)	SQ(W1)	I(W1)	WEIGHT	CONSISTENCY CHECKING
P1	D = Decrease	1	1/3	1/5	0.0114	Max eigenvalue= 3.029
	SQ = Status Quo	3	1	1	0.4050	CI = 0.014
	I = Increase	5	1	1	0.4810	CR = 0.025
		D(P2)	SQ(P2)	I(P2)		
P2	D = Decrease	1	1/5	1/3	0.1140	Max eigenvalue= 3.029
	SQ = Status Quo	5	1	1	0.4810	CI = 0.0145
	I = Intensity	3	1	1	0.4050	CR = 0.0250

Note:
P1 = OPEC Pricing Behaviour Sub-subfactor
P2 = Tension Between Individual State Sub-subfactor

TABLE A.18-6 PAIRWISE COMPARISON MATRIX FOR LEVEL OF INCREASES OF EACH LEVEL OF INTENSITY WITH RESPECT TO ITS ASSOCIATED LEVEL OF INTENSITY

LEVEL OF INTENSITY	LEVEL OF INCREASES	LEVEL OF INCREASES L(F1)	M(F1)	H(F1)	WEIGHT	CONSISTENCY CHECKING
L(W1)	L(F1)= Low Increase of F1	1	5	7	0.740	Max eigenvalue= 3.014
	M(F1)= Medium Increase of F1	1/5	1	2	0.167	CI = 0.007
	H(F1)= High Increase of F1	1/7	1/2	1	0.094	CR = 0.012
M(W1)	L(F1)= Low Increase of F1	1	1/7	1/5	0.075	Max eigenvalue= 3.014
	M(F1)= Medium Increase of F1	7	1	2	0.592	CI = 0.007
	H(F1)= High Increase of F1	5	1/2	1	0.333	CR = 0.012
H(W1)	L(F1)= Low Increase of F1	1	1/7	1/5	0.075	Max eigenvalue= 3.014
	M(F1)= Medium Increase of F1	7	1	1/2	0.333	CI = 0.007
	H(F1)= High Increase of F1	5	2	1	0.592	CR = 0.012
L(W2)	L(F1)= Low Increase of F1	1	1/5	1/5	0.090	Max eigenvalue= 3.018
	M(F1)= Medium Increase of F1	5	1	2/3	0.394	CI = 0.009
	H(F1)= High Increase of F1	5	3/2	1	0.516	CR = 0.016
M(W2)	L(F1)= Low Increase of F1	1	1/3	2	0.230	Max eigenvalue= 3.003
	M(F1)= Medium Increase of F1	3	1	5	0.648	CI = 0.0018
	H(F1)= High Increase of F1	1/2	1/5	1	0.122	CR = 0.003
H(W2)	L(F1)= Low Increase of F1	1	3	5	0.637	Max eigenvalue= 3.038
	M(F1)= Medium Increase of F1	1/3	1	3	0.258	CI = 0.019
	H(F1)= High Increase of F1	1/5	1/3	1	0.105	CR = 0.033
LF(W3)	L(F1)= Low Increase of F1	1	3	5	0.648	Max eigenvalue= 3.004
	M(F1)= Medium Increase of F1	1/3	1	2	0.230	CI = 0.0018
	H(F1)= High Increase of F1	1/5	1/2	1	0.122	CR = 0.003
SQ(W3)	L(F1)= Low Increase of F1	1	1/7	1/3	0.088	Max eigenvalue= 3.007
	M(F1)= Medium Increase of F1	7	1	3	0.669	CI = 0.003
	H(F1)= High Increase of F1	3	1/3	1	0.242	CR = 0.006
MF(W3)	L(F1)= Low Increase of F1	1	1/3	1/5	0.109	Max eigenvalue= 3.009
	M(F1)= Medium Increase of F1	3	1	1/2	0.309	CI = 0.0018
	H(F1)= High Increase of F1	5	2	1	0.582	CR = 0.0031
D(P1)	L(F1)= Low Increase of F1	1	3	5	0.637	Max eigenvalue= 3.038
	M(F1)= Medium Increase of F1	1/3	1	3	0.258	CI = 0.019
	H(F1)= High Increase of F1	1/5	1/3	1	0.105	CR = 0.033
SQ(P1)	L(F1)= Low Increase of F1	1	2	1/2	0.122	Max eigenvalue= 3.003
	M(F1)= Medium Increase of F1	1/2	1	3	0.648	CI = 0.0018
	H(F1)= High Increase of F1	2	1/3	1	0.230	CR = 0.0031
I(P1)	L(F1)= Low Increase of F1	1	1/3	1/5	0.105	Max eigenvalue= 3.038
	M(F1)= Medium Increase of F1	3	1	1/3	0.258	CI = 0.019
	H(F1)= High Increase of F1	5	3	1	0.637	CR = 0.033
D(P2)	L(F1)= Low Increase of F1	1	5	7	0.731	Max eigenvalue= 3.065
	M(F1)= Medium Increase of F1	1/5	1	3	0.188	CI = 0.032
	H(F1)= High Increase of F1	1/7	1/3	1	0.081	CR = 0.056
SQ(P2)	L(F1)= Low Increase of F1	1	1/3	3	0.258	Max eigenvalue= 3.038
	M(F1)= Medium Increase of F1	3	1	5	0.637	CI = 0.019
	H(F1)= High Increase of F1	1/3	1/5	1	0.105	CR = 0.033
I(P2)	L(F1)= Low Increase of F1	1	1/3	1/5	0.112	Max eigenvalue= 3.000
	M(F1)= Medium Increase of F1	3	1	2/3	0.348	CI = 0.0006
	H(F1)= High Increase of F1	5	3/2	1	0.540	CR = 0.001

TABLE A.18-7 PAIRWISE COMPARISON MATRIX FOR LEVEL OF INCREASES OF NON-OIL REVENUE AND EXTERNAL FUNDING FACTORS

FACTORS	LEVEL OF INCREASES	LEVEL OF INCREASES L(F2)	M(F2)	H(F2)	WEIGHT	CONSISTENCY CHECKING
F2	L(F2)= Low Increase of F2	1	1/5	1/3	0.105	Max eigenvalue= 3.038
	M(F2)= Medium Increase of F2	5	1	3	0.637	CI = 0.019
	H(F2)= High Increase of F2	3	1/3	1	0.258	CR = 0.033
		D(F3)	SQ(F3)	I(F3)		
F3	D(F3)= Decrease of F3	1	1	2	0.387	Max eigenvalue= 3.018
	SQ(F3)= Status Quo of F3	1	1	3	0.443	CI = 0.009
	I(F3)= Increase of F3	1/2	1/3	1	0.170	CR = 0.016

Note:
F2 = Non-oil Revenue Factor
F3 = External Funding Factor

TABLE A.18-8 PAIRWISE COMPARISON MATRIX FOR THE SCENARIO OF FUTURE BUDGET AVAILABILITY NON-OIL REVENUE AND EXTERNAL FUNDING FACTORS

LEVEL OF INCREASES OF PRIMARY FACTORS	ALTENATIVES OF SCENARIO OF FUTURE BUDGET AVAILABILITY	BUDGET SCENARIOS LB	NLB	UDB	WEIGHT	CONSISTENCY CHECKING
L(F1)= LOW INCREASE OF F1	LB = LIMITED BUDGET	1	9	5	0.751	Max eigenvalue= 3.029
	NLB = NON-LIMITED BUDGET	1/9	1	1/3	0.070	CI = 0.0145
	UDB = UNDETERMINED BUDGET	1/5	3	1	0.178	CR = 0.025
M(F1)= MEDIUM INCREASE OF F1	LB = LIMITED BUDGET	1	5	1/2	0.333	Max eigenvalue= 3.014
	NLB = NON-LIMITED BUDGET	1/5	1	1/7	0.075	CI = 0.007
	UDB = UNDETERMINED BUDGET	2	7	1	0.591	CR = 0.012
H(F1)= HIGH INCREASE OF F1	LB = LIMITED BUDGET	1	3	1/5	0.188	Max eigenvalue= 3.065
	NLB = NON-LIMITED BUDGET	1/3	1	1/9	0.081	CI = 0.032
	UDB = UNDETERMINED BUDGET	5	9	1	0.731	CR = 0.056
L(F2)= LOW INCREASE OF F2	LB = LIMITED BUDGET	1	9	5	0.751	Max eigenvalue= 3.029
	NLB = NON-LIMITED BUDGET	1/9	1	1/3	0.071	CI = 0.0145
	UDB = UNDETERMINED BUDGET	1/5	3	1	0.178	CR = 0.025
M(F2)= MEDIUM INCREASE OF F2	LB = LIMITED BUDGET	1	5	2	0.559	Max eigenvalue= 3.054
	NLB = NON-LIMITED BUDGET	1/5	1	1/5	0.089	CI = 0.027
	UDB = UNDETERMINED BUDGET	1/2	5	1	0.352	CR = 0.046
H(F2)= HIGH INCREASE OF F2	LB = LIMITED BUDGET	1	3	1/3	0.258	Max eigenvalue= 3.038
	NLB = NON-LIMITED BUDGET	1/3	1	1/2	0.105	CI = 0.019
	UDB = UNDETERMINED BUDGET	3	5	1	0.637	CR = 0.033
D(F3)= DECREASE OF F3	LB = LIMITED BUDGET	1	9	3	0.692	Max eigenvalue= 3.000
	NLB = NON-LIMITED BUDGET	1/9	1	1/3	0.077	CI = 0.0
	UDB = UNDETERMINED BUDGET	1/3	3	1	0.231	CR = 0.0
SQ(F3)= STATUS QUO OF F3	LB = LIMITED BUDGET	1	7	2	0.615	Max eigenvalue= 3.002
	NLB = NON-LIMITED BUDGET	1/7	1	1/3	0.093	CI = 0.001
	UDB = UNDETERMINED BUDGET	1/2	3	1	0.292	CR = 0.002
I(F3)= INCREASES OF F3	LB = LIMITED BUDGET	1	3	1/3	0.231	Max eigenvalue= 3.000
	NLB = NON-LIMITED BUDGET	1/3	1	1/9	0.077	CI = 0.00
	UDB = UNDETERMINED BUDGET	3	9	1	0.692	CR = 0.00

TABLE A.18-9 SUMMARY OF WEIGHTS AND COMPOSITE WEIGHTS FOR PRIMARY FACTORS, SUFACTORS, LEVELS OF INTENSITY, AND LEVELS INCREASES

PRIMARY FACTORS INDEX	WEIGHTS	SUBFACTORS INDEX	WEIGHTS	COMPOSITE WEIGHTS	LEVEL OF INTENSITY INDEX	WEIGHTS	COMPOSITE WEIGHTS	LEVEL OF INCREASES INDEX	WEIGHTS	COMPOSITE WEIGHTS
F1	0.54	W1	0.414	0.224	L(W1)	0.066	0.015	L	0.740	0.0111
								M	0.167	0.0025
								H	0.094	0.0014
					M(W1)	0.467	0.105	L	0.075	0.0079
								M	0.592	0.0622
								H	0.333	0.0349
					H(W1)	0.467	0.104	L	0.075	0.0078
								M	0.333	0.0346
								H	0.592	0.0616
		W2	0.109	0.058	L(W2)	0.066	0.004	L	0.090	0.0004
								M	0.394	0.0015
								H	0.516	0.0021
					M(W2)	0.467	0.027	L	0.230	0.0062
								M	0.648	0.0175
								H	0.122	0.0033
					H(W2)	0.467	0.027	L	0.637	0.0172
								M	0.258	0.0070
								H	0.105	0.0028
		W3	0.063	0.034	LF(W3)	0.200	0.007	L	0.648	0.0046
								M	0.230	0.0016
								H	0.122	0.0008
					SQ(W3)	0.600	0.020	L	0.088	0.0018
								M	0.669	0.0134
								H	0.242	0.0048
					MF(W3)	0.200	0.007	L	0.109	0.0007
								M	0.309	0.0022
								H	0.582	0.0041
W4 (SUB-FACTOR)	0.224	P1	0.60	0.134	D(P1)	0.114	0.015	L(P1)	0.637	0.0096
								M(P1)	0.258	0.0039
								H(P1)	0.105	0.0015
					SQ(P1)	0.405	0.054	L(P1)	0.122	0.0066
								M(P1)	0.648	0.0350
								H(P1)	0.230	0.0124
					I(P1)	0.481	0.065	L(P1)	0.105	0.0068
								M(P1)	0.258	0.0168
								H(P1)	0.637	0.0414
		P2	0.40	0.090	D(P2)	0.114	0.010	L(P2)	0.731	0.0073
								M(P2)	0.188	0.0019
								H(P2)	0.081	0.0008
					SQ(P2)	0.481	0.043	L(P2)	0.258	0.0111
								M(P2)	0.637	0.0274
								H(P2)	0.105	0.0045
					I(P2)	0.405	0.037	L(P2)	0.112	0.0040
								M(P2)	0.348	0.0125
								H(P2)	0.540	0.0915
							TOTAL WEIGHTS (F1):			
									L(F1) =	0.1041
									M(F1) =	0.2400
									H(F1) =	0.1959
F2	0.350	-	-	-	-	-	-	L(F2)	0.105	0.0367
								M(F2)	0.637	0.2230
								H(F2)	0.258	0.0903
F3	0.110	-	-	-	-	-	-	L(F3)	0.387	0.0426
								M(F3)	0.443	0.0487
								H(F)	0.170	0.0187

TABLE A.18-10 COMPOSITE WEIGHTS FOR THE SCENARIO OF FUTURE BUDGET AVAILABILITY

PRIMARY FACTORS	LEVELS OF INCREASE INDEX	LEVELS OF INCREASE WEIGHTS	SCENARIOS OF BUDGET INDEX	SCENARIOS OF BUDGET WEIGHTS	COMPOSITE WEIGHTS
F1	L(F1)	0.1041	LMB	0.751	0.0782
			NLB	0.071	0.0073
			UDB	0.178	0.0186
	M(F1)	0.2400	LMB	0.333	0.0799
			NLB	0.076	0.0182
			UDB	0.591	0.1419
	H(F1)	0.1959	LMB	0.188	0.0368
			NLB	0.081	0.0159
			UDB	0.731	0.1432
F2	L(F2)	0.0367	LMB	0.751	0.0276
			NLB	0.071	0.0026
			UDB	0.178	0.0065
	M(F2)	0.2230	LMB	0.559	0.1246
			NLB	0.089	0.0198
			UDB	0.352	0.0786
	H(F2)	0.0903	LMB	0.2583	0.0233
			NLB	0.1047	0.0095
			UDB	0.6370	0.0575
F3	D(F3)	0.0426	LMB	0.6923	0.0295
			NLB	0.0769	0.0033
			UDB	0.2308	0.0098
	SQ(F3)	0.0487	LMB	0.615	0.0300
			NLB	0.093	0.0045
			UDB	0.292	0.0142
	I(F2)	0.0187	LMB	0.2308	0.0043
			NLB	0.0769	0.0015
			UDB	0.6923	0.0129
	OVERALL COMPOSITE WEIGHTS OF SCENARIO:				
				LMB =	0.4342
				NLB =	0.0826
				UDB =	0.4826

NOTE : F1 = WORLD OIL PRICE
F2 = NON-OIL REVENUE
F3 = EXTERNAL FUNDING

L(i) = Low increase of the i factor
M(i) = Medium increase of the i factor
H(i) = High increase of the i factor

LMB = LIMITED BUDGET SCENARIO
NLB = NON-LIMITED BUDGET SCENARIO
UDB = UNDERTEMINED BUDGET SCENARIO

D(i) = Decrease of the i factor
SQ(i) = Status Quo of the i factor
I(i) = Increase of the i factor

Table A.19: Projects Selected At Stage t=1 by the IGP and PIGP Model Under The Various Cases of Multiobjective Analysis for Possible Funding Decision/Allocation D_1^1/BT_1^1

Proposed Projects		YEAR IN WHICH CONSTRUCTION STARTED												
Project Number & Name	Area (ha)	Case A	Case B	Case C	Case D	Case D PIGP	Case E	Case E PIGP	Case F	Case F PIGP	Case G	Case G PIGP	Case H	Case I
1 Krueng Baro	16772	1st	1st	1st	1st	0	1st	0	1st	0	1st	1st	1st	1st
2 North Sumatra	41000	1st	1st	0	1st	0	1st	0	1st	0	1st	1st	1st	1st
3 Pasaman	4926	2nd	1st	0	1st	2nd	1st	2nd	1st	0	1st	1st	1st	2nd
4 Batang Kumu	13800	1st	1st	1st	0	0	1st	0	1st	0	0	0	1st	1st
5 Limun Sungkat	2500	4th	4th	3rd	0	4th	4th	4th	2nd	3rd	0	0	4th	4th
6 Komering	55904	0	1st	1st	0	0	1st	0	0	0	1st	1st	1st	1st
7 Baal	5500	0	0	0	1st	0	2nd	0	1st	0	2nd	2nd	0	0
8 Way Abung	5000	2nd	2nd	0	1st	2nd	2nd	1st	2nd	2nd	1st	1st	2nd	2nd
9 Way Perdada	13550	1st	1st	0	1st	0	1st	0	1st	1st	1st	1st	1st	0
10 Alas	4400	0	0	0	2nd	2nd	2nd	1st	1st	1st	1st	1st	0	0
11 Manjuto Kanan	10000	0	0	1st	0	0	1st	0	0	2nd	0	0	0	1st
12 Teluk Lada	18923	0	1st	0	1st	1st	1st	1st	1st	0	1st	1st	1st	1st
13 Jatigede	130158	1st	1st	0	0	1st	0	1st	0	1st	0	0	1st	0
14 Jratunseluna	74537	1st	1st	0	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
15 Dumpil	25415	1st	1st	0	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
16 Madura	2580	4th	4th	0	3rd	4th	3rd	4th	3rd	4th	4th	4th	4th	1st
17 East Java Rehab	42912	1st	0	0	1st	1st	0	1st	1st	1st	1st	1st	0	1st
18 Sanggau Ledo	555	0	4th	0	0	4th	3rd	4th	4th	4th	0	0	4th	1st
19 Kasau	5000	0	0	1st	0	0	1st	0	0	0	0	0	0	1st
20 Riam Kanan	12000	0	0	1st	0	0	1st	0	1st	0	0	0	0	1st
21 Toraut Bongo	7820	0	0	1st	1st	0	1st	0	1st	0	1st	1st	0	1st
22 Taopa	8000	0	0	1st	0	0	1st	0	0	0	0	0	0	1st
23 Kalong	1200	0	0	1st	0	4th	1st	1st	4th	4th	0	0	0	4th
24 Boya	10000	0	1st	1st	1st	0	1st	0	1st	1st	1st	1st	1st	1st
25 San Rego	7500	0	0	1st	1st	1st	1st	1st	1st	1st	1st	1st	0	1st
26 Wawotobi	21200	1st	1st	1st	0	1st	1st	1st	0	0	1st	1st	1st	1st
27 Dataran Kobi	1950	0	3rd	2nd	1st	3rd	1st	4th	4th	0	3rd	3rd	3rd	4th
28 Wimbo Erang	1963	0	4th	4th	0	4th	1st	4th	0	0	0	0	4th	4th
29 Irigasi Bali	3425	0	0	0	1st	3rd	1st	3rd	2nd	3rd	3rd	3rd	0	0
30 Embung NTB	1520	0	0	0	3rd	3rd	1st	4th	4th	4th	4th	4th	0	0
31 Kalimantong	2850	0	0	0	1st	4th	1st	4th	2th	0	3rd	3rd	0	1st
32 Irigasi NTT	3360	0	0	0	2nd	3rd	2nd	3rd	3rd	3rd	2nd	2nd	0	0
33 Embung NTB	8276	0	0	0	1st	1st	1st	1st	1st	1st	1st	1st	0	0

PARAMETERS	GOAL ATTAINMENT												
1 Irrigation Area (ha)	415570	461953	196809	261236	386370	371646	386370	291291	355831	359540	359540	461953	415527
2 N.P.V. of Benefit ($10^6)	1590.5	1537.6	278.1	1116.6	1432.3	1136.1	1432.9	1202.7	1396.9	1372.7	1372.7	1537.6	1425.2
3 Transmigration Support (number of families)	12500	30000	42500	6500	9500	42500	9500	14000	5000	22500	22500	30000	42500
4 Number Selected Projects	13	18	15	21	21	31	21	26	18	23	23	18	25
5 Total Budget ($10^6)	923.87	924	435.19	744.8	923.66	853.89	923.49	811.63	922.23	895.8	895.8	924	923.68

