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COST - EFFECTIVENESS OF WATER RESOURCES SYSTEM DESIGN IN DEVELOPING COUNTRIES: CASE OF THE LOWER MEKONG

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Cost-Effectiveness of Water Resources System Design in Developing Countries: Case of the Lower Mekong

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0. Abstract

The purpose of this paper is to introduce the cost-effectiveness approach for analysis and design of water resources systems. The approach is used to study various possible alternative water resources systems and to identify the best systems for the desired goals in developing countries where problems such as shortage of foreign currencies, non-equilibrium of market conditions, unemployment, etc. generally exist.

In studying possible water resources systems, the standardized cost-effectiveness as proposed by Kazanowski is followed:

1. Define the desired goals, objectives, or purposes that systems are to accomplish.
2. Identify the system requirements or specifications.
3. Develop alternative systems for attaining the desired goals.
4. Establish systems evaluation criteria that relate system capabilities to specifications.
5. Select fixed-cost or fixed-effectiveness approach.
6. Determine capabilities of the alternative systems.
7. Generate system versus criteria array.
8. Analyze merits of alternative systems.
9. Perform sensitivity analysis.
10. Document the rationale, assumptions and analyses underlying the previous steps.

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In development of water resources systems, a developing country must be able to establish the desired goals. For example, the desired goals are broadly speaking to develop a water resource system for producing goods and services to meet economic and social demand of people in the year, say, 2000. System requirements or specifications can be, for example, how much power, agricultural products and other goods are required up to the year 2000. Costs of various alternative systems must be the total cost such as capital requirements for implementing the project and operating and maintenance cost. The measure of effectiveness can be defined, for example, as to how much better it is to produce goods and services above the requirements and how much worse it is if the production is below the requirements for all alternatives.

In selecting the system, a country has the option to use a fixed cost or a fixed effectiveness approach. In view of the multiple measures of effectiveness that are used to evaluate a project, the fixed cost approach seems appropriate but is not generally followed.

Major advantages of the cost-effectiveness approach are the following:

1. The approach will suggest and identify the best systems implemented to meet the desired goals.
2. The approach will help the government in the preparation of programming and budgeting of capital investments. The method will automatically identify unnecessary expenses that might be incurred if projects are planned on an individual basis.
3. The approach provides a detailed and careful analysis; omissions of important factors in making decisions are less likely to occur than from methods used to date.

An example of the application of the approach in designing of water resources systems in the Lower-Mekong basin is given in the paper. Classical methods of project analysis, such as cost-benefit analysis, are contrasted with the approach. In fact, net benefit or the cost-benefit ratio are imbedded as one of the criteria in the fourth step of the cost-effectiveness procedure.

1. Introduction

Cost-effectiveness is a very broad term. Cost-effectiveness analysis was defined by Quade (1, p.1) as "any analytic study designed to assist a decision-maker to identify a preferred choice from among possible alternatives". The term "cost-effectiveness" may imply a new concept; however, it is an extension of an old discipline, namely, engineering economic analysis in which alternative plans are sought and compared (English (2), p.2).

The first applications of the cost-effectiveness approach were found in defense systems analysis. The main purpose of such applications was to identify the most effective system that would reach given goals such as targets, together with the consideration of the implementation cost. One of the advantages of these techniques is that the word "effectiveness" has a powerful meaning in itself; it does not necessarily require an evaluation in monetary terms.

Applications of this approach to public and civilian systems have emerged in recent years. Hatry (3) suggested general measures of effectiveness of non-defense public programs such as improvement of health, of highway safety, etc.; Drobny, et al (4) applied the cost-effectiveness approach to the analysis of waste management systems; de Neufville (5) attempted to utilize this technique in

designing a portion of the New York primary water supply system. The most recent publications of this approach appear to be Ko and Duckstein (6) and Duckstein and Kisiel (7) for the analysis of wastewater reuses and the water quality control in the river basin, respectively.

The proposed approach combines several aspects. First, the approach deals with structural transformations; it accepts several goals as desired. The approach allows alternatives to be compared on the basis of several criteria and not a sole criterion. Risk and uncertainty are considered through the sensitivity analysis, and may for example appear as variance of benefits. Furthermore, the alternatives can be compared from the viewpoint of predicted undesirable ecological consequences. The recent issue of the Water Resources Council (8) on "Proposed Principles and Standards for Planning Water and Related Land Resources" is in the context of the cost-effectiveness approach.

