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# Water resources allocation in Ghana in the post-Volta dam era: a linear programming approach

William Kobena Gyapea Erbynn
*Iowa State University*

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# WATER RESOURCES ALLOCATION IN GHANA IN THE POST-VOLTA DAM ERA

## (A LINEAR PROGRAMMING APPROACH)

by

William Kobena Gyapea Erbynn

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Graduate Faculty in Partial Fulfillment of
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## CHAPTER 1. INTRODUCTION

The relative abundance of water in most parts of Ghana has been a basic factor in shaping our patterns of water use. Water has been traditionally free for the taking. Only in the semi-arid regions have practices evolved from a concept of scarcity. In addition to the abundance of freedom to capture, water is usually cheap to transport and handle. The consequence of these and other factors have led to patterns of water uses which are very generous and perhaps wasteful in most parts of the country.

It is undoubtedly true that people of the semi-arid areas of the Northern Region and the Accra Plains in the southern part of the country appreciate the value of water more than any other region. Certainly to any observer in these areas (especially in the Accra Plains), the line which divides rich land from waste land is a water line. The key to the present and future development of these areas is water. Even in the water abundant areas, as water grows relatively scarce with respect to the fast-increasing demand, changes will be required in water use practices in Ghana. Public welfare in many areas may require a more restrictive use of water for all purposes.

### The Volta River Project

The Volta, Ghana's major river, is about 1,000 miles long. It begins as the Black Volta in a range of hills west of Bobo Dioulasso in Upper Volta. From there it flows some 200 miles in a northwest direction, bends southeast to form the upper boundary line between Ghana and the Ivory Coast, thence meandering down to the Gulf of Guinea and into the Atlantic

Ocean.

On its way to the sea--through sparce scrub tree and grassy savanna of northern Ghana, the rain forest region of the south and the mangrove zone of the coast--the river is joined by the waters of the Red Volta, White Volta, the Afram, Oti and minor tributaries. The total catchment area of the Volta River Basin covers some 152,000 square miles and extends into three countries adjoining Ghana (see Figure 1).

This was the course of the Volta River for centuries before Akosombo Dam was constructed at a site where the river narrows between converging hills about 60 miles from the coast. Now, along a 250-mile stretch of the river channel north of Akosombo, the dammed up waters have risen and spread out to form Lake Volta.

Creation of Lake Volta, in area the largest man-made lake in the world,[*] has brought about both problems and opportunities. About 80,000 persons lived in the area inundated by the lake. Thus, apart from the necessity of spending a large amount of money for resettlement, there was the human attachment to familiar places forever lost from sight. To ease the move, the Government of Ghana and the Volta River Authority (a statutory corporation owned by the Republic of Ghana) planned and built entire new communities on higher ground. New farms have been established and new roads constructed. It is hoped that the potential benefits of the lake (principally, cheap hydro-electric power, irrigation, domestic, and industrial water, flood control, low cost water