SATISFACTION OF SELECTION CRITERIA

	Number of Projects												
1 Physical Potential													
Range: > 85%	7	10	4	13	16	14	16	13	11	14	14	10	11
80% - 85%	5	7	5	7	5	11	5	10	7	8	8	7	8
< 80%	1	1	6	1	0	6	0	3	0	1	1	1	6
2 Existing Rice Fields													
Range: > 85%	5	6	1	10	12	10	12	11	12	10	10	6	7
60% - 80%	2	3	2	5	3	6	5	6	5	5	5	3	3
50% - 60%	3	4	4	5	4	6	2	7	1	5	5	4	7
< 50%	3	5	8	1	2	9	2	2	0	3	3	5	8
3 Farmer Readiness													
Range: > 80%	5	6	0	10	11	9	11	10	10	10	10	6	6
60% - 80%	6	8	6	10	6	12	6	10	5	12	12	8	8
< 60%	2	4	9	1	4	10	4	6	3	1	1	4	10

Table A.20: Projects Selected At Stage $t = 1$ by the FCCIGP Under the Three Confidence Limits on NPVB for the Five Levels of Possible Funding Allocation BT_1^1 - BT_1^5 with the Associated Membership Grade of Confidence Limit on NPVB

Proposed Projects		YEAR IN WHICH CONSTRUCTION STARTED														
		BT_1^1			BT_1^2			BT_1^3			BT_1^4			BT_1^5		
Project Number & Name	Area (ha)	Confidence Levels			Confidence Levels			Confidence Levels			Confidence Levels			Confidence Levels		
		Mean	Upper Limit	Lower Limit	Mean	Upper Limit	Lower Limit	Mean	Upper Limit	Lower Limit	Mean	Upper Limit	Lower Limit	Mean	Upper Limit	Lower Limit
1 Krueng Baro	16772	1st	1st	0	1st	1st	0	1st	1st	1st	1st	1st	1st	0	1st	0
2 North Sumatra	41000	1st	0	1st	0	0	0	1st	1st	1st	1st	0	1st	0	0	0
3 Pasaman	4926	2nd	2nd	1st	0	0	1st	2nd	2nd	2nd	2nd	1st	2nd	2nd	1st	2nd
4 Batang Kumu	13800	1st	1st	0	1st	1st	0	0	1st	1st	1st	1st	1st	1st	1st	1st
5 Limun Sungkat	2500	4th	4th	3rd	0	4th	0	4th	3rd	3rd	0	4th	0	4th	4th	4th
6 Komering	55904	0	1st	0	0	0	0	1st	1st	0	0	1st	0	0	0	0
7 Baal	5500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8 Way Abung	5000	2nd	0	2nd	0	0	0	2nd	0	2nd	0	1st	0	2nd	0	2nd
9 Way Perdada	13550	1st	0	1st	1st	1st	1st	1st	0	1st	1st	1st	1st	1st	0	1st
10 Alas	4400	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11 Manjuto Kanan	10000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12 Teluk Lada	18923	0	0	1st	0	0	1st	1st	1st	1st	1st	0	1st	1st	1st	1st
13 Jatigede	130158	1st	1st	1st	1st	1st	1st	0	0	0	0	0	0	0	0	0
14 Jratunseluna	74537	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
15 Dumpil	25415	1th	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
16 Madura	2580	4th	2nd	4th	3rd	4th	3rd	3rd	4th	3rd	3rd	4th	2nd	1st	2nd	4th
17 East Java Rehab	42912	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
18 Sanggau Ledo	555	0	4th	0	2nd	4th	1st	0	3rd	3rd	2nd	4th	2nd	0	0	0
19 Kasau	5000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20 Riam Kanan	12000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21 Toraut Bongo	7820	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22 Taopa	8000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23 Kalong	1200	0	2nd	0	0	0	0	4th	3rd	0	0	4th	0	0	4th	0
24 Boya	10000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25 San Rego	7500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26 Wawotobi	21200	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
27 Dataran Kobi	1950	0	2nd	0	0	0	0	0	0	0	0	4th	0	0	4th	0
28 Wimbo Erang	1963	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29 Irigasi Bali	3425	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30 Embung NTB	1520	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 Kalimantong	2850	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 Irigasi NTT	3360	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33 Embung NTB	8276	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PARAMETERS		GOAL ATTAINMENT														
1 Irrigation Area (ha)		415570	415629	404476	365199	365199	355976	347639	348444	304890	297390	304021	297390	246563	247935	246563
2 N.P.V. of Benefit ($10^6)		1590.5	2379.5	796.6	1454.9	2165.7	737.37	1368	2023.8	666.89	1242.5	1827.7	682.16	1108.9	1603.2	625.86
3 Transmigration Support (number of families)		16500	27500	6500	16500	16500	6000	22000	27000	16500	16000	27500	16000	11500	17500	11500
4 Number Selected Projects		13	14	13	10	11	10	14	15	14	12	15	12	11	12	11
5 Total Budget ($10^6)		923.87	923.25	920.25	807.55	807.31	808.73	692.64	692.93	923.68	577.65	577.93	577.83	461.88	461.88	461.88
6 Membership Grade Of Confidence Limit On NPVB		1.0	0.083	0.085	1.0	0.083	0.085	1.0	0.083	0.085	1.0	0.083	0.085	1.0	0.083	0.085
		ANNUAL BUDGET ALLOCATION														
First Year (B1)		147.46	147.53	148.3	132.85	131.39	132.98	109.43	108.7	92.56	92.91	93.72	92.73	71.86	72.22	71.86
Second Year (B2)		285.39	289.57	284.29	251.07	250.73	251.93	212.36	211.69	180.88	178.95	176.76	181	141.12	141.84	141.11
Third Year (B3)		184.82	188.35	185.42	161.71	159.43	162.87	140.33	141.45	122.52	117.37	114.44	117.37	93.06	92.37	93.06
Fourth Year (B4)		178.59	174.15	176.78	154.35	154.66	153.08	135.49	135.4	115.46	110.23	113.41	108.36	91.02	90.28	91.02
Fifth Year (B5)		127.75	124.39	125.46	109.03	112.79	108.14	95.39	95.76	80.52	78.54	79.66	78.54	64.96	65.29	64.96

Table A.21: Projects Selected At Stage $t = 2$ by the FCCIGP Under the Three Confidence Limits on NPVB for the Five Levels of Possible Funding Allocation BT_2^1 - BT_2^5 with the Associated Membership Grade of Confidence Limit on NPVB

Proposed Projects		YEAR IN WHICH CONSTRUCTION STARTED														
		BT_2^1			BT_2^2			BT_2^3			BT_2^4			BT_2^5		
Project Number & Name	Area (ha)	Confidence Levels			Confidence Levels			Confidence Levels			Confidence Levels			Confidence Levels		
		Mean	Upper Limit	Lower Limit	Mean	Upper Limit	Lower Limit	Mean	Upper Limit	Lower Limit	Mean	Upper Limit	Lower Limit	Mean	Upper Limit	Lower Limit
1 Krueng Aceh	24000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2 Irigasi Aceh	9000	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
3 Irigasi Nias	8000	1st	0	1st	1st	0	1st	1st	0	1st	0	0	0	0	0	0
4 Irigasi Sumut	15000	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
5 Bt. Kalulutan	4600	2nd	2nd	2nd	1st	3rd	1st	2nd	1st	2nd	2nd	1st	2nd	0	0	0
6 Irigasi Sumbar	6000	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
7 Batang Teso	2960	2nd	1st	3rd	2nd	3rd	3rd	3rd	3rd	3rd	3rd	3rd	3rd	3rd	1st	3rd
8 Pematang Limit	2200	3rd	1st	4th	2nd	1st	4th	4th	1st	1st	1st	1st	3rd	0	0	0
9 Musi Rawas	15800	1st	0	1st	1st	0	1st	0	0	0	0	0	0	0	0	0
10 Muncak Kabu	10700	1st	0	1st	1st	0	1st	0	0	0	0	0	0	0	0	0
11 Lampung	5000	3rd	1st	3rd	2nd	3rd	3rd	3rd	3rd	2nd	3rd	3rd	3rd	0	0	0
12 Irigasi Lampung	12000	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	3rd	1st	1st	1st
13 Nokan Kanan	1500	2nd	1st	4th	2nd	1st	2nd	3rd	1st	4th	3rd	0	4th	0	0	0
14 Penago	10000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15 Irigasi Bengkulu	4500	1th	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
16 Tanjung	5568	1st	1st	1st	1st	1st	1st	1st	1st	1st	0	0	1st	0	0	0
17 Karian	10300	1st	1st	1st	1st	1st	1st	1st	1st	1st	0	1st	0	0	0	0
18 West Java	7260	1st	1st	1st	1st	1st	1st	1st	3rd	1st	1st	1st	1st	1st	1st	1st
19 Central Java	24800	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
20 Losari	4180	2nd	2nd	1st	1st	2nd	1st	1st	1st	1st	1st	2nd	1st	0	0	0
21 Merowi	2077	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22 Irigasi Kalteng	4000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23 Irigasi Kalsel	17682	0	0	1st	0	0	0	0	0	0	0	0	0	0	0	0
24 Tangkup	3400	0	1st	0	0	0	3rd	0	0	0	0	0	0	0	0	0
25 Taopa Lambun	6100	1st	1st	1st	1st	1st	1st	1st	1st	0	1st	0	0	0	0	0
26 Bonta Manai	7800	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	0	0	0
27 Bili-Bili	26050	1st	1st	1st	1st	1st	1st	0	1st	1st	1st	1st	1st	1st	1st	1st
28 Poleang	2530	2nd	1st	4th	2nd	1st	4th	1st	1st	3rd	3rd	0	4th	0	0	0
29 Arso	3638	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30 Irigasi Bali	1000	3rd	0	2nd	2nd	0	0	3rd	0	3rd	0	0	3rd	0	0	0
31 Irigasi NTB	7667	1st	0	1st	0	0	0	0	0	0	0	0	0	0	0	0
32 Irigasi NTT	8531	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PARAMETERS		GOAL ATTAINMENT														
1 Irrigation Area (ha)		202100	157433	225529	194433	157433	196833	166433	157433	166433	141565	139535	142033	107655	107655	107655
2 N.P.V. of Benefit ($10^6)		891.59	369.59	1499.6	874.57	369.59	1413.2	855.21	334.37	1333.8	808.14	375.24	1251.7	735.55	366.21	1103.5
3 Transmigration Support (number of families)		15700	10700	20400	14600	10700	16700	10700	19600	19600	19600	24100	22600	5500	5500	5500
4 Number Selected Projects		24	19	27	23	19	23	20	19	19	17	14	19	9	9	9
5 Total Budget ($10^6)		710.03	549.9	795.05	690	549.9	689.78	580	692.93	580	478	478	478	368.82	368.82	370
6 Membership Grade Of Confidence Limit On NPVB		1.0	0.083	0.085	1.0	0.083	0.085	1.0	0.083	0.085	1.0	0.083	0.085	1.0	0.083	0.085
		ANNUAL BUDGET ALLOCATION														
First Year (B1)		105.92	98.25	120.94	107.4	93.79	107.62	91.59	108.7	92	74.94	68.4	68.09	57.83	57.83	59.01
Second Year (B2)		300.48	421:26	213.52	224.55	308.34	201.48	171.65	211.69	173.89	138.62	141.45	135.63	115.44	115.44	114.26
Third Year (B3)		151.89	109.2	156.29	150.03	109.2	141.76	117.65	141.45	120.54	101.99	100.06	99.48	74.02	74.02	74.02
Fourth Year (B4)		141.89	97.34	159.97	126.38	105.03	140.67	119.09	135.4	118.11	98.44	97.81	104.62	71.5	71.5	71.5
Fifth Year (B5)		95.96	69.95	114.67	81.64	73.64	98.46	80.42	95.76	75.46	64.01	70.28	70.17	51.21	51.21	51.21

Table A.22: Projects Selected At Stage $t = 3$ by the FCCIGP Under the Three Confidence Limits on NPVB for the Five Levels of Possible Funding Allocation BT_3^1 - BT_3^5 with the Associated Membership Grade of Confidence Limit on NPVB

Proposed Projects		YEAR IN WHICH CONSTRUCTION STARTED														
		BT_3^1			BT_3^2			BT_3^3			BT_3^4			BT_3^5		
Project Number & Name	Area (ha)	Confidence Levels			Confidence Levels			Confidence Levels			Confidence Levels			Confidence Levels		
		Mean	Upper Limit	Lower Limit	Mean	Upper Limit	Lower Limit	Mean	Upper Limit	Lower Limit	Mean	Upper Limit	Lower Limit	Mean	Upper Limit	Lower Limit
1 Krueng Jrue	2365	2nd	3rd	4th	4th	3rd	4th	2nd	3rd	4th	4th	3rd	1st	4th	3rd	4th
2 Bt. Indrapura	2678	2nd	0	3rd	3rd	0	3rd	3rd	0	3rd	3rd	0	3rd	3rd	0	3rd
3 Sungai Murai	12000	1st	0	1st	1st	0	1st	0	0	0	0	0	0	0	0	0
4 Batang Uloh	500	1st	0	4th	4th	0	0	0	0	4th	4th	0	3rd	0	0	0
5 Belitang	20600	1st	0	1st	1st	0	1st	1st	0	1st	0	0	0	0	0	0
6 Lempoing	13100	1st	0	1st	1st	0	1st	1st	0	1st	1st	0	1st	0	0	0
7 Tulang Bawang	44500	0	0	1st	0	0	0	0	0	0	0	0	0	0	0	0
8 Bumi Agung	3150	1st	0	0	1st	0	0	1st	0	3rd	0	0	3rd	0	0	0
9 Mesuji II	20980	1st	0	1st	1st	0	1st	1st	0	1st	1st	0	0	0	0	0
10 Bengkenang	5000	1st	0	1st	1st	0	2nd	0	0	2nd	0	0	2nd	0	0	0
11 Sadawarna	6277	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	3rd	1st	1st	1st
12 Cibeber	8900	1st	0	1st	1st	0	1st	1st	0	1st	1st	0	3rd	1st	0	1st
13 Irg. West Java	15000	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
14 Kedu Selatan	24000	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
15 Banjarejo	7750	1th	0	0	1st	0	1st	0	0	0	0	0	0	0	0	0
16 Irg Central Java	15000	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
17 Lesti Left	2300	2nd	0	1st	2nd	0	2nd	0	0	2nd	0	0	0	0	0	0
18 Widas	7750	1st	0	0	1st	0	1st	1st	0	0	0	0	0	0	0	0
19 Irg. East Java	22500	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
20 Sebangun	15000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21 Batu Licin	4640	1st	0	2nd	1st	0	2nd	2nd	0	2nd	1st	0	2nd	1st	0	0
22 Irigasi Sulut	8000	0	0	1st	0	0	1st	0	0	0	0	0	0	0	0	0
23 Parigi Poso	14056	1st	0	1st	1st	0	1st	1st	0	1st	1st	0	1st	1st	0	1st
24 Sidrang	3500	2nd	0	3rd	3rd	0	3rd	3rd	0	3rd	0	0	3rd	3rd	0	3rd
25 Cenranae	4100	1st	0	1st	1st	0	0	0	0	0	0	0	0	0	0	0
26 Kalaena Kanan	4748	1st	0	1st	1st	0	1st	1st	0	1st	0	0	1st	0	0	0
27 Mappi	59800	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28 Irigasi NTB	2720	1st	2nd	2nd	1st	2nd	2nd	1st	2nd	2nd	2nd	2nd	2nd	2nd	2nd	2nd
29 Pelora	9054	1st	0	1st	1st	0	1st	1st	0	1st	1st	0	1st	1st	0	1st
30 Irigasi NTT	8530	1st	0	1st	1st	0	1st	1st	0	1st	1st	0	1st	0	0	0
PARAMETERS		GOAL ATTAINMENT														
1 Irrigation Area (ha)		248618	95362	282468	248618	95362	248868	216968	95362	217018	177720	95362	173218	138190	95362	138190
2 N.P.V. of Benefit ($10^6)		768.06	379.01	1597	933.91	379.01	1515.3	900.22	379.01	1422.1	828	379.01	1287.9	786.73	379.01	1178.3
3 Transmigration Support (number of families)		15500	0	25000	15500	0	17000	11500	0	11500	7000	0	7000	4000	0	4000
4 Number Selected Projects		26	7	25	26	7	24	20	7	22	16	7	19	13	7	13
5 Total Budget ($10^6)		911.6	345.17	1049.6	909.35	345.17	909.23	769.62	345.47	769.25	626	345.47	478	490	345.47	489.2
6 Membership Grade of Confidence Limit on NPVB		1.0	0.083	0.085	1.0	0.083	0.085	1.0	0.083	0.085	1.0	0.083	0.085	1.0	0.083	0.085
		ANNUAL BUDGET ALLOCATION														
First Year (B1)		288.82	53.47	166.71	150.05	93.79	137.81	124.91	53.47	111.38	100.16	53.47	87.81	76.02	53.47	76.02
Second Year (B2)		282.97	105.45	320.52	273.69	308.34	274.42	231.79	105.45	224.01	185.37	105.45	177.21	145.5	105.45	145.5
Third Year (B3)		193.26	71.04	217.05	190.05	109.2	189.82	160.95	71.04	161.82	123.55	71.04	130.26	101.36	71.04	101.36
Fourth Year (B4)		172.5	67.89	201.24	176.47	105.03	177.31	148.54	67.89	161.82	137.02	67.89	144.56	98.56	67.89	98.56
Fifth Year (B5)		112.46	47.32	144.48	119.75	73.64	130.64	103.8	47.32	113.3	83.9	47.32	90.16	68.57	47.32	68.57

Table A.23: Projects Selected At Stage $t = 4$ by the FCCIGP Under the Three Confidence Limits on NPVB for the Five Levels of Possible Funding Allocation BT_4^1 - BT_4^5 with the Associated Membership Grade of Confidence Limit on NPVB

Proposed Projects		YEAR IN WHICH CONSTRUCTION STARTED														
		BT_4^1			BT_4^2			BT_4^3			BT_4^4			BT_4^5		
Project Number & Name	Area (ha)	Confidence Levels			Confidence Levels			Confidence Levels			Confidence Levels			Confidence Levels		
		Mean	Upper Limit	Lower Limit	Mean	Upper Limit	Lower Limit	Mean	Upper Limit	Lower Limit	Mean	Upper Limit	Lower Limit	Mean	Upper Limit	Lower Limit
1 Irigasi Aceh	6000	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
2 Irigasi Sumut	9000	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
3 West Sumatra	19512	1st	0	1st	1st	0	1st	0	0	0	0	0	0	0	0	0
4 Irigasi Sumbar	6000	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
5 Irigasi Riau	1165	4th	0	3rd	4th	0	4th	4th	0	4th	0	0	0	2nd	0	0
6 Ulak Beras	500	0	0	4th	0	0	0	0	0	0	0	0	1st	0	0	0
7 Small Sumsel	17100	1st	0	1st	1st	0	1st	1st	0	1st	1st	0	1st	0	0	0
8 Rupit	11000	1st	0	1st	1st	0	0	1st	0	0	0	0	0	0	0	0
9 Irigasi Sumsel	6000	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
10 Air Malus	8800	1st	0	1st	0	0	1st	0	0	0	0	0	0	0	0	1st
11 Talang Niur	4500	2nd	0	1st	1st	0	0	0	0	0	0	0	0	1st	0	0
12 Air Limau	7000	2nd	0	2nd	0	0	2nd	0	0	2nd	0	0	0	0	0	0
13 Lower Komering	22174	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14 Lower Lematang	11070	2nd	0	2nd	0	0	0	0	0	1st	0	0	0	0	0	0
15 Way Tahmi	5550	1th	0	1st	1st	0	1st	1st	0	1st	1	0	1st	1st	0	1st
16 Way Mesuji II	18750	1st	0	1st	1st	0	1st	0	0	1st	0	0	0	0	0	0
17 Way Buaya	4880	1st	0	1st	0	0	0	0	0	0	0	0	0	1st	0	0
18 Air Selagan	11000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 Irg. West Java	19500	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
20 Jragung	12200	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
21 Kedungwaru	1330	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22 Central Java	2320	3rd	0	3rd	0	0	2nd	3rd	0	0	0	0	0	1st	0	3rd
23 Irg Central Java	24000	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
24 Beng	3200	2nd	0	2nd	2nd	0	2rd	2nd	0	2nd	0	0	0	2rd	0	2nd
25 Irg East Java	22500	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
26 Batang Alai	6220	0	0	3rd	0	0	0	0	0	0	0	0	0	0	0	0
27 Barabai	2280	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28 Irigasi NTB	11518	1st	0	1st	1st	0	1st	1st	0	0	0	0	0	0	0	0
29 Batu Bulan	7000	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
30 Central Sulawesi	6410	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31 Bila	24040	1st	0	1st	1st	0	0	1st	0	1st	1st	0	1st	0	0	0
32 Kuti	74000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PARAMETERS		GOAL ATTAINMENT														
1 Irrigation Area (ha)		258565	112200	264785	235565	112200	238185	195093	112200	217018	158890	112200	173218	129315	112200	132070
2 N.P.V. of Benefit ($10^6)		1298.2	567.77	2030.8	1233.9	567.77	1902	1163.2	567.77	1422.1	1098.7	310.66	1287.9	975.16	567.77	1404.7
3 Transmigration Support (number of families)		12500	0	14000	7000	0	8000	6500	0	11500	4500	0	4500	0	0	1500
4 Number Selected Projects		24	9	26	19	9	20	17	9	22	12	9	13	14	9	13
5 Total Budget ($10^6)		1060.4	433.74	1078.9	932.83	433.74	935.75	785.47	433.74	769.25	646.32	433.74	647.98	500.91	433.74	503.86
6 Membership Grade of Confidence Limit on NPVB		1.0	0.083	0.085	1.0	0.083	0.085	1.0	0.083	0.085	1.0	0.083	0.085	1.0	0.083	0.085
		ANNUAL BUDGET ALLOCATION														
First Year (B1)		171.4	71.06	175.38	155.55	71.05	150.29	126.99	71.05	111.38	108.43	71.05	108.43	83.57	53.47	79.79
Second Year (B2)		302.16	135.62	304.06	270.95	135.62	267.08	229.66	135.62	224.01	191.07	135.62	191.07	156.83	105.45	150.06
Third Year (B3)		226.71	86.24	236.9	193.93	86.24	200.51	161.88	86.24	161.82	131.62	86.24	131.62	103.24	71.04	104.6
Fourth Year (B4)		219.23	82.34	219.17	188.46	82.34	192.05	163.88	82.34	161.82	127.34	82.34	127.32	96.81	67.89	100.79
Fifth Year (B5)		140.93	58.49	143.35	127.12	58.49	126.06	109.57	58.49	113.3	87.85	58.49	89.53	63.55	47.32	68.61