It is observed from various references that each individual seems to have different procedures in performing the cost-effectiveness analysis. The standardized approach proposed by Kazanowski (9) seems to be very appropriate to our case and may be described as follows:

Step 1. Define the desired goals, objectives, missions or the purpose that systems are to fulfill.

Step 2. Identify the systems requirements.

Step 3. Develop the mission alternatives.

Step 4. Establish system evaluation criteria that relate systems capabilities to specifications.

Step 5. Select fixed-cost or fixed-effectiveness approach.

Step 6. Determine capabilities of the alternative systems.

Step 7. Generate system vs. criteria array.

Step 8. Analyze merits of alternative systems.

Step 9. Perform sensitivity analysis.

Step 10. Document the rationale, assumptions and analysis underlying the previous nine steps.

2.0 Background to the development of water resources systems

In water resources planning, it is important to explore to the fullest possible extent all the systems that can meet future needs. The plan selected should usually be the most economical among alternative plans that will meet the desired goals. This statement is generally accepted by all planners. However, there have been many water resources projects implemented without viewing possible alternatives. The general criterion to build such projects rested upon the exceedance of benefits over costs or upon a benefit-cost ratio greater than one. The use of benefit-cost analysis or ratios in the economic evaluation of projects has been subjected to much criticism. As pointed out clearly by Duckstein and Dupnick (10), these techniques imply the enumeration and evaluation of all the relevant effects in a common measure. In fact, the project impact on some factors, e.g., scenery, cannot be quantified. The weaknesses of the benefit-cost analysis are:

a) the difficulty in identifying which costs and which benefits are to be included;

b) the monetary evaluation of qualitative factors.

Use of a ratio criteria for comparison of alternatives is a common fallacy. To illustrate this fallacy, the following example was taken from McKean (11).

		Project A		Project B
Investment		$100,000		$100,000
Each year's benefit		70,000		20,000
Each year's expense		50,000		5,000
Present value of 20-year cost stream-discounted at 5%				
Initial investment	100,000		100,000	
Recurring costs	623,000	723,000	62,300	162,300
Present value of 20-year benefit stream-discounted at 5%		872,200		249,200
Ratio of present value of benefits to present value of costs		1.21		1.54
Mean annual costs*				
[100,000+(20x5,000)]÷[20]		-		10,000
[100,000+(20x50,000)]÷[20]		55,000		-
Mean annual benefits		70,000		20,000
Ratio of mean annual benefits to mean annual costs		1.27		2.00
Increase in present worth (Present value of benefits minus present value of costs)		149,200		86,900

It is seen that, by using ratio criteria expressed as the ratio of present value of benefit to present value of cost or ratio of mean annual benefits to mean annual costs, project B has an advantage over project A. However, project A would increase net benefit twice as

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*The procedure for calculating "annual values" is not correct, as it gives future benefits and costs the same weight as initial benefits and costs; the calculation is shown here because the method is used.

much as Project B.

It is a major limitation of benefit-cost analysis that it recognizes only a sole objective (maximizing national income) because the benefits accrued are irrespective of who receives them. McKean (11, p. 132-133) comments along this line: "Our partial criterion can only tell us which project is efficient 'by itself', this test cannot tell us which position is best in any ultimate sense..... Hence it is deemed appropriate here to have the cost-benefit measurement shed light on efficiency in this limited sense, and to have further exhibits shed slight on redistribution effects." He further suggested that (p. 127, 206-208, 240-242) decision makers be provided as well with "descriptions" of benefits (and costs, if appropriate) for each alternative project design that was analyzed.

McKean's statements essentially suggest the selection of alternative projects by means of lists of money-valued benefits and non-commensurable effects, for each alternative presented openly to the decision-makers.

Marglin (12, p. 18) states that "in view of the three dimensional nature of national welfare, the size of economic pie, its division, and the method of slicing, we believe unwise to attempt to define a single criterion for the broad objective, instead we shall develop alternative objectives for the most important ways in which water resources development can contribute to the national welfare..... efficiency... and income redistribution". Marglin's approach is that a single objective function is established to be maximized for determining the optimum project design subject to some minimum level of the other objective as the constraint. The ranking of projects can be done through comparing the value of the objective function of

each alternative project already meeting the constraint.