Table A.24: Projects Selected At Stage $t = 5$ by the FCCIGP Under the Three Confidence Limits on NPVB for the Five Levels of Possible Funding Allocation BT_5^1 - BT_5^5 with the Associated Membership Grade of Confidence Limit on NPVB

Proposed Projects		YEAR IN WHICH CONSTRUCTION STARTED														
		BT_5^1			BT_5^2			BT_5^3			BT_5^4			BT_5^5		
Project Number & Name	Area (ha)	Confidence Levels			Confidence Levels			Confidence Levels			Confidence Levels			Confidence Levels		
		Mean	Upper Limit	Lower Limit	Mean	Upper Limit	Lower Limit	Mean	Upper Limit	Lower Limit	Mean	Upper Limit	Lower Limit	Mean	Upper Limit	Lower Limit
1 Irigasi Aceh	15000	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
2 Irigasi Sumut	15000	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
3 Ampik Parek	2365	4th	0	1st	1st	0	4th	3rd	0	3rd	4th	0	4th	2nd	0	2nd
4 Perjaya	21555	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5 Lematang	11070	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6 Lakitan	11600	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7 Batanghari	13000	1st	0	1st	1st	0	1st	1st	0	1st	1st	0	1st	0	0	0
8 Sekayu Lupatan	8600	0	0	1st	1st	0	1st	0	0	1st	0	0	0	0	0	0
9 Air Lebak Bungu	8344	1st	0	1st	1st	0	1st	0	0	1st	0	0	0	0	0	0
10 Air Ratan	13830	0	0	0	0	0	1st	0	0	0	0	0	0	0	0	0
11 Way Hitam	5705	1st	0	0	1st	0	0	0	0	0	0	0	0	0	0	0
12 Belitang	8750	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13 Way Saka	12600	1st	0	1st	1st	0	1st	1st	0	1st	1st	0	1st	1st	0	1st
14 Way Mesuji III	15820	1st	0	1st	0	0	0	0	0	0	0	0	0	0	0	0
15 Bungin Tambun	8000	0	0	1st	1st	0	0	0	0	1st	0	0	0	0	0	0
16 Maya	2900	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17 Telaga Herang	7700	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18 Cimulya	8350	1st	0	1st	1st	0	1st	1st	0	1st	1st	0	1st	1st	0	0
19 Ciniru	2976	1st	0	3rd	3rd	0	3rd	2nd	0	3rd	2nd	0	0	1st	0	0
20 Gunung Wulan	21838	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
21 Glapan	19050	1st	0	1st	1st	0	1st	1st	0	0	0	0	0	0	0	0
22 East Java	4300	2nd	0	2nd	2nd	0	2nd	2nd	0	2nd	2nd	0	1st	2nd	0	2nd
23 Irg East Java	30000	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
24 Amandit	6430	1st	0	1st	1st	0	1st	1st	0	1st	1st	0	1st	1st	0	1st
25 Tapin	5330	1st	0	0	1st	0	2nd	1st	0	0	0	0	2nd	0	0	0
26 Ctrl. Sulawesi	6087	1st	0	1st	1st	0	1st	1st	0	1st	1st	0	1st	1st	0	1st
27 Maluso	11106	1st	0	1st	1st	0	1st	1st	0	1st	0	0	0	0	0	0
28 Langkone	16398	1st	0	1st	1st	0	1st	1st	0	1st	1st	0	1st	0	0	1st
29 Walane	26000	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
30 Padangeng	4200	0	0	3rd	3rd	0	2nd	1st	0	3rd	3rd	0	3rd	1st	0	0
31 Kias	66000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 Irg. Kecil NTB	12040	4th	4th	3rd	3rd	4th	4th	1st	4th	3rd	3rd	4th	2nd	3rd	4th	4th
33 Pela Pelado	7000	2nd	0	2nd	2nd	0	1st	1st	0	2nd	2nd	0	2nd	0	0	0
PARAMETERS		GOAL ATTAINMENT														
1 Irrigation Area (ha)		252403	78588	262168	230473	78588	230598	194494	78588	200388	164344	78588	166698	129116	78588	134718
2 N.P.V. of Benefit ($10^6)		837.68	296.5	1513.4	824.22	296.5	1412.6	784.21	296.5	1324	753.44	296.5	1212.2	685.32	296.5	1084
3 Transmigration Support (number of families)		20000	5000	21000	23000	5000	24000	12500	5000	21000	16000	5000	17000	10500	5000	13500
4 Number Selected Projects		22	6	23	24	6	23	19	6	21	17	6	17	14	6	12
5 Total Budget ($10^6)		1137.8	342.27	1181.2	1019.3	342.27	1026.7	854.83	342.27	864.93	699.63	342.27	707.51	550.76	342.27	552.83
6 Membership Grade of Confidence Limit on NPVB		1.0	0.083	0.085	1.0	0.083	0.085	1.0	0.083	0.085	1.0	0.083	0.085	1.0	0.083	0.085
		ANNUAL BUDGET ALLOCATION														
First Year (B1)		184.37	64.69	183.2	157.91	71.05	160.35	126.99	71.05	131.44	108.43	71.05	104.34	95.79	53.47	83.28
Second Year (B2)		348.39	104.39	351.48	300.89	135.62	308.41	229.66	135.62	248.61	191.07	135.62	210.13	170.03	105.45	167.66
Third Year (B3)		232.61	66.4	249.28	215.34	86.24	214.26	161.88	86.24	190.53	131.62	86.24	151.96	119.86	71.04	116.71
Fourth Year (B4)		214.47	67.48	231.59	200.89	82.34	200.05	163.88	82.34	171.63	127.34	82.34	137.03	95.57	67.89	103.76
Fifth Year (B5)		157.94	49.31	165.67	144.29	58.49	143.65	109.57	58.49	122.72	87.85	58.49	104.05	69.52	47.32	81.44

Table A.25: Projects Selected At Stage $t = 1$ By the FCCIGP Under the Three Confidence Limits on NPVB for Various Goal Preferences, the Possible Funding Decision /Allocation D_1^1/BT_1^1 and Membership Grade of Budgetary Constraint $\lambda = 1$

PROPOSED PROJECTS		YEAR IN WHICH CONSTRUCTION STARTED											
		NET BENEFIT			IRRIGATION AREA			TRANSMIGRATION			FARMER READINESS		
PROJECT NUMBER & NAME	Area (ha)	Confidence Levels			Confidence Levels			Confidence Levels			Confidence Levels		
		Mean	Lower Limit	Upper Limit	Mean	Lower Limit	Upper Limit	Mean	Lower Limit	Upper Limit	Mean	Lower Limit	Upper Limit
1 Krueng Baro	16772	1st	1st	0	1st	1st	1st	1st	1st	1st	0	0	0
2 North Sumatra	41000	1st	0	1st	1st	1st	1st	0	0	0	0	0	0
3 Pasaman	4926	2nd	2nd	1st	1st	1st	1st	0	0	0	1st	2nd	2nd
4 Batang Kumu	13800	1st	1st	0	1st	1st	1st	1st	1st	1st	0	0	0
5 Limun Sungkat	2500	4th	4th	3rd	4th	4th	4th	3rd	4th	4th	0	0	0
6 Komering	55904	0	1st	0	1st	1st	1st	1st	1st	1st	0	0	0
7 Baal	5500	0	0	0	0	0	0	0	0	0	0	0	0
8 Way Abung	5000	2nd	0	2nd	2nd	2nd	2nd	1	0	0	2nd	2nd	2nd
9 Way Perdada	13550	1st	0	1st	1st	1st	1st	1	0	0	1st	1st	1st
10 Alas	4400	0	0	0	0	0	0	0	0	0	2nd	2nd	2nd
11 Manjuto Kanan	10000	0	0	0	0	0	0	1st	1st	1st	0	0	0
12 Teluk Lada	18923	0	0	1st	1st	1st	1st	0	0	0	0	0	0
13 Jatigede	130158	1st	1st	1st	1st	1st	1st	0	0	0	1st	1st	1st
14 Jratunseluna	74537	1st	1st	1st	1st	1st	1st	0	0	0	1st	1st	1st
15 Dumpil	25415	1th	1st	1st	1st	1st	1st	0	0	0	1st	1st	1st
16 Madura	2580	4th	2nd	4th	4th	4th	4th	0	0	0	4th	4th	4th
17 East Java Rehab	42912	1st	1st	1st	0	0	0	0	0	0	1st	1st	1st
18 Sanggau Ledo	555	0	4th	0	4th	4th	4th	0	0	0	4th	4th	4th
19 Kasau	5000	0	0	0	0	0	0	1st	1st	1st	0	0	0
20 Riam Kanan	12000	0	0	0	0	0	0	1st	1st	1st	0	0	0
21 Toraut Bongo	7820	0	0	0	0	0	0	1st	1st	1st	0	0	0
22 Taopa	8000	0	0	0	0	0	0	1st	1st	1st	0	0	0
23 Kalong	1200	0	2nd	0	0	0	0	1st	1st	1st	4th	4th	4th
24 Boya	10000	0	0	0	1st	1st	1st	1st	1st	1st	1st	1st	1st
25 San Rego	7500	0	0	0	0	0	0	1st	1st	1st	1st	1st	1st
26 Wawotobi	21200	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
27 Dataran Kobi	1950	0	2nd	0	3rd	3rd	3rd	2nd	4th	4th	4th	4th	4th
28 Wimbo Erang	1963	0	0	0	4th	4th	4th	4th	4th	4th	0	0	0
29 Irigasi Bali	3425	0	0	0	0	0	0	0	0	0	3rd	3rd	3rd
30 Embung NTB	1520	0	0	0	0	0	0	0	0	0	4th	4th	4th
31 Kalimantong	2850	0	0	0	0	0	0	0	0	0	4th	4th	4th
32 Irigasi NTT	3360	0	0	0	0	0	0	0	0	0	3rd	3rd	3rd
33 Embung NTT	8276	0	0	0	0	0	0	0	0	0	1th	1th	1th

PARAMETERS	GOAL ATTAINMENT											
1 Irrigation Area (ha)	415570	415629	404476	461953	461953	461953	196809	196809	196809	386534	386534	386534
2 N.P.V. of Benefit ($10^6)	1590.5	2379.5	796.6	1537.6	2325	750.58	278.1	527.38	41.22	1409.7	2153.6	673.19
3 Transmigration Support (number of families)	16500	27500	6500	30000	30000	30000	42500	42500	42500	11000	11000	11500
4 Number Selected Projects	13	14	12	18	18	18	15	15	15	20	20	20
5 Total Budget ($10^6)	923.87	923.25	920.25	924	923.92	923.92	435.19	432.82	432.82	923.5	923.51	923.51

SATISFACTION OF SELECTION CRITERIA

	Number of Projects											
1 Physical Potential												
Range: > 85%	7	8	8	10	10	10	4	4	4	14	14	14
80% - 85%	5	5	3	7	7	7	5	5	5	6	6	6
< 80%	1	1	1	1	1	1	6	6	6	0	0	0
2 Existing Rice Fields												
Range: > 85%	5	6	6	6	6	6	1	1	1	11	11	11
60% - 80%	2	1	2	3	3	3	2	2	2	5	5	5
50% - 60%	3	3	3	4	4	4	4	4	4	3	3	3
< 50%	3	4	1	5	5	5	8	8	8	1	1	1
3 Farmer Readiness												
Range: > 80%	5	5	6	6	6	6	0	0	0	10	10	10
60% - 80%	6	5	5	8	8	8	6	6	6	8	8	8
< 60%	2	4	1	4	4	4	9	9	9	2	2	2

Table A.26: Projects Selected At Stage $t = 1$ By the FCCIGP Under the Three Confidence Limits on NPVB for Various Compromise Goal Preferences, the Possible Funding Decision/Allocation D_1^1/BT_1^1 and Membership Grade of Budgetary Constraint $\lambda = 1$

PROPOSED PROJECTS		YEAR IN WHICH CONSTRUCTION STARTED								
		CASE A (NPVB=IAD)			CASE B (NPVB=TS)			CASE C (NPVB=FRD)		
PROJECT NUMBER & NAME	Area (ha)	Confidence Levels			Confidence Levels			Confidence Levels		
		Mean	Lower Limit	Upper Limit	Mean	Lower Limit	Upper Limit	Mean	Lower Limit	Upper Limit
1 Krueng Baro	16772	1st	1st	1st	1st	1st	1st	0	0	0
2 North Sumatra	41000	1st	1st	1st	1st	1st	1st	0	0	0
3 Pasaman	4926	2nd	2nd	2nd	2nd	1st	0	2nd	2nd	1st
4 Batang Kumu	13800	1st	1st	1st	1st	1st	1st	0	0	0
5 Limun Sungkat	2500	4th	4th	4th	1st	4th	2nd	4th	4th	0
6 Komering	55904	1st	1st	1st	1st	1st	1st	0	0	0
7 Baal	5500	0	0	0	0	0	0	0	0	0
8 Way Abung	5000	2nd	1st	2nd	0	0	0	1st	2nd	2nd
9 Way Perdada	13550	1st	1st	1st	1st	1st	1st	1st	1st	1st
10 Alas	4400	0	0	0	0	0	0	1st	1st	2nd
11 Manjuto Kanan	10000	0	0	0	1st	1st	1st	0	0	0
12 Teluk Lada	18923	1st	1st	1st	1st	1st	1st	0	0	0
13 Jatigede	130158	1st	1st	1st	0	0	0	1st	1st	1st
14 Jratunseluna	74537	1st	1st	1st	1st	1st	1st	1st	1st	1st
15 Dumpil	25415	1th	1st	1st	1st	1st	1st	1st	1st	1st
16 Madura	2580	3rd	4th	3rd	0	0	4th	4th	4th	4th
17 East Java Rehab	42912	0	0	0	1st	1st	1st	1st	1st	1st
18 Sanggau Ledo	555	2nd	4th	4th	3rd	1st	3rd	4th	4th	3rd
19 Kasau	5000	0	0	0	1st	1st	1st	0	0	0
20 Riam Kanan	12000	0	0	0	1st	1st	1st	0	0	0
21 Toraut Bongo	7820	0	0	0	1st	1st	1st	0	0	0
22 Taopa	8000	0	0	0	1st	1st	1st	0	0	0
23 Kalong	1200	0	0	0	1st	1st	1st	0	0	4th
24 Boya	10000	1st	1st	1st	1st	1st	1st	1st	1st	1st
25 San Rego	7500	0	0	0	1st	1st	1st	1st	1st	1st
26 Wawotobi	21200	1st	1st	1st	1st	1st	1st	1st	1st	1st
27 Dataran Kobi	1950	2nd	3rd	3rd	3rd	2nd	3rd	4th	4th	4th
28 Wimbo Erang	1963	4th	4th	4th	4th	4th	2nd	0	0	0
29 Irigasi Bali	3425	0	0	0	0	0	0	3rd	3rd	3rd
30 Embung NTB	1520	0	0	0	0	0	0	1st	4th	4th
31 Kalimantong	2850	0	0	0	0	0	0	1st	4th	1th
32 Irigasi NTT	3360	0	0	0	0	0	0	1st	1st	1st
33 Embung NTT	8276	0	0	0	0	0	0	1st	1st	1st
PARAMETERS		GOAL ATTAINMENT								
1 Irrigation Area (ha)		461953	461953	461953	418647	418647	416301	387834	387834	386534
2 N.P.V. of Benefit ($10^6)		1537.8	2325	750.58	1420.7	2189.6	643.76	1416.6	2163.4	673.19
3 Transmigration Support (number of families)		30000	30000	30000	42500	42500	42500	11000	11000	11000
4 Number Selected Projects		18	18	18	25	25	25	20	20	20
5 Total Budget ($10^6)		923.96	924	924.67	923.81	922.53	923.92	923.98	923.98	924
SATISFACTION OF SELECTION CRITERIA										
1 Physical Potential		Number of Projects								
Range: > 85%		10	10	10	9	9	9	14	14	14
80% - 85%		7	7	7	8	8	8	6	6	6
< 80%		1	1	1	6	6	6	0	0	0
2 Existing Rice Fields										
Range: > 85%		6	6	6	6	6	6	12	12	12
60% - 80%		3	3	3	3	3	3	4	4	4
50% - 60%		4	4	4	6	6	6	3	3	3
< 50%		5	5	5	8	8	8	1	1	1
3 Farmer Readiness										
Range: > 80%		6	6	6	4	4	4	10	10	10
60% - 80%		8	8	8	9	9	9	8	8	8
< 60%		4	4	4	10	10	10	2	2	2

NOTE: NPVB=IAD : PREFERENCE IS GIVEN TO BOTH NPVB AND IAD GOALS
NPVB=TS : PREFERENCE IS GIVEN TO BOTH NPVB AND TS GOALS
NPVB=FRD : PREFERENCE IS GIVEN TO BOTH NPVB AND FRD GOALS

Table A.27: Input Data for All Cases of the SDP Resulting from the FCCIGP At Mean Confidence Limit of the NPVB Criterion for Stage 1 of the SDP

Index [a] of Level of Actual Funding Received F_1^l	Index [b] of Level of Possible Funding D_1^k	Level [c] of Possible Funding Allocation BT_1^k ($ Million)	Cost [d] Escalation Coefficient (%)	$AD_1^{k,l}$ [e] Irrigation Area Developed (hectares)	Optimal [f] Return in Term of NPVB $V_1^{k,l}$	Total [g] cost Required ($ Million)
$l=1$	$k=1$	924.0	0	415,570	1590.48	923.87
$l=1$	$k=2$	809.0	4	363,944	1307.25	808.58
$l=1$	$k=3$	693.0	7	326,369	1244.93	690.61
$l=1$	$k=4$	578.0	10	255,914	1008.56	577.97
$l=1$	$k=5$	462.0	13	198,345	820.59	461.92
$l=2$	$k=1$	924.0	4	384,122	1435.23	923.43
$l=2$	$k=2$	809.0	0	365,199	1454.88	807.55
$l=2$	$k=3$	693.0	7	326,369	1244.93	690.61
$l=2$	$k=4$	578.0	10	255,914	1008.56	577.97
$l=2$	$k=5$	462.0	13	198,345	820.59	461.92
$l=3$	$k=1$	924.0	13	363,944	1160.78	923.90
$l=3$	$k=2$	809.0	4	363,944	1307.25	808.58
$l=3$	$k=3$	693.0	0	347,639	1367.96	692.64
$l=3$	$k=4$	578.0	7	283,562	1142.36	577.88
$l=3$	$k=5$	462.0	10	212,062	893.34	461.93
$l=4$	$k=1$	924.0	13	363,944	1160.78	923.90
$l=4$	$k=2$	809.0	10	341,871	1162.83	808.20
$l=4$	$k=3$	693.0	7	326,369	1244.93	690.61
$l=4$	$k=4$	578.0	0	297,390	1242.46	577.65
$l=4$	$k=5$	462.0	4	214,645	908.35	461.64
$l=5$	$k=1$	924.0	13	363,944	1160.78	923.90
$l=5$	$k=2$	809.0	10	341,871	1162.83	808.20
$l=5$	$k=3$	693.0	7	326,369	1244.93	690.61
$l=5$	$k=4$	578.0	4	267,040	1070.16	577.91
$l=5$	$k=5$	462.0	0	246,563	1108.90	461.88