For the two objectives - maximum national income and the income redistribution, Maass (13, pp. 210) proposed that the trade-off ratio between these two objectives be determined through the political process. "...the experts in the executive department need to develop data that show the effects in the design of programs and projects of different trade-off ratios. The President needs to select one or a range of these ratios and thereby initiate formally the legislative process".

Regarding the environmental aspects, Hufschmidt (14) proposed that the benefit or loss function for environmental quality effects should be constructed and altered in the form and nature of constraints relating to such effects.

Because each alternative contributes unequal effects in achieving each objective, one alternative amy be more effective than the other in a certain objective, but another alternative may be more effective in achieving one or more additional objectives. James (15) proposed that the way to rank one objective above the other is to assign a weighting factor. This attaches a relative importance to each objective and converts various objectives into a one dimensional scalar quantity. The best alternative will be selected according to the highest scalar index. The process of weighting is in our judgement fraught with difficulties.

The above allows different opinions in arriving at the best alternative design to cover the multiobjective problem. This problem developed from a recognition that the efficiency criteria through the traditional benefit-cost analysis are inadequate for such a multiobjective viewpoint. Efforts toward solving the problem of selecting the best alternative are summarized as follows:

i. Express money-valued benefits and noncommensurable effects openly;

ii. Establish the single objective function and express the other objective as a constraint. This approach requires a weighting factor or trade-off ratio (Maass, 13). As stated by Haveman (16, p. 696), "can a meaningful trade-off ratio between the efficiency and equity be established for such programs on the basis of the identification?"

iii. Use of a relative weight in order to convert various objectives into a one dimensional scalar index, as proposed by James (15);

iv. Construct a benefit or loss function to account for the environmental quality aspect.

The solution of the mentioned multiple objectives seems to revolve around this question: "It is whether choice should be allowed to determine value or should value be determined independently of any particular project analysis and used to make choice". (Freeman, 17, p. 571). These issues are explicitly identified in the multiple goal framework of the cost-effectiveness approach.

Purpose of the study

In the design of water resource systems, it appears that even though a project is economically feasible, there is no absolute guarantee that the projects selected would constitute the best system because of the intangible or non-quantifiable benefits and costs. As indicated by McKean (11), the projects selected may be economically justified by themselves, but they may require additional unnecessary expenses unless other alternatives are sought. The design of water resources projects should be done in a system

framework. We also feel that the standardized cost-effectiveness approach as outlined by Kazanowski (9) should be applied in order to identify the best system which will produce the necessary goods and services under budgetary constraint. We are of the opinion that the approach will guide and improve the decision-making process in water resources development, especially in the developing countries where resources are extremely limited. In the next section, we illustrate its application to projects in the Mekong Basin.

3.0 Application to the design of water resources systems in the Lower Mekong Basin

3.1 The Lower Mekong Basin

The Mekong River, one of the largest rivers in the world, originates in the snow-covered mountains of the Tibet Plateau. After traveling about 1,800 kilometers, the river enters the boundary of the Lower Mekong Basin at Chiang Saen, near the common border of Burma, Laos and Thailand, at an evaluation of about 360 meters. The drainage area of the Lower Mekong Basin is more than 600,000 km^2 covering almost the whole of Laos and the Khmer Republic, one third of Thailand and two-fifths of the Republic of Viet-Nam. A population of 30 million (half of the total population of these four countries) inhabit the basin. Fig. 1 shows the area of the Lower Mekong Basin.

The Mekong River is a majestic river; each year, the river discharges to the South China Sea, almost completely unutilized, about 473,000 million m^3.

The hydrologic regime of the lower basin is not markedly influenced by conditions of the upper basin, but is influenced by Southeast and Northeast monsoons over the lower basin. The southeast monsoon starts by mid-May when the air mass moves in from the

South picking up moisture from the Indian Ocean and rain is produced causing the rise of water stage in the river. The period from mid-May to mid-October is the rainy season, in which the heaviest rainfall occurs in August and September. Following the rainy season, cold, dry air masses originating in the polar region move southward across Siberia and the mainland of China. Consequently, from mid-October to February, the weather is cool and practically no rain occurs; the period is called the cool season. From mid-February to mid-May, a transition period occurs where the polar pacific air-masses are modified by tropical heat and move east and southeast; this is the hot season.