Note:

[a] For $l = 1, ..., N_{F_{t,i,m}}$; $N_{F_{t,i,m}}$=5; $t = 1$, $i = 1, ..., J_1 = 26$; and $m = 1, ..., N_{PF_{t,i}} = 5$

Where: $N_{F_{t,i,m}}$ = number of levels of actual funding received at the state $L_t^{i,m}$

[b] For $k = 1, ..., N_{D_{t,i,m}}$; $N_{D_{t,i,m}}$=5; $t = 1$; $i = 1, ..., J_1 = 26$; and $m = 1, ..., N_{PF_{t,i}} = 5$

Where: $N_{D_{t,i,m}}$ = number of levels of the possible funding decisions planned at the state $L_t^{i,m}$

[c] Level of Possible Funding Allocation (BT_1^k) in monetary terms ($ Million)

[d] Cost Escalation Coefficient = 0, or without cost escalation, when $k = l$

[e] Irrigation Area Developed associated with each level of possible funding (hectares)

[f] Optimal Economic Return in terms of NPVB for each level of possible funding ($ Million)

[g] Total cost required associated with each level of $AD_1^{k,l}$

Table A.28: Input Data for All Cases of the SDP Resulting from the FCCIGP At Lower Confidence Limit of the NPVB Criterion for Stage t =1 of the SDP

Index[a)] of Level of Actual Funding Received F_1^l	Index[b)] of Level of Possible Funding D_1^k (\$ Million)	Level[c)] of Possible Funding Allocation BT_1^k	Cost [d)] Escalation Coefficient (%)	$AD_1^{k,l}$[e)] Irrigation Area Developed (hectares)	Optimal [f)] Return in Term of NPVB $V_1^{k,l}$	Total[g)] cost Required (\$ Million)
$l=1$	$k=1$	924.0	0	415,629	2379.53	923.25
$l=1$	$k=2$	809.0	4	372,744	2044.97	808.58
$l=1$	$k=3$	693.0	7	312,463	1771.47	692.89
$l=1$	$k=4$	578.0	10	255,914	1512.21	577.96
$l=1$	$k=5$	462.0	13	239,409	1115,71	461.87
$l=2$	$k=1$	924.0	4	382,448	2168.38	923.83
$l=2$	$k=2$	809.0	0	365,199	2165.65	807.31
$l=2$	$k=3$	693.0	7	312,463	1771.47	692.89
$l=2$	$k=4$	578.0	10	255,914	1512.21	577.96
$l=2$	$k=5$	462.0	13	239,409	1115.71	461.87
$l=3$	$k=1$	924.0	13	328,332	1593.45	923.76
$l=3$	$k=2$	809.0	4	372,744	2044,97	808.58
$l=3$	$k=3$	693.0	0	348,444	2023.79	692.93
$l=3$	$k=4$	578.0	7	269,003	1602.70	577.70
$l=3$	$k=5$	462.0	10	212,062	1319.89	461.93
$l=4$	$k=1$	924.0	13	328,332	1593.45	923.76
$l=4$	$k=2$	809.0	10	341,871	1801.26	808.63
$l=4$	$k=3$	693.0	7	312,463	1771.47	692.89
$l=4$	$k=4$	578.0	0	304,021	1827.65	577.93
$l=4$	$k=5$	462.0	4	236,241	1491.44	461.93
$l=5$	$k=1$	924.0	13	328,332	1593.45	923.76
$l=5$	$k=2$	809.0	10	341,871	1801.26	808.63
$l=5$	$k=3$	693.0	7	312,463	1771.47	692.89
$l=5$	$k=4$	578.0	4	282,935	1680.17	577.98
$l=5$	$k=5$	462.0	0	247,935	1603.23	461.82

Note:

a) For $l = 1, ..., N_{F_{t,i,m}}$; $N_{F_{t,i,m}}$=5; $t = 1$; $i = 1, ..., J_1 = 26$; and $m = 1, ..., N_{PF_{t,i}} = 5$
Where: $N_{F_{t,i,m}}$ = number of levels of actual funding received at the state $L_t^{i,m}$

b) For $k = 1, ..., N_{D_{t,i,m}}$; $N_{D_{t,i,m}}$=5; $t = 1$; $i = 1, ..., J_1 = 26$; and $m = 1, ..., N_{PF_{t,i}} = 5$
Where: $N_{D_{t,i,m}}$ = number of levels of the possible funding decisions planned at the state $L_t^{i,m}$

c) Level of Possible Funding Allocation (BT_1^k) in monetary terms (\$ Million)

d) Cost Escalation Coefficient = 0, or without cost escalation, when $k = l$

e) Irrigation Area Developed associated with each level of possible funding (hectares)

f) Optimal Economic Return in terms of NPVB for each level of possible funding (\$ Million)

g) Total cost required associated with each level of $AD_1^{k,l}$

Table A.29: Input Data for All Cases of the SDP Resulting from the FCCIGP At Upper Confidence Limit of the NPVB Criterion for Stage $t = 1$ of the SDP

Index[a)] of Level of Actual Funding Received F_1^l	Index[b)] of Level of Possible Funding D_1^k	Level[c)] of Possible Funding Allocation BT_1^k ($ Million)	Cost [d)] Escalation Coefficient (%)	$AD_1^{k,l}$[e)] Irrigation Area Developed (hectares)	Optimal [f)] Return in Term of NPVB $V_1^{k,l}$	Total[g)] cost Required ($ Million)
$l = 1$	$k = 1$	924.0	0	404,476	796.60	920.35
$l = 1$	$k = 2$	809.0	4	304,890	615.50	653.89
$l = 1$	$k = 3$	693.0	7	304,890	578.68	680.15
$l = 1$	$k = 4$	578.0	10	250,090	498.27	570.50
$l = 1$	$k = 5$	462.0	13	171,995	415.87	461.72
$l = 2$	$k = 1$	924.0	4	380,248	682.21	922.56
$l = 2$	$k = 2$	809.0	0	355,976	737.37	808.73
$l = 2$	$k = 3$	693.0	7	304,890	578.68	680.15
$l = 2$	$k = 4$	578.0	10	250,090	498.27	570.50
$l = 2$	$k = 5$	462.0	13	171,995	415.87	461.72
$l = 3$	$k = 1$	924.0	13	304,890	403.30	793.16
$l = 3$	$k = 2$	809.0	4	304,890	615.50	653.89
$l = 3$	$k = 3$	693.0	0	304,890	666.89	591.94
$l = 3$	$k = 4$	578.0	7	263,890	547.49	570.49
$l = 3$	$k = 5$	462.0	10	209,395	466.51	461.25
$l = 4$	$k = 1$	924.0	13	304,890	403.30	793.16
$l = 4$	$k = 2$	809.0	10	304,890	494.29	733.22
$l = 4$	$k = 3$	693.0	7	304,890	578.68	680.15
$l = 4$	$k = 4$	578.0	0	297,390	682.16	577.83
$l = 4$	$k = 5$	462.0	4	227.763	555.67	461.87
$l = 5$	$k = 1$	924.0	13	304,890	403.30	793.16
$l = 5$	$k = 2$	809.0	10	304,890	494.29	733.22
$l = 5$	$k = 3$	693.0	7	304,890	578.68	680.15
$l = 5$	$k = 4$	578.0	4	271,818	594.68	577.25
$l = 5$	$k = 5$	462.0	0	246,563	625.86	461.88

Note:

a) For $l = 1, ..., N_{F_{t,i,m}}$; $N_{F_{t,i,m}}$=5, $t = 1$; $i = 1, ..., J_1 = 26$; and $m = 1, ..., N_{PF_{t,i}} = 5$
Where: $N_{F_{t,i,m}}$= number of levels of actual funding received at the state $L_t^{i,m}$

b) For $k = 1, ..., N_{D_{t,i,m}}$; $N_{D_{t,i,m}}$=5; $t = 1$; $i = 1, ..., J_1 = 26$; and $m = 1, ..., N_{PF_{t,i}} = 5$
Where: $N_{D_{t,i,m}}$= number of levels of the possible funding decisions planned at the state $L_t^{i,m}$

c) Level of Possible Funding Allocation (BT_1^k) in monetary terms ($ Million)

d) Cost Escalation Coefficient = 0, or without cost escalation, when $k = l$

e) Irrigation Area Developed associated with each level of possible funding (hectares)

f) Optimal Economic Return in terms of NPVB for each level of possible funding ($ Million)

g) Total cost required associated with each level of $AD_1^{k,l}$

Table A.30: Input Data for All Cases of the SDP Resulting from the FCCIGP At Mean Confidence Limit of the NPVB Criterion for Stage $t = 2$ of the SDP

Index[a)] of Level of Actual Funding Received F_2^l	Index[b)] of Level of Possible Funding D_2^k ($ Milion)	Level[c)] of Possible Funding Allocation BT_2^k	Cost [d)] Escalation Coefficient (%)	$AD_2^{k,l}$ [e)] Irrigation Area Developed (hectares)	Optimal [f)] Return in Term of NPVB $V_2^{k,l}$	Total[g)] cost Required ($ Million)
$l = 1$	$k = 1$	796.0	0	202,100	891.59	710.03
$l = 1$	$k = 2$	690.0	4	182,233	809.46	689.63
$l = 1$	$k = 3$	580.0	7	146,603	736.90	579.55
$l = 1$	$k = 4$	478.0	10	116,075	661.40	477.53
$l = 1$	$k = 5$	370.0	13	97,825	521.05	369.74
$l = 2$	$k = 1$	796.0	4	202,100	822.57	769.03
$l = 2$	$k = 2$	690.0	0	194,433	880.61	684.84
$l = 2$	$k = 3$	580.0	7	146,603	736.90	579.55
$l = 2$	$k = 4$	478.0	10	116,075	661.40	477.53
$l = 2$	$k = 5$	370.0	13	97,825	521.05	369.74
$l = 3$	$k = 1$	796.0	13	178,703	664.79	795.74
$l = 3$	$k = 2$	690.0	4	182,233	809.46	689.63
$l = 3$	$k = 3$	580.0	0	166,433	855.21	578.35
$l = 3$	$k = 4$	478.0	7	124,635	704.67	477.91
$l = 3$	$k = 5$	370.0	10	102,425	551.57	369.52
$l = 4$	$k = 1$	796.0	13	178,703	664.79	795.74
$l = 4$	$k = 2$	690.0	10	163,933	709.01	689.61
$l = 4$	$k = 3$	580.0	7	146,603	736.90	579.55
$l = 4$	$k = 4$	478.0	0	141,565	808.38	477.76
$l = 4$	$k = 5$	370.0	4	89,695	643.87	369.15
$k = 5$	$l = 1$	796.0	13	178,703	664.79	795.74
$k = 5$	$l = 2$	690.0	10	163,933	709.01	689.61
$k = 5$	$l = 3$	580.0	7	146,603	736.90	579.55
$k = 5$	$l = 4$	478.0	4	132,435	754.61	477.80
$k = 5$	$l = 5$	370.0	0	107,655	735.55	368.82

Note:

a) For $l = 1, ..., N_{F_{t,i,m}}$; $N_{F_{t,i,m}}$=5, $t = 2$; $i = 1, ..., J_2 = 26$; and $m = 1, ..., N_{PF_{t,i}} = 5$

Where: $N_{F_{t,i,m}}$= number of levels of actual funding received at the state $L_t^{i,m}$

b) For $k = 1, ..., N_{D_{t,i,m}}$; $N_{D_{t,i,m}}$=5, $t = 2$; $i = 1, ..., J_2 = 26$, and $m = 1, ..., N_{PF_{t,i}} = 5$

Where: $N_{D_{t,i,m}}$= number of levels of the possible funding decisions planned at the state $L_t^{i,m}$

c) Level of Possible Funding Allocation (BT_2^k) in monetary terms ($ Million)

d) Cost Escalation Coefficient = 0, or without cost escalation, when $k = l$

e) Irrigation Area Developed associated with each level of possible funding (hectares)

f) Optimal Economic Return in terms of NPVB for each level of possible funding ($ Million)

g) Total cost required associated with each level of $AD_2^{k,l}$

Table A.31: Input Data for All Cases of the SDP Resulting from the FCCIGP At Lower Confidence Limit of the NPVB Criterion for Stage t=2 of the SDP

Index[a)] of Level of Actual Funding Received F_2^l	Index[b)] of Level of Possible Funding D_2^k	Level[c)] of Possible Funding Allocation BT_2^k ($ Million)	Cost [d)] Escalation Coefficient (%)	$AD_2^{k,l}$ [e)] Irrigation Area Developed (hectares)	Optimal [f)] Return in Term of NPVB $V_2^{k,l}$	Total[g)] cost Required ($ Million)
$l = 1$	$k = 1$	796.0	0	225,259	1499.56	795.05
$l = 1$	$k = 2$	690.0	4	182,233	1314.78	686.14
$l = 1$	$k = 3$	580.0	7	146,635	1182.33	579.61
$l = 1$	$k = 4$	478.0	10	116,075	1047.26	477.80
$l = 1$	$k = 5$	370.0	13	97,825	817.80	369.74
$l = 2$	$k = 1$	796.0	4	211,115	1398.14	795.76
$l = 2$	$k = 2$	690.0	0	196,833	1413.15	689.78
$l = 2$	$k = 3$	580.0	7	146,635	1182.33	579.61
$l = 2$	$k = 4$	478.0	10	116,075	1047.26	477.80
$l = 2$	$k = 5$	370.0	13	97,825	817.80	369.74
$l = 3$	$k = 1$	796.0	13	178,633	1168.60	797.91
$l = 3$	$k = 2$	690.0	4	182,233	1314.78	689.63
$l = 3$	$k = 3$	580.0	0	166,433	1334.76	579.03
$l = 3$	$k = 4$	478.0	7	124,635	1106.47	477.91
$l = 3$	$k = 5$	370.0	10	102,425	858.67	369.51
$l = 4$	$k = 1$	796.0	13	178,633	1168.60	797.91
$l = 4$	$k = 2$	690.0	10	163,933	1184.36	689.91
$l = 4$	$k = 3$	580.0	7	146,635	1182.33	579.61
$l = 4$	$k = 4$	478.0	0	142,033	1251.77	477.91
$l = 4$	$k = 5$	370.0	4	89,695	982.64	369.15
$l = 5$	$k = 1$	796.0	13	178,633	1168.60	797.91
$l = 5$	$k = 2$	690.0	10	163,933	1184.36	689.91
$l = 5$	$k = 3$	580.0	7	146,635	1182.33	579.61
$l = 5$	$k = 4$	478.0	4	132,435	1172.31	477.77
$l = 5$	$k = 5$	370.0	0	107,655	1104.89	368.82

Note:

a) For $l = 1, ..., N_{F_{t,i,m}}$; $N_{F_{t,i,m}}$=5, $t = 2$; $i = 1, ..., J_2 = 26$, and $m = 1, ..., N_{PF_{t,i}} = 5$

Where: $N_{F_{t,i,m}}$= number of levels of actual funding received at the state $L_t^{i,m}$

b) For $k = 1, ..., N_{D_{t,i,m}}$; $N_{D_{t,i,m}}$=5; $t = 2$; $i = 1, ..., J_2 = 26$; and $m = 1, ..., N_{PF_{t,i}} = 5$

Where: $N_{D_{t,i,m}}$= number of levels of the possible funding decisions planned at the state $L_t^{i,m}$

c) Level of Possible Funding Allocation (BT_2^k) in monetary terms ($ Million)

d) Cost Escalation Coefficient = 0, or without cost escalation, when $k = l$

e) Irrigation Area Developed associated with each level of possible funding (hectares)

f) Optimal Economic Return in terms of NPVB for each level of possible funding ($ Million)

g) Total cost required associated with each level of $AD_2^{k,l}$

Table A.32: Input Data for All Cases of the SDP Resulting from the FCCIGP At Upper Confidence Limit of the NPVB Criterion for Stage $t = 2$ of the SDP

Index[a) of Level of Actual Funding Received F_2^l	Index[b) of Level of Possible Funding D_2^k ($ Million)	Level[c) of Possible Funding Allocation BT_2^k	Cost [d) Escalation Coefficient (%)	$AD_2^{k,l}$ [e) Irrigation Area Developed (hectares)	Optimal [f) Return in Term of NPVB $V_2^{k,l}$	Total[g) cost Required ($ Million)
$l=1$	$k=1$	796.0	0	157,433	368.59	549.90
$l=1$	$k=2$	690.0	4	157,433	315.85	595.83
$l=1$	$k=3$	580.0	7	146,603	291.16	579.36
$l=1$	$k=4$	478.0	10	116,075	274.97	477.82
$l=1$	$k=5$	370.0	13	97,825	224.31	369.74
$l=2$	$k=1$	796.0	4	157,433	337.07	600.80
$l=2$	$k=2$	690.0	0	157,433	369.59	549.90
$l=2$	$k=3$	580.0	7	146,603	291.16	579.36
$l=2$	$k=4$	478.0	10	116,075	274.97	477.83
$l=2$	$k=5$	370.0	13	97,825	224.31	369.74
$l=3$	$k=1$	796.0	13	157,433	179.84	712.10
$l=3$	$k=2$	690.0	4	157,433	315.85	595.83
$l=3$	$k=3$	580.0	0	157,433	369.59	549.90
$l=3$	$k=4$	478.0	7	124,635	302.87	477.91
$l=3$	$k=5$	370.0	10	102,425	244.23	369.96
$l=4$	$k=1$	796.0	13	157,433	179.84	712.10
$l=4$	$k=2$	690.0	10	157,433	231.89	667.59
$l=4$	$k=3$	580.0	7	146,603	291.16	579.36
$l=4$	$k=4$	478.0	0	139,535	376.24	477.91
$l=4$	$k=5$	370.0	4	89,695	305.10	369.15
$l=5$	$k=1$	796.0	13	157,433	179.84	712.10
$l=5$	$k=2$	690.0	10	157,433	231.89	667.59
$l=5$	$k=3$	580.0	7	146,603	291.16	579.36
$l=5$	$k=4$	478.0	4	131,435	333.52	476.68
$l=5$	$k=5$	370.0	0	107,655	366.21	368.82

Note:

a) For $l = 1, ..., N_{F_{t,i,m}}$; $N_{F_{t,i,m}}$=5; $t = 2$; $i = 1, ..., J_t = 26$; and $m = 1, ..., N_{PF_{t,i}} = 5$

Where: $N_{F_{t,i,m}}$ = number of levels of actual funding received at the state $L_t^{i,m}$

b) For $k = 1, ..., N_{D_{t,i,m}}$; $N_{D_{t,i,m}}$=5; $t = 2$; $i = 1, ..., J_t = 26$; and $m = 1, ..., N_{PF_{t,i}} = 5$

Where: $N_{D_{t,i,m}}$ = number of levels of the possible funding decisions planned at the state $L_t^{i,m}$

c) Level of Possible Funding Allocation (BT_2^k) in monetary terms ($ Million)

d) Cost Escalation Coefficient = 0, or without cost escalation, when $k = l$

e) Irrigation Area Developed associated with each level of possible funding (hectares)

f) Optimal Economic Return in terms of NPVB for each level of possible funding ($ Million)

g) Total cost required associated with each level of $AD_2^{k,l}$

Table A.33: Input Data for All Cases of the SDP Resulting from the FCCIGP At Mean Confidence Limit of the NPVB Criterion for Stage $t = 3$ of the SDP

Index[a] of Level of Actual Funding Received F_3^l	Index[b] of Level of Possible Funding D_3^k ($ Million)	Level[c] of Possible Funding Allocation BT_3^k	Cost [d] Escalation Coefficient (%)	$AD_3^{k,l}$ [e] Irrigation Area Developed (hectares)	Optimal [f] Return in Term of NPVB $V_3^{k,l}$	Total[g] cost Required ($ Million)
$l=1$	$k=1$	1050.0	0	248,618	934.38	910.62
$l=1$	$k=2$	910.0	4	233,118	835.70	908.95
$l=1$	$k=3$	770.0	7	188,970	729.24	769.33
$l=1$	$k=4$	630.0	10	146,720	672.55	629.87
$l=1$	$k=5$	490.0	13	104,916	584.76	485.36
$l=2$	$k=1$	1050.0	4	248,618	836.44	1000.16
$l=2$	$k=2$	910.0	0	248,618	933.91	909.35
$l=2$	$k=3$	770.0	7	188,970	729.24	769.33
$l=2$	$k=4$	630.0	10	146,720	672.55	629.87
$l=2$	$k=5$	490.0	13	104,916	584.76	485.36
$l=3$	$k=1$	1050.0	13	228,868	645.97	1047.30
$l=3$	$k=2$	910.0	4	233,118	835.70	908.95
$l=3$	$k=3$	770.0	0	216,968	900.22	769.62
$l=3$	$k=4$	630.0	7	151,790	704.70	628.87
$l=3$	$k=5$	490.0	10	112,234	625.32	488.18
$l=4$	$k=1$	1050.0	13	228,868	645.97	1047.30
$l=4$	$k=2$	910.0	4	209,570	700.32	904.26
$l=4$	$k=3$	770.0	0	216,968	900.22	769.62
$l=4$	$k=4$	630.0	7	177,720	824.00	626.07
$l=4$	$k=5$	490.0	10	129,290	721.28	488.18
$l=5$	$k=1$	1050.0	13	228,868	645.97	1047.30
$l=5$	$k=2$	910.0	4	209,570	700.32	904.26
$l=5$	$k=3$	770.0	0	216,968	900.22	769.62
$l=5$	$k=4$	630.0	7	160,320	755.80	629.45
$l=5$	$k=5$	490.0	10	138,190	786.73	489.20

Note:

[a] For $l = 1, ..., N_{F_{t,i,m}}$; $N_{F_{t,i,m}}=5$, $t = 3$, $i = 1, ..., J_3 = 26$, and $m = 1, ..., N_{PF_{t,i}} = 5$

Where: $N_{F_{t,i,m}}$ = number of levels of actual funding received at the state $L_t^{i,m}$

[b] For $k = 1, ..., N_{D_{t,i,m}}$; $N_{D_{t,i,m}}=5$; $t = 3$; $i = 1, ..., J_3 = 26$; and $m = 1, ..., N_{PF_{t,i}} = 5$

Where: $N_{D_{t,i,m}}$ = number of levels of the possible funding decisions planned at the state $L_t^{i,m}$

[c] Level of Possible Funding Allocation (BT_3^k) in monetary terms ($ Million)

[d] Cost Escalation Coefficient = 0, or without cost escalation, when $k = l$

[e] Irrigation Area Developed associated with each level of possible funding (hectares)

[f] Optimal Economic Return in terms of NPVB for each level of possible funding ($ Million)

[g] Total cost required associated with each level of $AD_3^{k,l}$

Table A.34: Input Data for All Cases of the SDP Resulting from the FCCIGP At Lower Confidence Limit of the NPVB Criterion for Stage $t = 3$ of the SDP

Index[a] of Level of Actual Funding Received F_3^l	Index[b] of Level of Possible Funding D_3^k ($ Million)	Level[c] of Possible Funding Allocation BT_3^k	Cost [d] Escalation Coefficient (%)	$AD_3^{k,l}$ [e] Irrigation Area Developed (hectares)	Optimal [f] Return in Term of NPVB $V_3^{k,l}$	Total[g] cost Required ($ Million)
$l = 1$	$k = 1$	1050.0	0	282,468	1597.36	1049.60
$l = 1$	$k = 2$	910.0	4	233,118	1390.71	908.94
$l = 1$	$k = 3$	770.0	7	185,420	1233.74	769.73
$l = 1$	$k = 4$	630.0	10	146,720	1081.71	629.64
$l = 1$	$k = 5$	490.0	13	107,527	915.87	490.00
$l = 2$	$k = 1$	1050.0	4	262,468	1447.09	1049.35
$l = 2$	$k = 2$	910.0	0	248,868	1515.28	909.23
$l = 2$	$k = 3$	770.0	7	185,420	1233.74	769.73
$l = 2$	$k = 4$	630.0	10	146,720	1081.71	629.64
$l = 2$	$k = 5$	490.0	13	107,527	915.87	490.00
$l = 3$	$k = 1$	1050.0	13	229,968	1192.55	1049.74
$l = 3$	$k = 2$	910.0	4	233,118	1390.71	908.94
$l = 3$	$k = 3$	770.0	0	217,018	1422.14	769.25
$l = 3$	$k = 4$	630.0	7	151,790	1123.17	629.15
$l = 3$	$k = 5$	490.0	10	114,873	937.54	489.94
$l = 4$	$k = 1$	1050.0	13	229,968	1192.55	1049.74
$l = 4$	$k = 2$	910.0	10	204,968	1219.63	909.16
$l = 4$	$k = 3$	770.0	7	185,420	1233.74	769.73
$l = 4$	$k = 4$	630.0	0	173,218	1287.85	628.80
$l = 4$	$k = 5$	490.0	4	129,290	1094.79	489.58
$l = 5$	$k = 1$	1050.0	13	229,968	1192.55	1049.74
$l = 5$	$k = 2$	910.0	10	204,968	1219.63	909.16
$l = 5$	$k = 3$	770.0	7	185,420	1233.74	769.73
$l = 5$	$k = 4$	630.0	4	160,320	1192.16	628.19
$l = 5$	$k = 5$	490.0	0	138,190	1178.32	489.20

Note:

[a] For $l = 1, ..., N_{F_{t,i,m}}$; $N_{F_{t,i,m}}$=5, $t = 3$, $i = 1, ..., J_3 = 26$; and $m = 1, ..., N_{PF_{t,i}} = 5$

Where: $N_{F_{t,i,m}}$ = number of levels of actual funding received at the state $L_t^{i,m}$

[b] For $k = 1, ..., N_{D_{t,i,m}}$; $N_{D_{t,i,m}}$=5, $t = 3$, $i = 1, ..., J_3 = 26, andm$=1,...,N$_{PF_{t,i}}$ = 5

Where: $N_{D_{t,i,m}}$ = number of levels of the possible funding decisions planned at the state $L_t^{i,m}$

[c] Level of Possible Funding Allocation (BT_3^k) in monetary terms ($ Million)

[d] Cost Escalation Coefficient = 0, or without cost escalation, when $k = l$

[e] Irrigation Area Developed associated with each level of possible funding (hectares)

[f] Optimal Economic Return in terms of NPVB for each level of possible funding ($ Million)

[g] Total cost required associated with each level of $AD_3^{k,l}$

Table A.35: Input Data for All Cases of the SDP Resulting from the FCCIGP At Upper Confidence Limit of the NPVB Criterion for Stage $t = 3$ of the SDP

Index[a] of Level of Actual Funding Received F_3^l	Index[b] of Level of Possible Funding D_3^k ($ Million)	Level[c] of Possible Funding Allocation BT_3^k	Cost[d] Escalation Coefficient (%)	$AD_3^{k,l}$[e] Irrigation Area Developed (hectares)	Optimal[f] Return in Term of NPVB $V_3^{k,l}$	Total[g] cost Required ($ Million)
$l = 1$	$k = 1$	1050.0	0	95,362	379.01	345.17
$l = 1$	$k = 2$	910.0	4	95,362	344.93	374.05
$l = 1$	$k = 3$	770.0	7	95,362	318.64	396.33
$l = 1$	$k = 4$	630.0	10	95,362	292.04	418.87
$l = 1$	$k = 5$	490.0	13	95,362	264.73	442.02
$l = 2$	$k = 1$	1050.0	4	95,362	344.92	374.05
$l = 2$	$k = 2$	910.0	0	95,362	379.01	345.17
$l = 2$	$k = 3$	770.0	7	95,362	318.64	396.33
$l = 2$	$k = 4$	630.0	10	95,362	292.04	418.87
$l = 2$	$k = 5$	490.0	13	95,362	264.73	442.02
$l = 3$	$k = 1$	1050.0	13	95,362	264.73	442.02
$l = 3$	$k = 2$	910.0	4	95,362	344.93	374.05
$l = 3$	$k = 3$	770.0	0	95,362	379.01	345.17
$l = 3$	$k = 4$	630.0	7	95,362	318.64	396.33
$l = 3$	$k = 5$	490.0	10	95,362	292.04	418.87
$l = 4$	$k = 1$	1050.0	13	95,362	264.73	442.02
$l = 4$	$k = 2$	910.0	10	95,362	292.04	418.87
$l = 4$	$k = 3$	770.0	7	95,362	318.64	396.33
$l = 4$	$k = 4$	630.0	0	95,362	379.01	345.17
$l = 4$	$k = 5$	490.0	4	95,362	344.93	374.05
$l = 5$	$k = 1$	1050.0	13	95,362	264.73	442.02
$l = 5$	$k = 2$	910.0	10	95,362	292.04	418.87
$l = 5$	$k = 3$	770.0	7	95,362	318.64	396.33
$l = 5$	$k = 4$	630.0	4	95,362	344.93	374.05
$l = 5$	$k = 5$	490.0	0	95,362	379.01	345.17

Note:

[a] For $l = 1, ..., N_{F_{t,i,m}}$; $N_{F_{t,i,m}}$=5, $t = 3$, $i = 1, ..., J_3 = 26$; and $m = 1, ..., N_{PF_{t,i}} = 5$

Where: $N_{F_{t,i,m}}$= number of levels of actual funding received at the state $L_t^{i,m}$

[b] For $k = 1, ..., N_{D_{t,i,m}}$; $N_{D_{t,i,m}}$=5, $t = 3$, $i = 1, ..., J_3 = 26, and m$=1,...,$N_{PF_{t,i}} = 5$

Where: $N_{D_{t,i,m}}$= number of levels of the possible funding decisions planned at the state $L_t^{i,m}$

[c] Level of Possible Funding Allocation (BT_3^k) in monetary terms ($ Million)

[d] Cost Escalation Coefficient = 0, or without cost escalation, when $k = l$

[e] Irrigation Area Developed associated with each level of possible funding (hectares)

[f] Optimal Economic Return in terms of NPVB for each level of possible funding ($ Million)

[g] Total cost required associated with each level of $AD_3^{k,l}$

Table A.36: Input Data for All Cases of the SDP Resulting from the FCCIGP At Mean Confidence Limit of the NPVB Criterion for Stage $t = 4$ of the SDP

Index[a] of Level of Actual Funding Received F_4^l	Index[b] of Level of Possible Funding D_4^k ($ Million)	Level[c] of Possible Funding Allocation BT_4^k	Cost [d] Escalation Coefficient (%)	$AD_4^{k,l}$ [e] Irrigation Area Developed (hectares)	Optimal [f] Return in Term of NPVB $V_4^{k,l}$	Total[g] cost Required ($ Million)
$l = 1$	$k = 1$	1080.0	0	258,565	1298.23	1060.44
$l = 1$	$k = 2$	936.0	4	214,605	1110.24	930.31
$l = 1$	$k = 3$	792.0	7	146,415	909.55	644.50
$l = 1$	$k = 4$	648.0	10	139,215	863.76	641.03
$l = 1$	$k = 5$	504.0	13	98,550	738.52	499.63
$l = 2$	$k = 1$	1080.0	4	251,565	1164.82	1077.97
$l = 2$	$k = 2$	936.0	0	235,565	1233.89	932.83
$l = 2$	$k = 3$	792.0	7	146,415	909.55	644.50
$l = 2$	$k = 4$	648.0	10	139,215	863.76	641.03
$l = 2$	$k = 5$	504.0	13	98,550	738.52	499.63
$l = 3$	$k = 1$	1080.0	13	208,485	899.60	1075.51
$l = 3$	$k = 2$	936.0	4	235,565	1233.89	932.83
$l = 3$	$k = 3$	792.0	0	195,093	1163.19	785.47
$l = 3$	$k = 4$	648.0	7	146,415	909.55	644.50
$l = 3$	$k = 5$	504.0	10	105,550	798.64	502.19
$l = 4$	$k = 1$	1080.0	13	208,485	899.60	1075.51
$l = 4$	$k = 2$	936.0	10	192,893	970.46	934.66
$l = 4$	$k = 3$	792.0	7	146,415	909.55	644.50
$l = 4$	$k = 4$	648.0	0	158,890	1098.70	646.32
$l = 4$	$k = 5$	504.0	4	129,315	975.24	500.91
$l = 5$	$k = 1$	1080.0	13	208,485	899.60	1075.51
$l = 5$	$k = 2$	936.0	10	192,893	970.46	934.66
$l = 5$	$k = 3$	792.0	7	146,415	909.55	644.50
$l = 5$	$k = 4$	648.0	4	146,155	1022.60	647.78
$l = 5$	$k = 5$	504.0	0	129,315	975.16	500.91

Note:

[a] For $l = 1, ..., N_{F_{t,i,m}}$; $N_{F_{t,i,m}}$=5, $t = 4$, $i = 1, ..., J_4 = 31$; and $m = 1, ..., N_{PF_{t,i}} = 5$

Where: $N_{F_{t,i,m}}$= number of levels of actual funding received at the state $L_t^{i,m}$

[b] For $k = 1, ..., N_{D_{t,i,m}}$; $N_{D_{t,i,m}}$=5, $t = 4$, $i = 1, ..., J_4 = 31, andm$=1,...,$N_{PF_{t,i}} = 5$

Where: $N_{D_{t,i,m}}$= number of levels of the possible funding decisions planned at the state $L_t^{i,m}$

[c] Level of Possible Funding Allocation (BT_4^k) in monetary terms ($ Million)

[d] Cost Escalation Coefficient = 0, or without cost escalation, when $k = l$

[e] Irrigation Area Developed associated with each level of possible funding (hectares)

[f] Optimal Economic Return in terms of NPVB for each level of possible funding ($ Million)

[g] Total cost required associated with each level of $AD_4^{k,l}$

Table A.37: Input Data for All Cases of the SDP Resulting from the FCCIGP At Lower Confidence Limit of the NPVB Criterion for Stage $t = 4$ of the SDP

Index[a] of Level of Actual Funding Received F_4^l	Index[b] of Level of Possible Funding D_4^k ($ Million)	Level[c] of Possible Funding Allocation BT_4^k	Cost [d] Escalation Coefficient (%)	$AD_4^{k,l}$ [e] Irrigation Area Developed (hectares)	Optimal [f] Return in Term of NPVB $V_4^{k,l}$	Total[g] cost Required ($ Million)
$l = 1$	$k = 1$	1080.0	0	264,785	2030.80	1078.85
$l = 1$	$k = 2$	936.0	4	208,547	1755.56	935.90
$l = 1$	$k = 3$	792.0	7	171,795	1553.98	791.76
$l = 1$	$k = 4$	648.0	10	125,205	1326.61	646.50
$l = 1$	$k = 5$	504.0	13	98,550	1093.20	501.75
$l = 2$	$k = 1$	1080.0	4	244,405	1874.82	1074.0
$l = 2$	$k = 2$	936.0	0	238,185	1901.96	935.75
$l = 2$	$k = 3$	792.0	7	171,795	1553.98	791.76
$l = 2$	$k = 4$	648.0	10	125,205	1326.61	646.50
$l = 2$	$k = 5$	504.0	13	98,550	1093.20	501.75
$l = 3$	$k = 1$	1080.0	13	215,402	1550.06	1079.55
$l = 3$	$k = 2$	936.0	4	208,547	1755.56	935.90
$l = 3$	$k = 3$	792.0	0	189,035	1775.70	791.20
$l = 3$	$k = 4$	648.0	7	135,955	1411.13	646.84
$l = 3$	$k = 5$	504.0	10	105,550	1167.14	502.19
$l = 4$	$k = 1$	1080.0	13	215,402	1550.06	1079.55
$l = 4$	$k = 2$	936.0	10	197,055	1573.95	935.82
$l = 4$	$k = 3$	792.0	7	171,795	1553.98	791.76
$l = 4$	$k = 4$	648.0	0	158,890	1619.38	647.97
$l = 4$	$k = 5$	504.0	4	120,950	1319.80	502.45
$l = 5$	$k = 1$	1080.0	13	215,402	1550.06	1079.55
$l = 5$	$k = 2$	936.0	10	197,055	1573.95	935.82
$l = 5$	$k = 3$	792.0	7	171,795	1553.98	791.76
$l = 5$	$k = 4$	648.0	4	146,155	1515.58	677.77
$l = 5$	$k = 5$	504.0	0	132,070	1404.70	503.86

Note:

[a] For $l = 1, ..., N_{F_{t,i,m}}$; $N_{F_{t,i,m}}$=5, $t = 4$, $i = 1, ..., J_4 = 31$; and $m = 1, ..., N_{PF_{t,i}} = 5$

Where: $N_{F_{t,i,m}}$= number of levels of actual funding received at the state $L_t^{i,m}$

[b] For $k = 1, ..., N_{D_{t,i,m}}$; $N_{D_{t,i,m}}$=5, $t = 4$, $i = 1, ..., J_4 = 31, and$m=1,...,$N_{PF_{t,i}} = 5$

Where: $N_{D_{t,i,m}}$= number of levels of the possible funding decisions planned at the state $L_t^{i,m}$

[c] Level of Possible Funding Allocation (BT_4^k) in monetary terms ($ Million)

[d] Cost Escalation Coefficient = 0, or without cost escalation, when $k = l$

[e] Irrigation Area Developed associated with each level of possible funding (hectares)

[f] Optimal Economic Return in terms of NPVB for each level of possible funding ($ Million)

[g] Total cost required associated with each level of $AD_4^{k,l}$

Table A.38: Input Data for All Cases of the SDP Resulting from the FCCIGP At Upper Confidence Limit of the NPVB Criterion for Stage $t = 4$ of the SDP

Index[a] of Level of Actual Funding Received F_4^l	Index[b] of Level of Possible Funding D_4^k ($ Million)	Level[c] of Possible Funding Allocation BT_4^k	Cost [d] Escalation Coefficient (%)	$AD_4^{k,l}$ [e] Irrigation Area Developed (hectares)	Optimal [f] Return in Term of NPVB $V_4^{k,l}$	Total[g] cost Required ($ Million)
$l = 1$	$k = 1$	1080.0	0	112,200	567.77	433.74
$l = 1$	$k = 2$	936.0	4	112,200	505.04	486.01
$l = 1$	$k = 3$	792.0	7	112,200	469.18	515.90
$l = 1$	$k = 4$	648.0	10	112,200	445.04	536.02
$l = 1$	$k = 5$	504.0	13	93,000	395.21	480.80
$l = 2$	$k = 1$	1080.0	4	112,200	505.04	486.01
$l = 2$	$k = 2$	936.0	0	112,200	567.77	433.74
$l = 2$	$k = 3$	792.0	7	112,200	469.18	515.90
$l = 2$	$k = 4$	648.0	10	112,200	445.04	536.02
$l = 2$	$k = 5$	504.0	13	93,000	395.21	480.80
$l = 3$	$k = 1$	1080.0	13	112,200	374.96	594.41
$l = 3$	$k = 2$	936.0	4	112,200	505.04	486.01
$l = 3$	$k = 3$	792.0	0	112,200	567.77	433.74
$l = 3$	$k = 4$	648.0	7	112,200	480.48	506.48
$l = 3$	$k = 5$	504.0	10	100,000	438.95	483.54
$l = 4$	$k = 1$	1080.0	13	112,200	374.96	594.41
$l = 4$	$k = 2$	936.0	10	112,200	416.80	559.55
$l = 4$	$k = 3$	792.0	7	112,200	469.18	515.90
$l = 4$	$k = 4$	648.0	0	112,200	567.77	433.74
$l = 4$	$k = 5$	504.0	4	112,200	517.01	476.04
$l = 5$	$k = 1$	1080.0	13	112,200	374.96	594.41
$l = 5$	$k = 2$	936.0	10	112,200	416.80	559.55
$l = 5$	$k = 3$	792.0	7	112,200	469.18	515.90
$l = 5$	$k = 4$	648.0	4	112,200	517.01	476.04
$l = 5$	$k = 5$	504.0	0	112,200	567.77	433.74

Note:

a) For $l = 1, ..., N_{F_{t,i,m}}$; $N_{F_{t,i,m}}=5$, $t = 4$, $i = 1, ..., J_4 = 31$; and $m = 1, ..., N_{PF_{t,i}} = 5$

Where: $N_{F_{t,i,m}}$ = number of levels of actual funding received at the state $L_t^{i,m}$

b) For $k = 1, ..., N_{D_{t,i,m}}$; $N_{D_{t,i,m}}=5$, $t = 4$, $i = 1, ..., J_4 = 31, and m=1,...,N_{PF_{t,i}} = 5$