3.2 Investigations and development of the Lower Mekong Basin

The investigations of the Lower Mekong Basin began when the Economic Commission for Asia and the Far East (thereafter referred as "ECAFE"), United Nations, established within its structure the Bureau of Flood Control. Several investigations and recommendations by various expert teams have been made for development of the resources of the river for power, irrigation, and navigation since then (the history of the project can be seen in Schaaf and Fifield, 18).

Perhaps 1957 marks the essential inception for the development and planning efforts for the Lower Mekong Basin. ECAFE published a report entitled "Development of Water Resources in the Lower Mekong Basin" (19). The Report indicates the potential of the Lower Mekong with respect to irrigation, hydroelectric power, navigation, and flood control and emphasizes the needs for basic data collection programs for planning purposes.

Under the recommendation of ECAFE in the thirteenth Commission Session held in Bangkok, a Committee for Coordination of Investigation of the Lower Mekong Basin was established (thereafter referred to as the Mekong Committee). The Committee is composed of representatives of Khmer Republic, Laos, Thailand, and the Republic of Viet-Nam. Its purpose is to promote, coordinate, supervise, and control the planning and investigation of water resource development projects in the Lower Mekong Basin.

Since the establishment of the Mekong Committee, it has pursued several broad categories of activity in the role of water resource development such as basic data collection, basin planning, mainstream projects, tributary projects, navigation and other transportation, flood forecasting and control, agriculture, fisheries, power market, industry and mineral resources, social development and public health. Twenty-six other countries and various United Nations Agencies have contributed to the Mekong program in terms of supplying funds, equipment, and services of personnel. About half the funds have been derived from the riparian countries and about fifteen per cent from the United States.

The Mekong Committee authorized in 1962 the preparation of the overall plan for the development of the Lower Mekong basin; as a result an indicative report on the basin plan was published in 1970 (20). This report contains the grand design for the next thirty years with a construction program of nearly eight billion dollars. The plan emphasizes the needs for developing the basin from the viewpoint of the following benefits to the people in the basin:

i. agricultural production

ii. power production

iii. waterway transportation

iv. flood protection and control

v. salinity control

vi. water supply

vii. education and public health

Further historical, political and social aspects of the Mekong River projects are described in some detail in another paper by B. Binson and W. J. van der Oord on "Planning Development of the Water Resources of the Lower Mekong Basin", presented concurrently in this Symposium. Our main emphasis here will therefore be on the methodology which we will illustrate by simplifying reality to a certain extent. Let us now proceed to develop the example.

3.3 Example

The level of detailed investigation of the projects used to illustrate the approach vary; the economical feasibility study of some projects is completed, while others are still in the preliminary study phase. However, all projects considered appear to be economically feasible and qualify to be included in the set of alternative systems.

We shall stay as close as possible to the standardized cost-effectiveness approach of Kazanowski (8) whose steps have been presented earlier and may be detailed as follows:

Step 1. Define the desired goals. The desired goals are broadly speaking to develop a water resources system for producing goods and services to meet the economic and social demand of people up to the year 2000.

In terms of economic development, the desired goals can be expressed as, for example:

i. to achieve the higher rate of economic growth;

ii. to promote self-sufficiency; and

iii. to improve the employment situation in order to obtain a more equitable income distribution.

Step 2. Identify the mission requirements. There is a judgement necessary here concerning those specifications that are to be met at all price and those that are desirable but not strictly necessary. The requirements of the system can be expressed as follows:

i. agricultural production by improvement and development of irrigation system up to the year 2000. Fig. 2 shows the needs of agricultural requirements in terms of paddy equivalence;

ii. power requirement up to the year 2000. Fig 3 shows the power load requirement of the 4 riparian states;

iii. improvement of waterway transportation;

iv. flood control at various local points and in the delta area;

v. salinity control in the delta area by augmentation of low flow during a dry season from a proposed reservoir storage along the mainstream of the river;

vi. water supply to various towns and villages in the basin.

Step 3. Developing alternative systems for attaining the goals. The alternative systems will be defined as follows (for purposes of illustration only):

System 1. Dams at High Luang Prabang, Pa Mong, Sambor, Strung Treng

System 2. Dams at Pa Mong, Bankoum, Sambor, Strung Treng

System 3. Dams at Nam Theun No. 2, Pa Mong, Upper Thakek, Sambor, Strung Treng.

Step 4. Established system evaluation criteria that relate system capabilities to specifications.

The system evaluation criteria may be expressed as follows:

i. power production in terms of annual kw-hr; we would like to know how much better it is to produce above the requirement and how much worse it is if the production is below the requirement;

ii. irrigation development in terms of ha. of land. Similarly, how much better or worse is it if the agricultural production is above or below the requirement, respectively?

iii. improvement of waterway transportation; the extent to which navigation is possible and extent to which number of trips of commercial ships may be increased;

iv. flood reduction and control; how much can flooding of land, villages and towns be reduced or controlled?

v. salinity control in the delta area: how much do we control salt water intrusion, especially during the dry season;

vi. internal rate of return of the system;

vii. sediment reduction in the low-land flood plain in the delta area (the extent to which crops would be destroyed due to reduction of soil nutrients);

viii. reliability of the system; severity of system failure; confidence in a successful implementation;

ix. manpower and skilled personnel requirement versus availability;

x. personnel training and institutional change requirements versus availability;

xi. time available versus time required for development;

xii. risk due to imperfect information on hydrologic, economic, social and ecological data.

xiii. number and type of technological changes brought forth by the project, such as change from primitive to modern farming practices or introduction of new water control techniques;

xiv. savings on foreign exchange or creation of foreign debts after implementation of the project;

xv. health and ecological effects such as appearance of a water-borne disease and destruction of fish, respectively;

xvi. man-months of employment created;

xvii. a measure of rural and urban change and of project impact on human well-being as a result of resettlement (e.g. possible conflicts between the resettled and new neighbors, etc.)

Step 5. Select fixed-cost or fixed-effectiveness approach. The development of water resources in developing countries is normally characterized by a shortage of capital and foreign currencies so that funding of projects may have to be sought abroad. In addition, complex systems deal with multiple objectives so that it may be very difficult to use the fixed-effectiveness approach. Therefore, the fixed-cost approach seems appropriate.

Step 6. Determine capabilities of the alternative systems. The performance of each system is examined in terms of the effectiveness criteria given above.

With the hydrologic data available, a computer simulation model may be used to evaluate quantifiable and non-quantifiable effectiveness criteria which can be generated. It should be noted that each alternative system should be optimum on its own merit, namely, with respect to timing and scale of development.

Steps 7 to 10. Generate an array similar to Table I on pages 24176-24180 and pages 24183-24188 of the "Proposed Principles and Standards" (11); the column entries are divided into two parts -- costs and effectiveness criteria (which include quantifiable and non-quantifiable criteria). Sensitivity analysis, which implies feedback through all steps, should be performed on the following:

i. change in power and agricultural demands;

ii. uncertainty of streamflows;

iii. uncertainty on discount rate;

iv. uncertainty on cost estimates of the alternative systems;

v. operating policy of reservoirs.

4.0 Multi-objective decision analysis

In view of the reality of multiple criteria, a decision analysis is required. We feel that the government or water resources development agencies can establish a ranking of the effectiveness criteria. It is possible that one alternative system may be superior to all others in one aspect, but is inferior to them in other aspects given that the fixed-cost approach is applied. For example, system I may produce kilowatt-hrs with the capability to irrigate y' ha of land whereas system II may produce χ' kilowatt-hrs and irrigate y' ha of land; $\chi > \chi'$ but $y' > y$. In this case, the analyst should be able to rank the relative importance of $(\chi - \chi')$ and $(y' - y)$. One solution might be to seek additional funding so that y can be increased to y' and then, to select system I.