Where: $N_{D_{t,i,m}}$ = number of levels of the possible funding decisions planned at the state $L_t^{i,m}$

c) Level of Possible Funding Allocation (BT_4^k) in monetary terms ($ Million)

d) Cost Escalation Coefficient = 0, or without cost escalation, when $k = l$

e) Irrigation Area Developed associated with each level of possible funding (hectares)

f) Optimal Economic Return in terms of NPVB for each level of possible funding ($ Million)

g) Total cost required associated with each level of $AD_4^{k,l}$

Table A.39: Input Data for All Cases of the SDP Resulting from the FCCIGP At Mean Confidence Limit of the NPVB Criterion for Stage $t = 5$ of the SDP

Index[a)] of Level of Actual Funding Received F_5^l	Index[b)] of Level of Possible Funding D_5^k ($ Million)	Level[c)] of Possible Funding Allocation BT_5^k	Cost [d)] Escalation Coefficient (%)	$AD_5^{k,l}$ [e)] Irrigation Area Developed (hectares)	Optimal [f)] Return in Term of NPVB $V_5^{k,l}$	Total[g)] cost Required ($ Million)
$l = 1$	$k = 1$	1185.0	0	252,403	837.68	1137.78
$l = 1$	$k = 2$	1027.0	4	216,168	718.54	1026.80
$l = 1$	$k = 3$	869.0	7	175,444	626.76	862.67
$l = 1$	$k = 4$	711.0	10	139,457	561.64	708.74
$l = 1$	$k = 5$	553.0	13	99,749	484.21	552.94
$l = 2$	$k = 1$	1185.0	4	242,554	724.29	1175.41
$l = 2$	$k = 2$	1027.0	0	230,473	824.22	1019.32
$l = 2$	$k = 3$	869.0	7	175,444	626.76	862.67
$l = 2$	$k = 4$	711.0	10	139,457	561.64	708.74
$l = 2$	$k = 5$	553.0	13	99,749	484.21	552.94
$l = 3$	$k = 1$	1185.0	13	210,838	498.04	1184.47
$l = 3$	$k = 2$	1027.0	4	205,168	718.54	1026.80
$l = 3$	$k = 3$	869.0	0	194,494	784.21	854.83
$l = 3$	$k = 4$	711.0	7	150,068	619.08	710.53
$l = 3$	$k = 5$	553.0	10	107,503	535.29	551.81
$l = 4$	$k = 1$	1185.0	13	210,838	498.04	1184.47
$l = 4$	$k = 2$	1027.0	10	191,738	567.31	1025.76
$l = 4$	$k = 3$	869.0	7	175,444	626.76	854.83
$l = 4$	$k = 4$	711.0	0	164,344	753.44	699.63
$l = 4$	$k = 5$	553.0	4	118,829	621.87	552.75
$l = 5$	$k = 1$	1185.0	13	210,838	498.04	1184.47
$l = 5$	$k = 2$	1027.0	10	191,738	567.31	1025.76
$l = 5$	$k = 3$	869.0	7	175,444	626.76	854.83
$l = 5$	$k = 4$	711.0	4	158,374	672.44	710.78
$l = 5$	$k = 5$	553.0	0	129,116	685.32	550.77

Note:

a) For $l = 1, ..., N_{F_{t,i,m}}$; $N_{F_{t,i,m}}=5$, $t = 5$, $i = 1, ..., J_5 = 31$; and $m = 1, ..., N_{PF_{t,i}} = 5$

Where: $N_{F_{t,i,m}}$= number of levels of actual funding received at the state $L_t^{i,m}$

b) For $k = 1, ..., N_{D_{t,i,m}}$; $N_{D_{t,i,m}}=5$, $t = 5$, $i = 1, ..., J_5 = 31, and m=1,...,N_{PF_{t,i}} = 5$

Where: $N_{D_{t,i,m}}$= number of levels of the possible funding decisions planned at the state $L_t^{i,m}$

c) Level of Possible Funding Allocation (BT_5^k) in monetary terms ($ Million)

d) Cost Escalation Coefficient = 0, or without cost escalation, when $k = l$

e) Irrigation Area Developed associated with each level of possible funding (hectares)

f) Optimal Economic Return in terms of NPVB for each level of possible funding ($ Million)

g) Total cost required associated with each level of $AD_5^{k,l}$

Table A.40: Input Data for All Cases of the SDP Resulting from the FCCIGP At Lower Confidence Limit of the NPVB Criterion for Stage $t = 5$ of the SDP

Index[a] of Level of Actual Funding Received F_5^l	Index[b] of Level of Possible Funding D_5^k ($ Million)	Level[c] of Possible Funding Allocation BT_5^k	Cost [d] Escalation Coefficient (%)	$AD_5^{k,l}$ [e] Irrigation Area Developed (hectares)	Optimal [f] Return in Term of NPVB $V_5^{k,l}$	Total[g] cost Required ($ Million)
$l = 1$	$k = 1$	1185.0	0	262,168	1513.35	1181.22
$l = 1$	$k = 2$	1027.0	4	216,168	1277.23	1026.80
$l = 1$	$k = 3$	869.0	7	178,173	1118.35	868.37
$l = 1$	$k = 4$	711.0	10	139,781	959.81	707.76
$l = 1$	$k = 5$	553.0	13	100,838	805.35	552.98
$l = 2$	$k = 1$	1185.0	4	246,458	1352.54	1184.76
$l = 2$	$k = 2$	1027.0	0	230,598	1412.57	1026.80
$l = 2$	$k = 3$	869.0	7	178,173	1118.35	868.37
$l = 2$	$k = 4$	711.0	10	139,781	959.81	707.76
$l = 2$	$k = 5$	553.0	13	100,838	805.35	552.98
$l = 3$	$k = 1$	1185.0	13	210,838	1046.90	1184.76
$l = 3$	$k = 2$	1027.0	4	216,168	1277.23	1026.80
$l = 3$	$k = 3$	869.0	0	200,388	1323.96	864.93
$l = 3$	$k = 4$	711.0	7	150,068	1037.81	710.53
$l = 3$	$k = 5$	553.0	10	107,503	870.84	552.19
$l = 4$	$k = 1$	1185.0	13	210,838	1046.90	1184.66
$l = 4$	$k = 2$	1027.0	10	197,493	1099.90	1026.96
$l = 4$	$k = 3$	869.0	7	178,173	1118.35	868.37
$l = 4$	$k = 4$	711.0	0	166,698	1212.19	707.51
$l = 4$	$k = 5$	553.0	4	122,201	990.15	552.16
$l = 5$	$k = 1$	1185.0	13	210,838	1046.90	1184.66
$l = 5$	$k = 2$	1027.0	10	197,493	1099.90	1026.96
$l = 5$	$k = 3$	869.0	7	178,173	1118.35	868.37
$l = 5$	$k = 4$	711.0	4	158,374	1106.53	710.78
$l = 5$	$k = 5$	553.0	0	134,718	1084.0	552.83

Note:

a) For $l = 1, ..., N_{F_{t,i,m}}$; $N_{F_{t,i,m}}$=5, $t = 5$, $i = 1, ..., J_5 = 31$; and $m = 1, ..., N_{PF_{t,i}} = 5$

Where: $N_{F_{t,i,m}}$= number of levels of actual funding received at the state $L_t^{i,m}$

b) For $k = 1, ..., N_{D_{t,i,m}}$; $N_{D_{t,i,m}}$=5, $t = 5$, $i = 1, ..., J_5 = 31, and$m=1,...,$N_{PF_{t,i}} = 5$

Where: $N_{D_{t,i,m}}$= number of levels of the possible funding decisions planned at the state $L_t^{i,m}$

c) Level of Possible Funding Allocation (BT_5^k) in monetary terms ($ Million)

d) Cost Escalation Coefficient = 0, or without cost escalation, when $k = l$

e) Irrigation Area Developed associated with each level of possible funding (hectares)

f) Optimal Economic Return in terms of NPVB for each level of possible funding ($ Million)

g) Total cost required associated with each level of $AD_5^{k,l}$

Table A.41: Input Data for All Cases of the SDP Resulting from the FCCIGP At Upper Confidence Limit of the NPVB Criterion for Stage $t = 5$ of the SDP

Index[a] of Level of Actual Funding Received F_5^l	Index[b] of Level of Possible Funding D_5^k ($ Million)	Level[c] of Possible Funding Allocation BT_5^k	Cost [d] Escalation Coefficient (%)	$AD_5^{k,l}$ [e] Irrigation Area Developed (hectares)	Optimal [f] Return in Term of NPVB $V_5^{k,l}$	Total[g] cost Required ($ Million)
$l = 1$	$k = 1$	1185.0	0	78,588	296.50	342.27
$l = 1$	$k = 2$	1027.0	4	78,588	252.85	378.64
$l = 1$	$k = 3$	869.0	7	78,588	221.51	404.76
$l = 1$	$k = 4$	711.0	10	78,588	219.29	406.61
$l = 1$	$k = 5$	553.0	13	78,588	166.80	450.35
$l = 2$	$k = 1$	1185.0	4	78,588	252.48	378.64
$l = 2$	$k = 2$	1027.0	0	78,588	296.50	342.77
$l = 2$	$k = 3$	869.0	7	78,588	221.51	404.76
$l = 2$	$k = 4$	711.0	10	78,588	219.29	406.61
$l = 2$	$k = 5$	553.0	13	78,588	166.80	450.35
$l = 3$	$k = 1$	1185.0	13	78,588	161.78	454.53
$l = 3$	$k = 2$	1027.0	4	78,588	252.85	378.64
$l = 3$	$k = 3$	869.0	0	78,588	296.50	342.27
$l = 3$	$k = 4$	711.0	7	78,588	221.51	404.76
$l = 3$	$k = 5$	553.0	10	78,588	195.10	426.77
$l = 4$	$k = 1$	1185.0	13	78,588	161.78	454.53
$l = 4$	$k = 2$	1027.0	10	78,588	219.29	406.61
$l = 4$	$k = 3$	869.0	7	78,588	221.51	404.76
$l = 4$	$k = 4$	711.0	0	78,588	296.50	342.27
$l = 4$	$k = 5$	553.0	4	78,588	254.52	377.25
$l = 5$	$k = 1$	1185.0	13	78,588	161.78	454.53
$l = 5$	$k = 2$	1027.0	10	78,588	219.29	406.61
$l = 5$	$k = 3$	869.0	7	78,588	221.51	404.76
$l = 5$	$k = 4$	711.0	4	78,588	252.85	378.64
$l = 5$	$k = 5$	553.0	0	78,588	296.50	342.27

Note:

[a] For $l = 1, ..., N_{F_{t,i,m}}$; $N_{F_{t,i,m}}$=5, $t = 5$, $i = 1, ..., J_5 = 31$; and $m = 1, ..., N_{PF_{t,i}} = 5$

Where: $N_{F_{t,i,m}}$ = number of levels of actual funding received at the state $L_t^{i,m}$

[b] For $k = 1, ..., N_{D_{t,i,m}}$; $N_{D_{t,i,m}}$=5, $t = 5$, $i = 1, ..., J_5 = 31, and$m=1,...,$N_{PF_{t,i}} = 5$

Where: $N_{D_{t,i,m}}$ = number of levels of the possible funding decisions planned at the state $L_t^{i,m}$

[c] Level of Possible Funding Allocation (BT_5^k) in monetary terms ($ Million)

[d] Cost Escalation Coefficient = 0, or without cost escalation, when $k = l$

[e] Irrigation Area Developed associated with each level of possible funding (hectares)

[f] Optimal Economic Return in terms of NPVB for each level of possible funding ($ Million)

[g] Total cost required associated with each level of $AD_5^{k,l}$

Table A.42: Relative Frequency of Optimal Funding Decision for Each Stage and Each Case with Their Associated Goal Attainment for Upper Confidence Limit on NPVB and Membership Grade of Confidence Limit on NPVB $\lambda_{Upper} = 0.083$

PARAMETERS	GOAL ATTAINMENT OPTIMAL DECISION For Lower Confidence Level (5% exceeded)					REMARKS
	D_t^1	D_t^2	D_t^3	D_t^4	D_t^5	
SCHEDULING HORIZON $t = 1$						RELATIVE FREQUENCY OF OPTIMAL DECISION (%)
Irrigation Area (ha)	415629	*)	*)	*)	*)	Scenario 1: D_1^1 100, D_1^2 0, D_1^3 0, D_1^4 0, D_1^5 0
N.P.V. Of Benefit ($ 10^6)	2379.5	*) Non optimal decision				Scenario 2: D_1^1 100, D_1^2 0, D_1^3 0, D_1^4 0, D_1^5 0
Number of selected projects	14					Scenario 3: D_1^1 100, D_1^2 0, D_1^3 0, D_1^4 0, D_1^5 0
Total budget used ($ 10^6)	923.87					
SCHEDULING HORIZON $t = 2$						RELATIVE FREQUENCY OF OPTIMAL DECISION (%)
Irrigation Area (ha)	225259	196833	166433	142033	107655	Scenario 1: D_2^1 0, D_2^2 1.20, D_2^3 10.80, D_2^4 34.00, D_2^5 54.00
N.P.V. Of Benefit ($ 10^6)	1499.56	1413.15	1334.76	1251.77	1104.89	Scenario 2: D_2^1 100, D_2^2 0, D_2^3 0, D_2^4 0, D_2^5 0
Number of selected projects	25	24	20	17	9	Scenario 3: D_2^1 0, D_2^2 0, D_2^3 13, D_2^4 20.8, D_2^5 66.20
Total budget used ($ 10^6)	795.05	795.76	579.03	477.91	368.82	
SCHEDULING HORIZON $t = 3$						RELATIVE FREQUENCY OF OPTIMAL DECISION (%)
Irrigation Area (ha)	282468	248618	217018	173218	138190	Scenario 1: D_3^1 0, D_3^2 0.8, D_3^3 12.90, D_3^4 83.30, D_3^5 3.00
N.P.V. Of Benefit ($ 10^6)	1597.36	1515.28	1422.14	1287.85	786.73	Scenario 2: D_3^1 100, D_3^2 0, D_3^3 0, D_3^4 0, D_3^5 0
Number of selected projects	28	26	20	16	12	Scenario 3: D_3^1 0, D_3^2 0, D_3^3 80.30, D_3^4 12.10, D_3^5 7.60
Total budget used ($ 10^6)	1049.6	909.35	769.25	628.8	489.2	
SCHEDULING HORIZON $t = 4$						RELATIVE FREQUENCY OF OPTIMAL DECISION (%)
Irrigation Area (ha)	264785	238138	189035	158890	132070	Scenario 1: D_4^1 0, D_4^2 0, D_4^3 22.60, D_4^4 75.20, D_4^5 2.20
N.P.V. Of Benefit ($ 10^6)	2030.8	1901.96	1775.7	1619.38	1404.7	Scenario 2: D_4^1 100, D_4^2 0, D_4^3 0, D_4^4 0, D_4^5 0
Number of selected projects	26	20	17	16	14	Scenario 3: D_4^1 0, D_4^2 0, D_4^3 83.0, D_4^4 10.90, D_4^5 6.10
Total budget used ($ 10^6)	1078.85	935.75	791.2	647.97	503.86	
SCHEDULING HORIZON $t = 5$						RELATIVE FREQUENCY OF OPTIMAL DECISION
Irrigation Area (ha)	262168	230598	200388	166698	134718	Scenario 1: D_5^1 0, D_5^2 0, D_5^3 29.90, D_5^4 67.30, D_5^5 2.80
N.P.V. Of Benefit ($ 10^6)	1513.35	1412.57	1323.96	1212.19	1084	Scenario 2: D_5^1 100, D_5^2 0, D_5^3 0, D_5^4 0, D_5^5 0
Number of selected projects	24	25	18	18	15	Scenario 3: D_5^1 0, D_5^2 0, D_5^3 97.40, D_5^4 0, D_5^5 2.60
Total budget used ($ 10^6)	1181.22	1026.72	864.93	707.51	552.83	

SCENARIO 1 = LIMITED BUDEGT
SCENARIO 2 = NON-LIMITED BUDGET
SCENARIO 3 = UNDETERMINED BUDGET

Table A.43: Relative Frequency of Optimal Funding Decision for Each Stage and Each Case with Their Associated Goal Attainment for Lower Confidence Limit on NPVB and Membership Grade of Confidence Limit on NPVB $\lambda_{Lower} = 0.085$

PARAMETERS	GOAL ATTAINMENT OPTIMAL DECISION For Upper Confidence Level (95% exceeded) D_t^1	D_t^2	D_t^3	D_t^4	D_t^5	REMARKS
SCHEDULING HORIZON $t = 1$						RELATIVE FREQUENCY OF OPTIMAL DECISION (%)
Irrigation Area (ha)	404476	*)	*)	*)	*)	Scenario 1: D_1^1 0, D_1^2 100, D_1^3 0, D_1^4 0, D_1^5 0
N.P.V. Of Benefit ($ 10^6)	796.6	*) Non optimal decision				Scenario 2: D_1^1 100, D_1^2 0, D_1^3 0, D_1^4 0, D_1^5 0
Number of selected projects	13					Scenario 3: D_1^1 0, D_1^2 100, D_1^3 0, D_1^4 0, D_1^5 0
Total budget used ($ 10^6)	920.25					
SCHEDULING HORIZON $t = 2$						RELATIVE FREQUENCY OF OPTIMAL DECISION (%)
Irrigation Area (ha)	157433	157433	157433	139535	107655	Scenario 1: D_2^1 0, D_2^2 0, D_2^3 14.50, D_2^4 58.00, D_2^5 27.50
N.P.V. Of Benefit ($ 10^6)	369.59	369.59	369.59	376.24	366.21	Scenario 2: D_2^1 100, D_2^2 0, D_2^3 0, D_2^4 0, D_2^5 0
Number of selected projects	20	20	20	17	9	Scenario 3: D_2^1 0, D_2^2 0, D_2^3 2.30, D_2^4 0, D_2^5 97.70
Total budget used ($ 10^6)	549.9	549.9	549.9	477	368.82	
SCHEDULING HORIZON $t = 3$						RELATIVE FREQUENCY OF OPTIMAL DECISION (%)
Irrigation Area (ha)	95362	95362	95362	95362	95362	Scenario 1: D_3^1 0, D_3^2 0, D_3^3 9.90, D_3^4 84.00, D_3^5 6.10
N.P.V. Of Benefit ($ 10^6)	379.01	379.01	379.01	379.01	379.01	Scenario 2: D_3^1 100, D_3^2 0, D_3^3 0, D_3^4 0, D_3^5 0
Number of selected projects	10	10	10	10	10	Scenario 3: D_3^1 0, D_3^2 0, D_3^3 0, D_3^4 3.00, D_3^5 97.0
Total budget used ($ 10^6)	345.17	345.17	345.17	345.17	345.17	
SCHEDULING HORIZON $t = 4$						RELATIVE FREQUENCY OF OPTIMAL DECISION (%)
Irrigation Area (ha)	112200	112200	112200	112200	112200	Scenario 1: D_4^1 0, D_4^2 0, D_4^3 24.50, D_4^4 70.70, D_4^5 4.80
N.P.V. Of Benefit ($ 10^6)	567.77	567.77	567.77	567.77	567.77	Scenario 2: D_4^1 100, D_4^2 0, D_4^3 0, D_4^4 0, D_4^5 0
Number of selected projects	12	12	12	12	12	Scenario 3: D_4^1 0, D_4^2 0, D_4^3 0, D_4^4 3.20, D_4^5 96.80
Total budget used ($ 10^6)	433.74	433.74	433.74	433.74	433.74	
SCHEDULING HORIZON $t = 5$						RELATIVE FREQUENCY OF OPTIMAL DECISION
Irrigation Area (ha)	78588	78588	78588	78588	78588	Scenario 1: D_5^1 0, D_5^2 0, D_5^3 24.10, D_5^4 0, D_5^5 75.90
N.P.V. Of Benefit ($ 10^6)	296.5	296.5	296.5	296.5	296.5	Scenario 2: D_5^1 100, D_5^2 0, D_5^3 0, D_5^4 0, D_5^5 0
Number of selected projects	9	9	9	9	9	Scenario 3: D_5^1 0, D_5^2 0, D_5^3 0, D_5^4 3.20, D_5^5 96.80
Total budget used ($ 10^6)	342.27	342.27	342.27	342.27	342.27	

SCENARIO 1 = LIMITED BUDGET
SCENARIO 2 = NON-LIMITED BUDEGT
SCENARIO 3 = UNDETERMINED BUDGET

Table A.44: Distribution of Optimal Funding Decision $D^*_{t,i,m}$ with Respect to the State Combination of Level of Development and Previous Funding, $L_t^{i,m}$ $\forall\, t,\ i,\ m$ for Undetermined Budget Scenario and Lower Confidence Limit on NPVB with Membership Grade of Confidence Limit on NPVB, λ_{Lower}=0.085