Discussion

We are of the opinion that the planning of water resources development especially in developing countries, should be performed in a system framework and that the cost-effectiveness approach has distinct advantages. These include:

i. The approach will suggest and help identify the best system established to meet the desired goals such as social and other goals as outlined in the Proposed Guidelines and Standards (11) of the U.S. Water Resources Council.

ii. The approach will help government in the preparation of programming and budgeting of capital for investments. The method will automatically reduce unnecessary expenses that might be incurred if projects are planned on an individual basis.

iii. The approach as set forth provides a detailed and careful analysis; omissions or double counting of important factors im making decisions are less likely to occur than with methods used to date.

iv. Both quantifiable and non-quantifiable criteria are included without attempting to weigh the factors.

v. The approach lends itself to sensitivity analyses which account for uncertainty in data and in the models.

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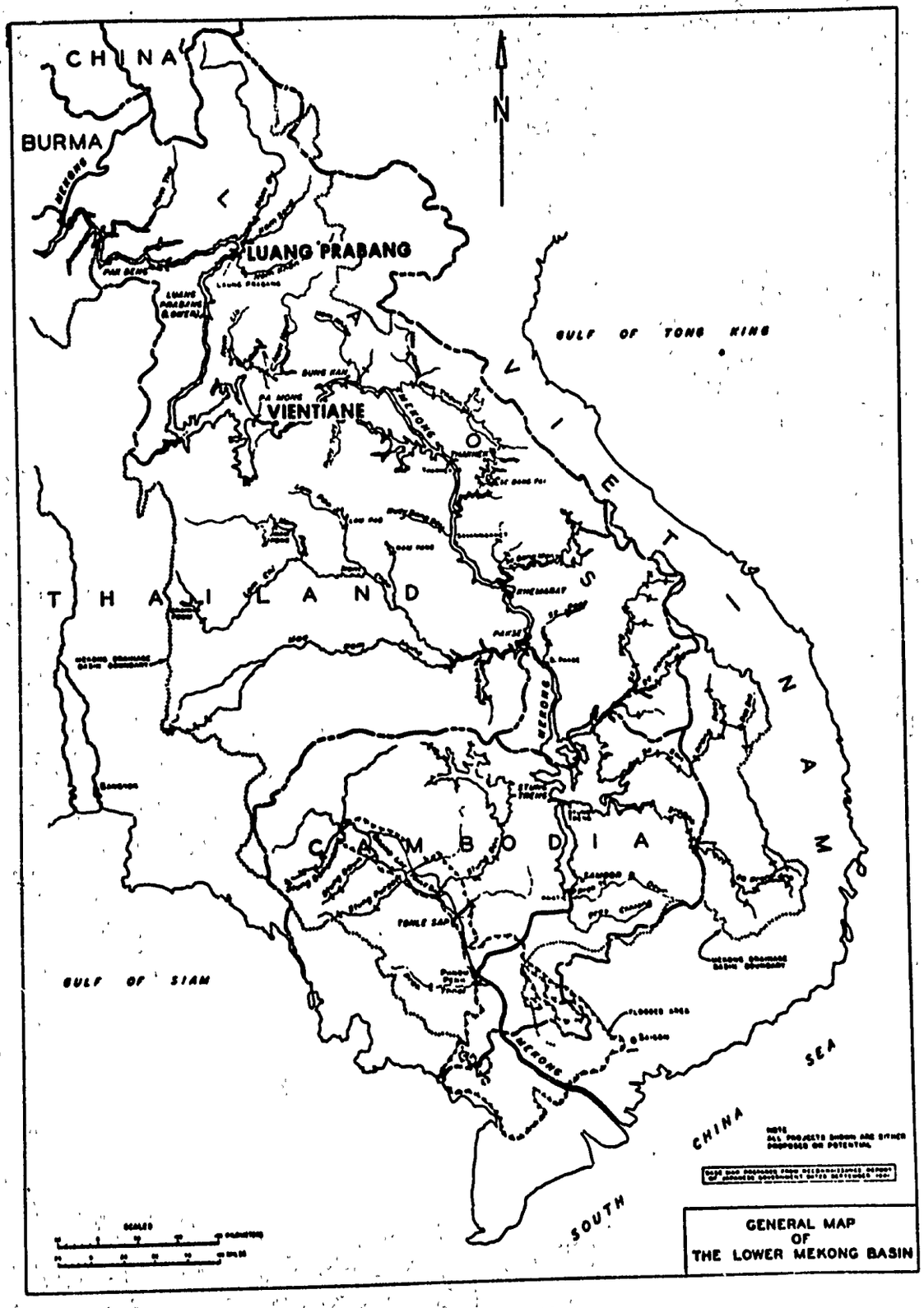

FIGURE 1 - GENERAL MAP OF THE LOWER MEKONG BASIN

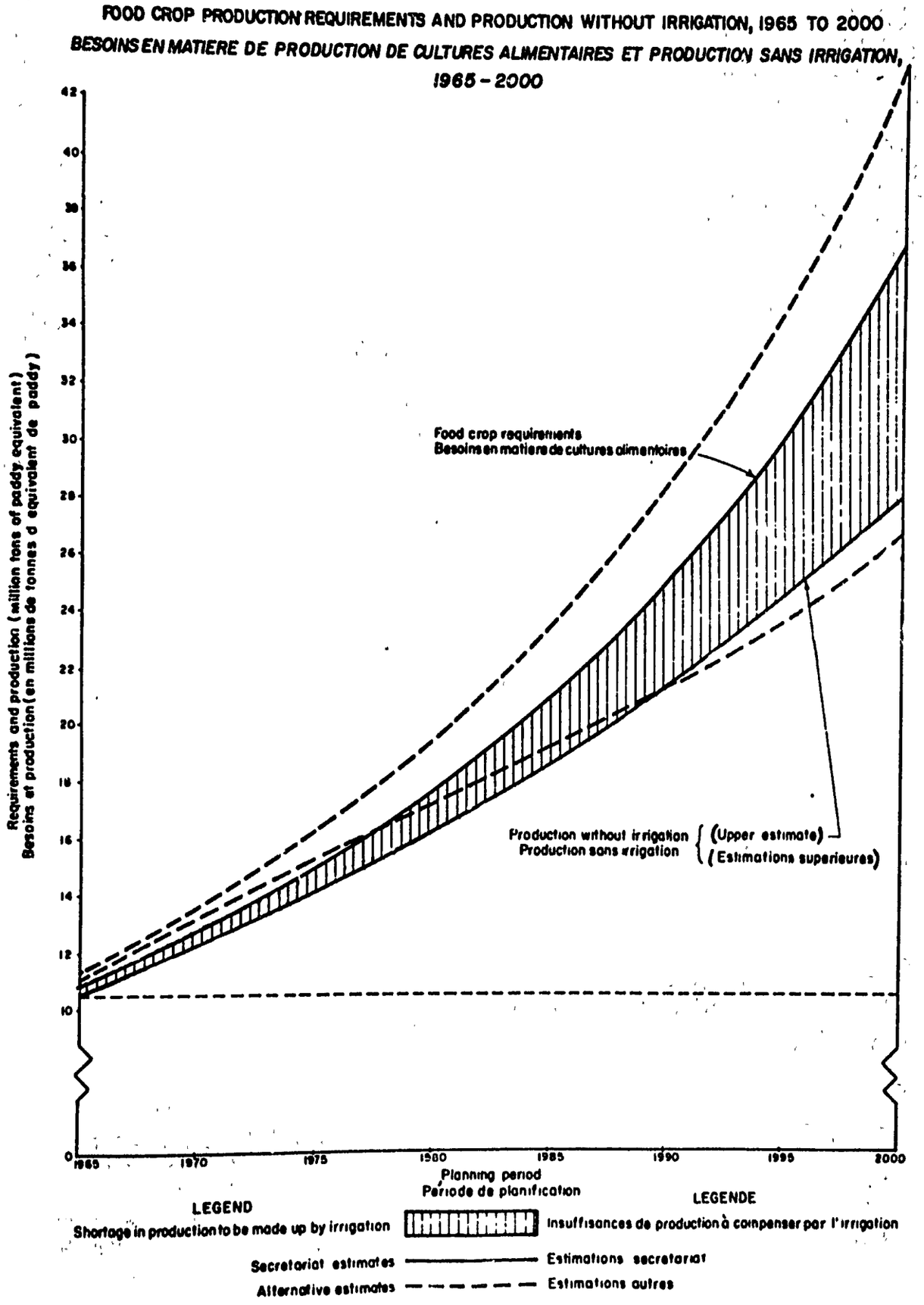

FIGURE 2 - FOOD CROP PRODUCTION REQUIREMENTS