SCHEDULING HORIZON ; LEVEL OF PREVIOUS FUNDING=1 ; OPTIMAL DECISION: $D^*_{1,1}=1$
$t=1$ LEVEL OF DEVELOPMENT: = 1

SCHEDULING HORIZON: $t=2$						SCHEDULING HORIZON: $t=3$						SCHEDULING HORIZON: $t=4$						SCHEDULING HORIZON: $t=5$					
LEVEL OF DEVEL-OPMENT	LEVEL OF PREVIOUS FUND m					LEVEL OF DEVEL-OPMENT	LEVEL OF PREVIOUS FUND m					LEVEL OF DEVEL-OPMENT	LEVEL OF PREVIOUS FUND m					LEVEL OF DEVEL-OPMENT	LEVEL OF PREVIOUS FUND m				
	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
i	OPTIMAL DECISION $D^*_{2,i,m}$					i	OPTIMAL DECISION $D^*_{3,i,m}$					i	OPTIMAL DECISION $D^*_{4,i,m}$					i	OPTIMAL DECISION $D^*_{5,i,m}$				
1	5	3	3	3	3	1	3	3	3	3	3	1	4	4	4	4	4	1	3	3	3	3	3
2	5	3	5	5	5	2	5	4	5	5	5	2	4	3	3	3	3	2	3	3	3	3	3
3	4	5	5	5	5	3	5	5	5	4	4	3	3	3	3	3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3
5	4	4	4	4	4	5	4	4	4	4	4	5	3	3	3	3	3	5	3	3	3	3	3
6	4	4	4	5	5	6	3	3	3	3	3	6	4	4	4	4	4	6	3	3	3	3	3
7	3	3	3	3	5	7	3	3	3	3	5	7	3	3	3	3	5	7	3	3	3	3	5
8	3	3	3	5	3	8	3	3	3	5	3	8	3	3	3	5	3	8	3	3	3	5	3
9	4	4	5	4	4	9	3	3	5	3	3	9	3	3	5	3	3	9	3	3	5	3	3
10	4	5	4	4	4	10	3	5	3	3	3	10	3	5	3	3	3	10	3	5	3	3	3
11	5	3	3	3	3	11	5	3	3	3	3	11	5	3	3	3	3	11	5	3	3	3	3
12	5	5	5	5	5	12	3	3	3	3	3	12	3	3	3	3	3	12	3	3	3	3	3
13	5	5	5	5	5	13	3	3	3	3	3	13	3	3	3	3	3	13	3	3	3	3	3
14	5	5	5	5	5	14	3	3	3	3	3	14	3	3	3	3	3	14	3	3	3	3	3
15	5	5	5	5	5	15	3	3	3	3	3	15	3	3	3	3	3	15	3	3	3	3	3
16	5	5	5	5	5	16	3	3	3	3	3	16	3	3	3	3	3	16	3	3	3	3	3
17	5	5	5	5	5	17	3	3	3	3	3	17	3	3	3	3	3	17	3	3	3	3	3
18	5	5	5	5	4	18	3	3	3	3	3	18	3	3	3	3	3	18	3	3	3	3	3
19	5	5	5	4	5	19	3	3	3	3	3	19	3	3	3	3	3	19	3	3	3	3	3
20	5	5	4	5	5	20	3	3	3	3	3	20	3	3	3	3	3	20	3	3	3	3	3
21	5	4	5	5	5	21	3	3	3	3	3	21	3	3	3	3	3	21	3	3	3	3	3
22	4	5	5	5	5	22	3	3	3	3	3	22	3	3	3	3	5	22	3	3	3	3	3
23	5	5	5	5	5	23	3	3	3	3	3	23	3	3	3	5	3	23	3	3	3	3	3
24	5	5	5	5	5	24	3	3	3	3	3	24	3	3	5	3	3	24	3	3	3	3	3
25	5	5	5	5	5	25	3	3	3	3	3	25	3	5	3	3	3	25	3	3	3	3	3
26	5	5	5	5	5	26	3	3	3	3	3	26	5	3	3	3	3	26	3	3	3	3	3
												27	3	3	3	3	3	27	3	3	3	3	3
												28	3	3	3	3	3	28	3	3	3	3	3
												29	3	3	3	3	3	29	3	3	3	3	3
												30	3	3	3	3	3	30	3	3	3	3	3
												31	3	3	3	3	3	31	3	3	3	3	3

Table A.45: Distribution of Optimal Funding Decision $D^*_{t,i,m}$ with Respect to the State Combination of Level of Development and Previous Funding, $L_t^{i,m}$ $\forall\, t,\ i,\ m$ for Undetermined Budget Scenario and Upper Confidence Limit on NPVB with Membership Grade of Confidence Limit on NPVB, λ_{Upper}=0.083

SCHEDULING HORIZON: $t = 1$; LEVEL OF PREVIOUS FUNDING =1 ; LEVEL OF DEVELOPMENT: = 1 ; OPTIMAL DECISION: $D^*_{1,1}$=2

SCHEDULING HORIZON: $t = 2$						SCHEDULING HORIZON: $t = 3$						SCHEDULING HORIZON: $t = 4$						SCHEDULING HORIZON: $t = 5$					
LEVEL OF DEVEL-OPMENT	LEVEL OF PREVIOUS FUND m					LEVEL OF DEVEL-OPMENT	LEVEL OF PREVIOUS FUND m					LEVEL OF DEVEL-OPMENT	LEVEL OF PREVIOUS FUND m					LEVEL OF DEVEL-OPMENT	LEVEL OF PREVIOUS FUND m				
	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
i	OPTIMAL DECISION $D^*_{2,i,m}$					i	OPTIMAL DECISION $D^*_{3,i,m}$					i	OPTIMAL DECISION $D^*_{4,i,m}$					i	OPTIMAL DECISION $D^*_{5,i,m}$				
1	5	5	5	5	5	1	5	5	5	5	5	1	5	5	5	5	5	1	5	5	5	5	5
2	5	5	5	5	5	2	5	5	5	5	5	2	5	5	5	5	5	2	5	5	5	5	5
3	5	5	5	5	5	3	5	5	5	5	5	3	5	5	5	5	5	3	5	5	5	5	5
4	5	5	5	5	5	4	5	5	5	5	5	4	5	5	5	5	5	4	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
6	5	5	5	5	5	6	5	5	5	5	5	6	5	5	5	5	5	6	5	5	5	5	5
7	5	5	5	5	5	7	5	5	5	5	5	7	5	5	5	5	5	7	5	5	5	5	5
8	5	5	5	5	5	8	5	5	5	5	5	8	5	5	5	5	5	8	5	5	5	5	5
9	5	5	5	5	5	9	5	5	5	5	5	9	5	5	5	5	5	9	5	5	5	5	5
10	5	5	5	5	5	10	5	5	5	5	5	10	5	5	5	5	5	10	5	5	5	5	5
11	5	5	5	5	5	11	5	5	5	5	5	11	5	5	5	5	5	11	5	5	5	5	5
12	5	5	5	5	5	12	5	5	5	5	5	12	5	5	5	5	5	12	5	5	5	5	5
13	5	5	5	5	5	13	5	5	5	5	5	13	5	5	5	5	5	13	5	5	5	5	5
14	5	5	5	5	5	14	5	5	5	5	5	14	5	5	5	5	5	14	5	5	5	5	5
15	5	5	5	5	5	15	5	5	5	5	5	15	5	5	5	5	5	15	5	5	5	5	5
16	5	5	5	5	5	16	5	5	5	5	5	16	5	5	5	5	5	16	5	5	5	5	5
17	5	5	5	5	5	17	5	5	5	5	5	17	5	5	5	5	5	17	5	5	5	5	5
18	5	5	5	5	3	18	5	5	5	5	4	18	5	5	5	5	3	18	5	5	5	5	4
19	5	5	5	3	5	19	5	5	5	4	5	19	5	5	5	3	5	19	5	5	5	4	5
20	5	5	3	5	5	20	5	5	4	5	5	20	5	5	3	5	5	20	5	5	4	5	5
21	5	3	5	5	5	21	5	4	5	5	5	21	5	3	5	5	5	21	5	4	5	5	5
22	3	5	5	5	5	22	4	5	5	5	5	22	3	5	5	5	5	22	4	5	5	5	5
23	5	5	5	5	5	23	5	5	5	5	5	23	5	5	5	5	5	23	5	5	5	5	5
24	5	5	5	5	5	24	5	5	5	5	5	24	5	5	5	5	5	24	5	5	5	5	5
25	5	5	5	5	5	25	5	5	5	5	5	25	5	5	5	5	5	25	5	5	5	5	5
26	5	5	5	5	5	26	5	5	5	5	5	26	5	5	5	5	5	26	5	5	5	5	5
												27	5	5	5	5	5	27	5	5	5	5	5
												28	5	5	5	5	5	28	5	5	5	5	5
												29	5	5	5	5	5	29	5	5	5	5	5
												30	5	5	5	5	5	30	5	5	5	5	5
												31	5	5	5	5	5	31	5	5	5	5	5

Table A.46: Distribution of Optimal Funding Decision $D^*_{t,i,m}$ with Respect to the State Combination of Level of Development and Previous Funding, $L_t^{i,m}$ $\forall$ t, i, m for Non-Limited Budget Scenario and Mean Confidence Limit on NPVB with Membership Grade of Confidence Limit on NPVB, λ_{Mean}=1.0

SCHEDULING HORIZON: ; LEVEL OF PREVIOUS FUNDING=1 ; OPTIMAL DECISION: $D^*_{1,1}=1$
$t=1$; LEVEL OF DEVELOPMENT: = 1

SCHEDULING HORIZON: $t=2$

LEVEL OF DEVEL-OPMENT i	LEVEL OF PREVIOUS FUND m = 1	2	3	4	5
	OPTIMAL DECISION $D^*_{2,i,m}$				
1	1	1	1	1	1
2	1	1	1	1	1
3	1	1	1	1	1
4	1	1	1	1	1
5	1	1	1	1	1
6	1	1	1	1	1
7	1	1	1	1	1
8	1	1	1	1	1
9	1	1	1	1	1
10	1	1	1	1	1
11	1	1	1	1	1
12	1	1	1	1	1
13	1	1	1	1	1
14	1	1	1	1	1
15	1	1	1	1	1
16	1	1	1	1	1
17	1	1	1	1	1
18	1	1	1	1	1
19	1	1	1	1	1
20	1	1	1	1	1
21	1	1	1	1	1
22	1	1	1	1	1
23	1	1	1	1	1
24	1	1	1	1	1
25	1	1	1	1	1
26	1	1	1	1	1

SCHEDULING HORIZON: $t=3$

LEVEL OF DEVEL-OPMENT i	LEVEL OF PREVIOUS FUND m = 1	2	3	4	5
	OPTIMAL DECISION $D^*_{3,i,m}$				
1	1	1	1	1	1
2	1	1	1	1	1
3	1	1	1	1	1
4	1	1	1	1	1
5	1	1	1	1	1
6	1	1	1	1	1
7	1	1	1	1	1
8	1	1	1	1	1
9	1	1	1	1	1
10	1	1	1	1	1
11	1	1	1	1	1
12	1	1	1	1	1
13	1	1	1	1	1
14	1	1	1	1	1
15	1	1	1	1	1
16	1	1	1	1	1
17	1	1	1	1	1
18	1	1	1	1	1
19	1	1	1	1	1
20	1	1	1	1	1
21	1	1	1	1	1
22	1	1	1	1	1
23	1	1	1	1	1
24	1	1	1	1	1
25	1	1	1	1	1
26	1	1	1	1	1

SCHEDULING HORIZON: $t=4$

LEVEL OF DEVEL-OPMENT i	LEVEL OF PREVIOUS FUND m = 1	2	3	4	5
	OPTIMAL DECISION $D^*_{4,i,m}$				
1	1	1	1	1	1
2	1	1	1	1	1
3	1	1	1	1	1
4	1	1	1	1	1
5	1	1	1	1	1
6	1	1	1	1	1
7	1	1	1	1	1
8	1	1	1	1	1
9	1	1	1	1	1
10	1	1	1	1	1
11	1	1	1	1	1
12	1	1	1	1	1
13	1	1	1	1	1
14	1	1	1	1	1
15	1	1	1	1	1
16	1	1	1	1	1
17	1	1	1	1	1
18	1	1	1	1	1
19	1	1	1	1	1
20	1	1	1	1	1
21	1	1	1	1	1
22	1	1	1	1	1
23	1	1	1	1	1
24	1	1	1	1	1
25	1	1	1	1	1
26	1	1	1	1	1
27	1	1	1	1	1
28	1	1	1	1	1
29	1	1	1	1	1
30	1	1	1	1	1
31	1	1	1	1	1

SCHEDULING HORIZON: $t=5$

LEVEL OF DEVEL-OPMENT i	LEVEL OF PREVIOUS FUND m = 1	2	3	4	5
	OPTIMAL DECISION $D^*_{5,i,m}$				
1	1	1	1	1	1
2	1	1	1	1	1
3	1	1	1	1	1
4	1	1	1	1	1
5	1	1	1	1	1
6	1	1	1	1	1
7	1	1	1	1	1
8	1	1	1	1	1
9	1	1	1	1	1
10	1	1	1	1	1
11	1	1	1	1	1
12	1	1	1	1	1
13	1	1	1	1	1
14	1	1	1	1	1
15	1	1	1	1	1
16	1	1	1	1	1
17	1	1	1	1	1
18	1	1	1	1	1
19	1	1	1	1	1
20	1	1	1	1	1
21	1	1	1	1	1
22	1	1	1	1	1
23	1	1	1	1	1
24	1	1	1	1	1
25	1	1	1	1	1
26	1	1	1	1	1
27	1	1	1	1	1
28	1	1	1	1	1
29	1	1	1	1	1
30	1	1	1	1	1
31	1	1	1	1	1

Table A.47: Distribution of Optimal Funding Decision $D^*_{t,i,m}$ with Respect to the State Combination of Level of Development and Previous Funding, $L_t^{i,m}$ $\forall$ t, i, m for Non-Limited Budget Scenario and Upper Confidence Limit on NPVB with Membership Grade of Confidence Limit on NPVB, λ_{Upper}=0.083

SCHEDULING HORIZON: $t = 1$; LEVEL OF PREVIOUS FUNDING =1 ; OPTIMAL DECISION: $D^*_{1,1}$=1
LEVEL OF DEVELOPMENT: = 1

SCHEDULING HORIZON: $t = 2$						SCHEDULING HORIZON: $t = 3$						SCHEDULING HORIZON: $t = 4$						SCHEDULING HORIZON: $t = 5$					
LEVEL OF DEVEL-OPMENT	LEVEL OF PREVIOUS FUND m					LEVEL OF DEVEL-OPMENT	LEVEL OF PREVIOUS FUND m					LEVEL OF DEVEL-OPMENT	LEVEL OF PREVIOUS FUND m					LEVEL OF DEVEL-OPMENT	LEVEL OF PREVIOUS FUND m				
	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
i	OPTIMAL DECISION $D^*_{2,i,m}$					i	OPTIMAL DECISION $D^*_{3,i,m}$					i	OPTIMAL DECISION $D^*_{4,i,m}$					i	OPTIMAL DECISION $D^*_{5,i,m}$				
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1
3	1	1	1	1	1	3	1	1	1	1	1	3	1	1	1	1	1	3	1	1	1	1	1
4	1	1	1	1	1	4	1	1	1	1	1	4	1	1	1	1	1	4	1	1	1	1	1
5	1	1	1	1	1	5	1	1	1	1	1	5	1	1	1	1	1	5	1	1	1	1	1
6	1	1	1	1	1	6	1	1	1	1	1	6	1	1	1	1	1	6	1	1	1	1	1
7	1	1	1	1	1	7	1	1	1	1	1	7	1	1	1	1	1	7	1	1	1	1	1
8	1	1	1	1	1	8	1	1	1	1	1	8	1	1	1	1	1	8	1	1	1	1	1
9	1	1	1	1	1	9	1	1	1	1	1	9	1	1	1	1	1	9	1	1	1	1	1
10	1	1	1	1	1	10	1	1	1	1	1	10	1	1	1	1	1	10	1	1	1	1	1
11	1	1	1	1	1	11	1	1	1	1	1	11	1	1	1	1	1	11	1	1	1	1	1
12	1	1	1	1	1	12	1	1	1	1	1	12	1	1	1	1	1	12	1	1	1	1	1
13	1	1	1	1	1	13	1	1	1	1	1	13	1	1	1	1	1	13	1	1	1	1	1
14	1	1	1	1	1	14	1	1	1	1	1	14	1	1	1	1	1	14	1	1	1	1	1
15	1	1	1	1	1	15	1	1	1	1	1	15	1	1	1	1	1	15	1	1	1	1	1
16	1	1	1	1	1	16	1	1	1	1	1	16	1	1	1	1	1	16	1	1	1	1	1
17	1	1	1	1	1	17	1	1	1	1	1	17	1	1	1	1	1	17	1	1	1	1	1
18	1	1	1	1	1	18	1	1	1	1	1	18	1	1	1	1	1	18	1	1	1	1	1
19	1	1	1	1	1	19	1	1	1	1	1	19	1	1	1	1	1	19	1	1	1	1	1
20	1	1	1	1	1	20	1	1	1	1	1	20	1	1	1	1	1	20	1	1	1	1	1
21	1	1	1	1	1	21	1	1	1	1	1	21	1	1	1	1	1	21	1	1	1	1	1
22	1	1	1	1	1	22	1	1	1	1	1	22	1	1	1	1	1	22	1	1	1	1	1
23	1	1	1	1	1	23	1	1	1	1	1	23	1	1	1	1	1	23	1	1	1	1	1
24	1	1	1	1	1	24	1	1	1	1	1	24	1	1	1	1	1	24	1	1	1	1	1
25	1	1	1	1	1	25	1	1	1	1	1	25	1	1	1	1	1	25	1	1	1	1	1
26	1	1	1	1	1	26	1	1	1	1	1	26	1	1	1	1	1	26	1	1	1	1	1
												27	1	1	1	1	1	27	1	1	1	1	1
												28	1	1	1	1	1	28	1	1	1	1	1
												29	1	1	1	1	1	29	1	1	1	1	1
												30	1	1	1	1	1	30	1	1	1	1	1
												31	1	1	1	1	1	31	1	1	1	1	1

Table A.48: Distribution of Optimal Funding Decision $D^*_{t,i,m}$ with Respect to the State Combination of Level of Development and Previous Funding, $L_t^{i,m}$ $\forall$ t, i, m for Non-Limited Budget Scenario and Lower Confidence Limit on NPVB with Membership Grade of Confidence Limit on NPVB, λ_{Lower}=0.085

SCHEDULING HORIZON: $t = 1$; LEVEL OF PREVIOUS FUNDING=1 ; LEVEL OF DEVELOPMENT: = 1 ;OPTIMAL DECISION: $D^*_{1,1}$=1

SCHEDULING HORIZON: $t = 2$						SCHEDULING HORIZON: $t = 3$						SCHEDULING HORIZON: $t = 4$						SCHEDULING HORIZON: $t = 5$					
LEVEL OF DEVEL-OPMENT	LEVEL OF PREVIOUS FUND m					LEVEL OF DEVEL-OPMENT	LEVEL OF PREVIOUS FUND m					LEVEL OF DEVEL-OPMENT	LEVEL OF PREVIOUS FUND m					LEVEL OF DEVEL-OPMENT	LEVEL OF PREVIOUS FUND m				
	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
i	OPTIMAL DECISION $D^*_{2,i,m}$					i	OPTIMAL DECISION $D^*_{3,i,m}$					i	OPTIMAL DECISION $D^*_{4,i,m}$					i	OPTIMAL DECISION $D^*_{5,i,m}$				
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1
3	1	1	1	1	1	3	1	1	1	1	1	3	1	1	1	1	1	3	1	1	1	1	1
4	1	1	1	1	1	4	1	1	1	1	1	4	1	1	1	1	1	4	1	1	1	1	1
5	1	1	1	1	1	5	1	1	1	1	1	5	1	1	1	1	1	5	1	1	1	1	1
6	1	1	1	1	1	6	1	1	1	1	1	6	1	1	1	1	1	6	1	1	1	1	1
7	1	1	1	1	1	7	1	1	1	1	1	7	1	1	1	1	1	7	1	1	1	1	1
8	1	1	1	1	1	8	1	1	1	1	1	8	1	1	1	1	1	8	1	1	1	1	1
9	1	1	1	1	1	9	1	1	1	1	1	9	1	1	1	1	1	9	1	1	1	1	1
10	1	1	1	1	1	10	1	1	1	1	1	10	1	1	1	1	1	10	1	1	1	1	1
11	1	1	1	1	1	11	1	1	1	1	1	11	1	1	1	1	1	11	1	1	1	1	1
12	1	1	1	1	1	12	1	1	1	1	1	12	1	1	1	1	1	12	1	1	1	1	1
13	1	1	1	1	1	13	1	1	1	1	1	13	1	1	1	1	1	13	1	1	1	1	1
14	1	1	1	1	1	14	1	1	1	1	1	14	1	1	1	1	1	14	1	1	1	1	1
15	1	1	1	1	1	15	1	1	1	1	1	15	1	1	1	1	1	15	1	1	1	1	1
16	1	1	1	1	1	16	1	1	1	1	1	16	1	1	1	1	1	16	1	1	1	1	1
17	1	1	1	1	1	17	1	1	1	1	1	17	1	1	1	1	1	17	1	1	1	1	1
18	1	1	1	1	1	18	1	1	1	1	1	18	1	1	1	1	1	18	1	1	1	1	1
19	1	1	1	1	1	19	1	1	1	1	1	19	1	1	1	1	1	19	1	1	1	1	1
20	1	1	1	1	1	20	1	1	1	1	1	20	1	1	1	1	1	20	1	1	1	1	1
21	1	1	1	1	1	21	1	1	1	1	1	21	1	1	1	1	1	21	1	1	1	1	1
22	1	1	1	1	1	22	1	1	1	1	1	22	1	1	1	1	1	22	1	1	1	1	1
23	1	1	1	1	1	23	1	1	1	1	1	23	1	1	1	1	1	23	1	1	1	1	1
24	1	1	1	1	1	24	1	1	1	1	1	24	1	1	1	1	1	24	1	1	1	1	1
25	1	1	1	1	1	25	1	1	1	1	1	25	1	1	1	1	1	25	1	1	1	1	1
26	1	1	1	1	1	26	1	1	1	1	1	26	1	1	1	1	1	26	1	1	1	1	1
												27	1	1	1	1	1	27	1	1	1	1	1
												28	1	1	1	1	1	28	1	1	1	1	1
												29	1	1	1	1	1	29	1	1	1	1	1
												30	1	1	1	1	1	30	1	1	1	1	1
												31	1	1	1	1	1	31	1	1	1	1	1

Table A.49: Distribution of Optimal Funding Decision $D^*_{t,i,m}$ with Respect to the State Combination of Level of Development and Previous Funding, $L_t^{i,m}$ $\forall$ t, i, m for Limited Budget Scenario and Mean Confidence Limit on NPVB with Membership Grade of Confidence Limit on NPVB, λ_{Mean}=1.0

SCHEDULING HORIZON: $t = 1$; LEVEL OF PREVIOUS FUNDING =1 ; OPTIMAL DECISION: $D^*_{1,1}$=1
LEVEL OF DEVELOPMENT: = 1

SCHEDULING HORIZON: $t = 2$						SCHEDULING HORIZON: $t = 3$						SCHEDULING HORIZON: $t = 4$						SCHEDULING HORIZON: $t = 5$					
LEVEL OF DEVEL-OPMENT	LEVEL OF PREVIOUS FUND m					LEVEL OF DEVEL-OPMENT	LEVEL OF PREVIOUS FUND m					LEVEL OF DEVEL-OPMENT	LEVEL OF PREVIOUS FUND m					LEVEL OF DEVEL-OPMENT	LEVEL OF PREVIOUS FUND m				
	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
i	OPTIMAL DECISION $D^*_{2,i,m}$					i	OPTIMAL DECISION $D^*_{3,i,m}$					i	OPTIMAL DECISION $D^*_{4,i,m}$					i	OPTIMAL DECISION $D^*_{5,i,m}$				
1	4	5	5	5	5	1	4	4	5	5	4	1	4	4	4	4	4	1	4	4	4	4	4
2	5	5	5	5	5	2	4	4	4	4	4	2	4	4	4	4	4	2	4	4	4	4	4
3	5	5	5	5	5	3	4	4	4	4	4	3	4	4	4	4	4	3	4	4	4	4	4
4	5	5	5	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
5	5	5	5	5	5	5	4	4	4	4	4	5	4	4	4	4	4	5	4	4	4	4	4
6	5	5	5	5	5	6	4	4	4	4	4	6	4	4	4	4	4	6	4	4	4	4	4
7	5	5	5	5	5	7	4	4	4	4	4	7	4	4	4	4	4	7	4	4	4	4	4
8	5	5	5	5	5	8	4	4	4	4	4	8	4	4	4	4	4	8	4	4	4	4	4
9	5	5	5	5	5	9	4	4	4	4	4	9	4	4	4	4	4	9	4	4	4	4	4
10	4	4	4	4	4	10	4	4	4	4	4	10	4	4	4	4	4	10	4	4	4	4	4
11	4	4	4	4	4	11	4	4	4	4	4	11	4	4	4	4	4	11	4	4	4	4	4
12	5	4	4	4	4	12	4	4	4	4	4	12	4	4	4	4	4	12	4	4	4	4	4
13	4	4	4	4	4	13	4	4	4	4	4	13	4	4	4	4	4	13	4	4	4	4	4
14	4	4	4	4	4	14	4	4	4	4	4	14	4	4	4	4	4	14	4	4	4	4	4
15	4	4	4	4	5	15	4	4	4	4	5	15	4	4	4	4	4	15	4	4	4	4	4
16	5	5	5	5	5	16	4	4	4	5	4	16	4	4	4	4	4	16	4	4	4	4	4
17	4	5	4	4	4	17	4	4	4	4	4	17	4	4	4	4	4	17	4	4	4	4	4
18	4	4	4	4	4	18	4	4	4	4	4	18	4	4	4	4	4	18	4	4	4	4	4
19	4	4	4	4	4	19	4	4	4	4	4	19	4	4	4	4	4	19	4	4	4	4	4
20	4	4	4	4	4	20	4	4	4	4	4	20	4	4	4	4	4	20	4	4	4	4	4
21	4	4	4	4	4	21	4	4	4	4	4	21	4	4	4	4	4	21	4	4	4	4	4
22	4	4	4	4	4	22	4	4	4	4	4	22	3	4	4	4	3	22	4	4	4	4	4
23	4	4	2	3	3	23	4	4	4	4	4	23	3	3	3	3	3	23	4	3	3	3	3
24	3	2	3	3	3	24	4	4	4	4	4	24	3	3	3	3	3	24	3	3	3	3	3
25	3	3	3	3	3	25	4	4	4	4	4	25	3	3	3	3	3	25	3	3	3	3	3
26	3	3	3	3	3	26	5	4	4	4	3	26	3	3	3	3	3	26	3	3	3	3	3
												27	3	3	3	3	3	27	3	3	3	3	3
												28	3	3	3	3	3	28	3	3	3	3	3
												29	3	3	3	3	3	29	3	3	3	3	3
												30	3	3	3	3	3	30	3	3	3	3	3
												31	3	3	3	3	3	31	3	3	3	3	3

Table A.50: Distribution of Optimal Funding Decision $D^*_{t,i,m}$ with Respect to the State Combination of Level of Development and Previous Funding, $L_t^{i,m}$ $\forall$ t, i, m for Limited Budget Scenario and Upper Confidence Limit on NPVB with Membership Grade of Confidence Limit on NPVB, λ_{Upper}=0.083

SCHEDULING HORIZON: $t = 1$; LEVEL OF PREVIOUS FUNDING=1 ;OPTIMAL DECISION: $D^*_{1,1}$=2
LEVEL OF DEVELOPMENT: = 1

SCHEDULING HORIZON: $t = 2$						SCHEDULING HORIZON: $t = 3$						SCHEDULING HORIZON: $t = 4$						SCHEDULING HORIZON: $t = 5$					
LEVEL OF DEVEL-OPMENT	LEVEL OF PREVIOUS FUND m					LEVEL OF DEVEL-OPMENT	LEVEL OF PREVIOUS FUND m					LEVEL OF DEVEL-OPMENT	LEVEL OF PREVIOUS FUND m					LEVEL OF DEVEL-OPMENT	LEVEL OF PREVIOUS FUND m				
	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
i	OPTIMAL DECISION $D^*_{2,i,m}$					i	OPTIMAL DECISION $D^*_{3,i,m}$					i	OPTIMAL DECISION $D^*_{4,i,m}$					i	OPTIMAL DECISION $D^*_{5,i,m}$				
1	4	5	5	5	5	1	4	4	5	5	5	1	4	4	5	5	5	1	5	5	5	5	5
2	5	5	5	5	5	2	4	5	5	5	5	2	4	5	5	5	5	2	5	5	5	5	5
3	5	5	5	5	5	3	4	4	4	4	4	3	4	4	4	4	4	3	5	5	5	5	5
4	5	5	5	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	5	5	5	5	5
5	5	5	5	5	4	5	4	4	4	4	4	5	4	4	4	4	4	5	5	5	5	5	5
6	5	5	5	4	4	6	4	4	4	4	4	6	4	4	4	4	4	6	5	5	5	5	5
7	5	5	4	4	4	7	4	4	4	4	4	7	4	4	4	4	4	7	5	5	5	5	5
8	5	5	5	4	4	8	4	4	4	4	4	8	4	4	4	4	4	8	5	5	5	5	5
9	5	4	4	4	4	9	4	4	4	4	4	9	4	4	4	4	4	9	5	5	5	5	5
10	4	4	4	4	4	10	4	4	4	4	4	10	4	4	4	4	4	10	5	5	5	5	5
11	4	4	4	4	4	11	4	4	4	4	4	11	4	4	4	4	4	11	5	5	5	5	5
12	4	4	4	4	4	12	4	4	4	4	4	12	4	4	4	4	4	12	5	5	5	5	5
13	4	4	4	4	4	13	4	4	4	4	4	13	4	4	4	4	4	13	5	5	5	5	5
14	4	4	4	4	4	14	4	4	4	4	4	14	4	4	4	4	4	14	5	5	5	5	5
15	4	4	4	4	5	15	4	4	4	4	4	15	4	4	4	4	4	15	5	5	5	5	5
16	4	4	4	5	4	16	4	4	4	4	4	16	4	4	4	4	4	16	5	5	5	5	5
17	4	5	4	4	4	17	4	5	4	4	4	17	4	4	4	4	4	17	5	5	5	5	5
18	4	4	4	4	4	18	4	4	4	4	4	18	4	4	4	4	4	18	5	5	5	5	4
19	4	4	4	4	4	19	4	4	4	4	4	19	4	4	4	4	4	19	5	5	5	4	5
20	4	4	4	4	4	20	4	4	4	4	4	20	4	4	4	4	4	20	5	5	4	5	5
21	4	4	4	4	4	21	4	4	4	4	4	21	4	4	4	4	4	21	5	4	5	5	5
22	4	4	4	4	4	22	4	4	4	4	4	22	4	4	4	4	4	22	4	5	5	5	5
23	4	3	3	3	3	23	4	4	4	4	3	23	4	3	3	3	3	23	3	3	3	3	3
24	3	3	3	3	3	24	3	4	4	3	3	24	3	3	3	3	3	24	3	3	3	3	3
25	3	3	3	3	3	25	3	4	3	3	3	25	3	3	3	3	3	25	3	3	3	3	3
26	3	3	3	3	3	26	3	3	3	3	3	26	3	3	3	3	3	26	3	3	3	3	3
												27	3	3	3	3	3	27	3	3	3	3	3
												28	3	3	3	3	3	28	3	3	3	3	3
												29	3	3	3	3	3	29	3	3	3	3	3
												30	3	3	3	3	3	30	3	3	3	3	3
												31	3	3	3	3	3	31	3	3	3	3	3

Table A.51: Distribution of Optimal Funding Decision $D^*_{t,i,m}$ with Respect to the State Combination of Level of Development and Previous Funding, $L_t^{i,m}$ $\forall$ t, i, m for Limited Budget Scenario and Lower Confidence Limit on NPVB with Membership Grade of Confidence Limit on NPVB, λ_{Lower}=0.085

SCHEDULING HORIZON: $t = 1$; LEVEL OF PREVIOUS FUNDING =1 ; LEVEL OF DEVELOPMENT: = 1 ; OPTIMAL DECISION: $D^*_{1,1}$=1

SCHEDULING HORIZON: $t = 2$						SCHEDULING HORIZON: $t = 3$						SCHEDULING HORIZON: $t = 4$						SCHEDULING HORIZON: $t = 5$					
LEVEL OF DEVEL-OPMENT	LEVEL OF PREVIOUS FUND m					LEVEL OF DEVEL-OPMENT	LEVEL OF PREVIOUS FUND m					LEVEL OF DEVEL-OPMENT	LEVEL OF PREVIOUS FUND m					LEVEL OF DEVEL-OPMENT	LEVEL OF PREVIOUS FUND m				
	1	2	3	4	5		1	2	3	4	5		1	2	3	4	5		1	2	3	4	5
i	OPTIMAL DECISION $D^*_{2,i,m}$					i	OPTIMAL DECISION $D^*_{3,i,m}$					i	OPTIMAL DECISION $D^*_{4,i,m}$					i	OPTIMAL DECISION $D^*_{5,i,m}$				
1	4	4	5	5	5	1	4	4	5	4	4	1	4	4	5	4	4	1	4	4	5	5	4
2	4	5	5	5	5	2	4	5	4	4	4	2	4	5	4	4	4	2	4	5	5	4	4
3	5	5	5	5	5	3	4	4	4	4	4	3	4	4	4	4	4	3	4	4	4	4	4
4	5	5	5	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
5	5	5	5	5	5	5	4	4	4	4	4	5	4	4	4	4	4	5	4	4	4	4	4
6	5	5	5	5	4	6	4	4	4	4	4	6	4	4	4	4	4	6	4	4	4	4	4
7	5	5	5	4	4	7	4	4	4	4	4	7	4	4	4	4	4	7	4	4	4	4	4
8	5	5	5	4	4	8	4	4	4	4	4	8	4	4	4	4	4	8	4	4	4	4	4
9	5	5	5	5	5	9	4	4	4	4	4	9	4	4	4	4	4	9	4	4	4	4	4
10	4	4	4	4	4	10	4	4	4	4	4	10	4	4	4	4	4	10	4	4	4	4	4
11	4	4	4	4	4	11	4	4	4	4	4	11	4	4	4	4	4	11	4	4	4	4	4
12	4	4	4	4	4	12	4	4	4	4	4	12	4	4	4	4	4	12	4	4	4	4	4
13	4	4	4	4	4	13	4	4	4	4	4	13	4	4	4	4	4	13	4	4	4	4	4
14	4	4	4	4	4	14	4	4	4	4	4	14	4	4	4	4	4	14	4	4	4	4	4
15	4	4	4	4	5	15	4	4	4	4	4	15	4	4	4	4	5	15	4	4	4	4	4
16	5	5	5	5	4	16	4	4	4	4	4	16	4	4	4	4	4	16	4	4	4	4	4
17	4	5	4	4	4	17	4	4	4	4	4	17	4	4	4	4	4	17	4	4	4	4	4
18	4	4	4	4	4	18	4	4	4	4	4	18	4	4	4	4	4	18	4	4	4	4	4
19	4	4	4	4	4	19	4	4	4	4	4	19	4	4	4	4	4	19	4	4	4	4	4
20	4	4	4	4	4	20	4	4	4	4	4	20	4	4	4	4	4	20	4	4	4	4	4
21	4	4	4	4	4	21	4	4	4	4	4	21	4	4	4	4	4	21	4	4	4	4	4
22	4	4	4	4	4	22	4	4	4	4	4	22	4	4	4	4	4	22	4	4	4	4	4
23	4	4	2	3	3	23	4	4	2	3	3	23	4	4	4	3	3	23	4	3	3	3	3
24	3	2	4	3	3	24	3	2	3	3	3	24	3	4	4	3	3	24	3	3	3	3	3
25	3	4	3	3	3	25	3	3	3	3	3	25	3	4	3	3	3	25	3	3	3	3	3
26	3	3	3	3	3	26	3	3	3	3	3	26	3	3	3	3	3	26	3	3	3	3	3
												27	3	3	3	3	3	27	3	3	3	3	3
												28	3	3	3	3	3	28	3	3	3	3	3
												29	3	3	3	3	3	29	3	3	3	3	3
												30	3	3	3	3	3	30	3	3	3	3	3
												31	3	3	3	3	3	31	3	3	3	3	3

Table A.52: Comparison of Project Portfolio Selected by the FCCIGP For $NT \leq 5$ and $NT \leq 10$ Years at Stage $t = 1$ Under the Various Levels of Possible Funding Decision D_1^1 to D_1^5 for Lower Confidence Limit on NPVB with Membership Grade of Confidence limit on NPVB λ_{Lower}=0.085

Proposed Project		YEAR IN WHICH CONSTRUCTION STARTED									
		DECISION									
Project Number & Name	Area (ha)	D_1^1 NT≤10	D_1^1 NT≤5	D_1^2 NT≤10	D_1^2 NT≤5	D_1^3 NT≤10	D_1^3 NT≤5	D_1^4 NT≤10	D_1^4 NT≤5	D_1^5 NT≤10	D_1^5 NT≤5
1 Krueng Baro	16772	6th	1st	6th	1st	6th	1st	5th	1st	6th	1st
2 Pasaman	4962	6th	2nd	7th	0	5th	1st	7th	1st	0	2nd
3 Batang Kumu	13800	4th	1st	4th	1st	4th	1st	4th	1st	3rd	1st
4 Limun Sungkat	2500	5th	4th	5th	4th	5th	4th	5th	0	4th	1st
5 Teluk Lada	18923	3th	0	3rd	0	0	1st	3rd	1st	3rd	1st
6 Jatigede	130158	1st	1st	1st	1st	1st	1st	0	0	0	0
7 Jratunseluna	74557	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
8 Dumpil	25415	3rd	1st	3rd	1st	3rd	1st	3rd	1st	3rd	1st
9 Madura	2580	7th	4th	2nd	4th	9th	4th	9th	4th	9th	4th
10 East Java Rehab	42912	4th	1st	6th	1st	6th	0	3rd	1st	6th	1st
11 Sanggau Ledo	555	9th	4th	9th	3rd	9th	4th	7th	4th	7th	3rd
12 Wawotobi	21200	3rd	1st	3rd	1st	3rd	1st	3rd	5th	3rd	1st
13 Dataran Kobi	1950	2nd	0	4th	0	0	0	5th	0	4th	4th
14 Kalimantong	2850	6th	3rd	6th	0	6th	3rd	6th	0	6th	0
15 North Sumatra	41000	1st	1st	0	0	0	0	1st	1st	1st	0
16 Way Pedada	13550	5th	1st	5th	1st	0	1st	5th	1st	0	0
17 Riam Kanan	12000	3rd	0	3rd	0	0	0	1st	0	0	0
18 Boya	10000	1st	0	5th	0	0	1st	3rd	o	0	0
		ANNUAL BUDGET ALLOCATION									
First Year (B1)		62.74	147.33	47.65	131.39	47.78	109.26	20.97	92.56	16.53	74.31
Second Year (B2)		66.79	283.11	47.53	250.73	45.48	210.41	21.74	178.61	15.77	141.78
Third Year (B3)		103.43	186.23	82.93	159.75	72.41	140.01	77.7	115.09	34.69	90.73
Fourth Year (B4)		137.57	180.25	90.83	154.66	76.14	136.14	115.44	110.54	46.64	89.41
Fifth Year (B5)		148.42	126.07	80.1	110.34	59.11	94.39	95.96	80.61	40.29	65.71
Sixth Year (B6)		123.46		111.38		90.92		97.92		68.42	
Seventh Year (B7)		112.30		123.79		110.94		69.35		85.37	
Eighth Year (B8)		95.13		98.44		82.41		37.31		62.5	
Nineth Year (B9)		43.04		74.74		61.37		26.46		54.06	
Tenth Year (B10)		31.12		51.61		46.44		15.15		37.73	
Total Budget ($10^6)		923.78	922.99	809	807.34	692.87	690.22	551	577.41	462	461.94
PARAMETERS		GOAL ACHIEVEMENTS									
Irrigation Area (ha)		435684	392841	394684	444129	338261	337822	405656	376356	365144	326256
N.P.V. of Benefit ($10^6)		2217.8	1957.4	2089.7	1784.9	1863.6	1562.6	1656.6	1497	1544.1	1314.4
Transmigration Support (number of families)		20500	11500	20500	11500	16000	14000	16000	11500	16000	11500
Number Projects Selected		18	14	17	11	12	14	17	12	13	12
Total Budget Used ($10^6)		923.78	922.99	809	807.34	693	690.22	578	577.41	462	461.94