AND PRODUCTION WITHOUT IRRIGATION, 1965 to 2000

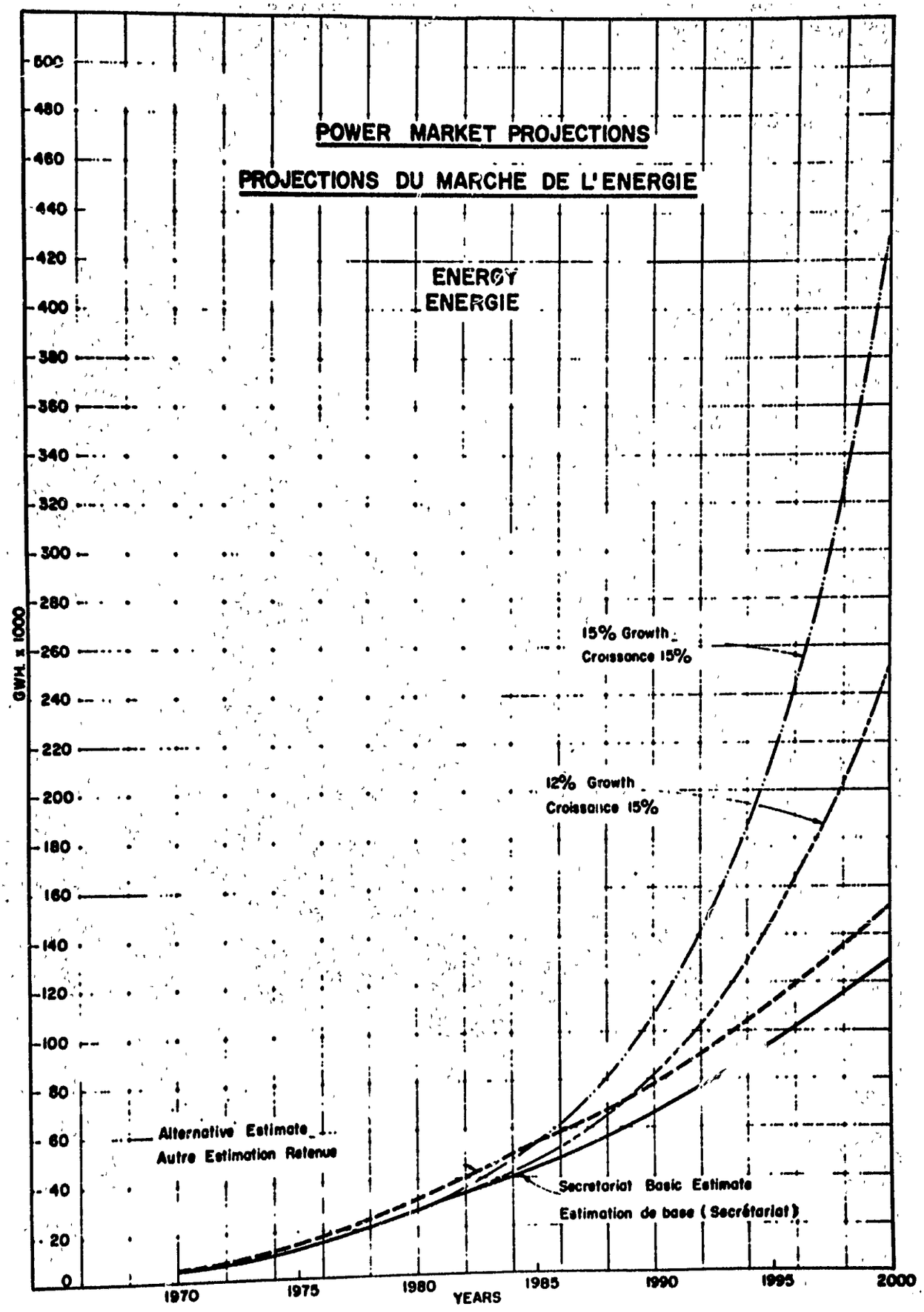

FIGURE 3 - POWER MARKET PROJECTIONS