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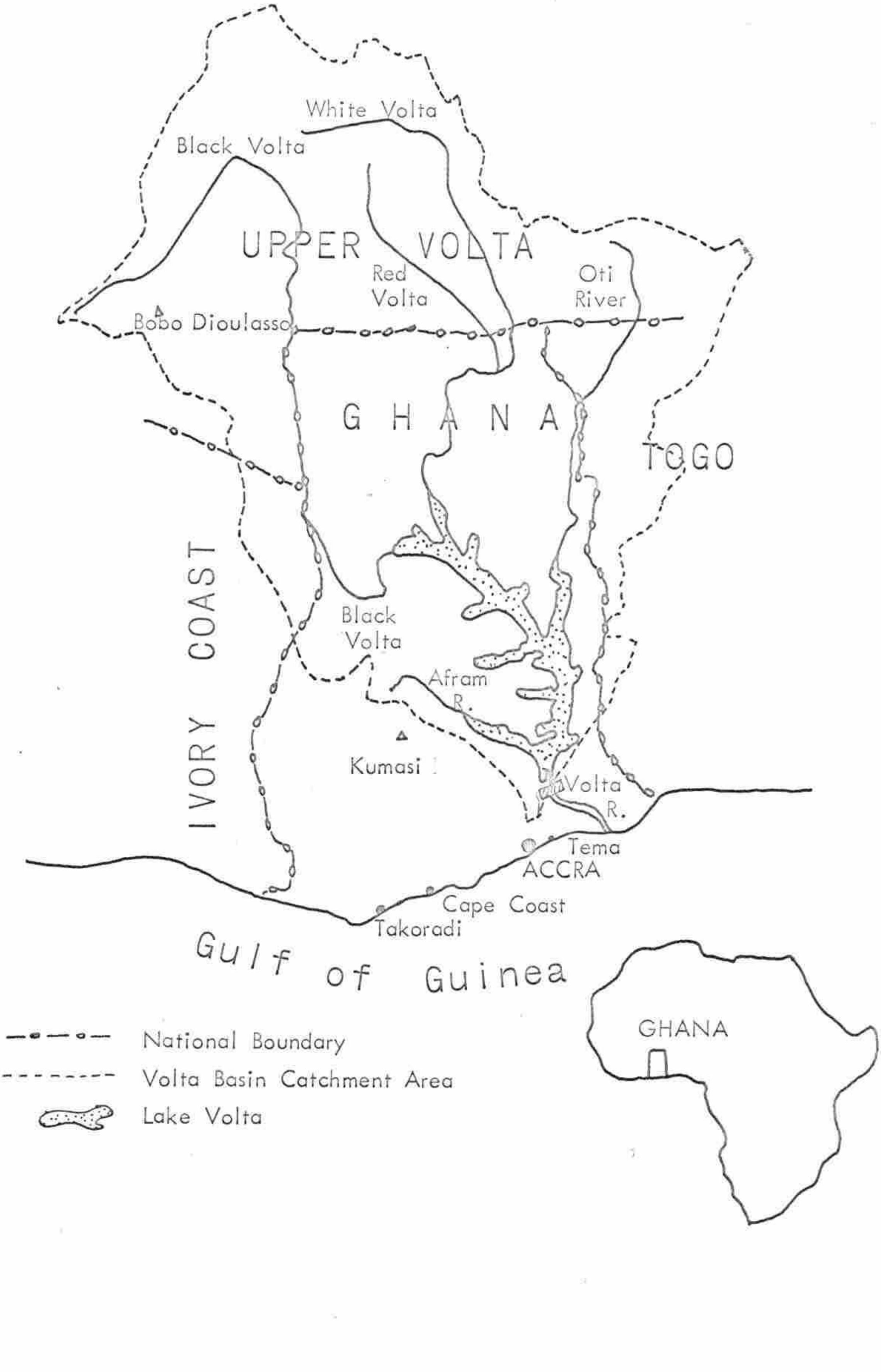
[*] Area: 3,275 square miles. Length: 250 miles. Capacity: 120,000,000 acre feet. Shoreline: 4,500 miles.

**Figure 1. Catchment area of Volta River Basin**


White Volta
Black Volta
UPPER VOLTA
Red Volta
Oti River
Bobo Dioulasso
GHANA
TOGO
IVORY COAST
Black Volta
Afram R.
Kumasi
Volta R.
Tema
ACCRA
Cape Coast
Takoradi
Gulf of Guinea
National Boundary
Volta Basin Catchment Area
Lake Volta
GHANA

transportation) will more than compensate for the problems of resettlement.

Almost all the previous water projects were single-purpose in concept; and irrigation was the only recognized paying water entity. The Volta River Project has brought about a shift to the multi-purpose concept. The project simultaneously allows the construction of power-generating facilities and the sale of power (the single most important product of the project) to help finance the associated irrigation schemes.

Generally, today's multi-purpose water projects may include a combination of the following functions: irrigation, power, municipal uses (for domestic, industrial and public purposes), recreation, flood control, pollution control, fish and wildlife, and inland water transportation (navigation). However, only a few of these water uses will attract the waters of Lake Volta. There is, therefore, the need for a judicious and efficient allocation of the additional water of about 120 million acre-feet (which Lake Volta will provide) between the most pressing water uses in Ghana now.

On many of the older projects multi-purpose benefits have been occurring regularly since the projects were built, but recognition was not made of these benefits in the project authorization and no costs have been allocated to them. The most prominent among these is recreation. Regardless of whether recreation is a planned activity, every new reservoir automatically creates a new swimming hole and people just naturally take advantage of it. Recreation has recently become a big business, for instance at Akosombo, where the main dam of the Volta River Project is situated.

## Economic Efficiency

The theoretical efficiency framework for water resource decisions has developed slowly because it is only recently that people of many countries have begun to think of water as a scarce resource. Most resources can be used for one or more of a number of purposes. Allocation to one purpose often means foregoing or deferring or reducing their use for other purposes. Economics has much to contribute to the solution of water problems, but meaningful economic analysis requires large quantities of technical data. Because of the many-sided characters of water policy, the economist, lawyer, political scientist, and engineer each have a voice and must be heard in order to understand economics in water policy.

For most resources, the pricing mechanism can be used as a choice criterion reflecting the wish of consumers back to users of resources such as water. Prices can be used conveniently in allocating water uses within a single firm, and sometimes between firms. However, for many uses of water, the pricing system cannot be used as a choice-indicating mechanism. The citizens in the lower part of a watershed have no effective means of expressing, through the price mechanism, to farmers in the upper reaches of the watershed the relative value which they attach to water uses and controls (i.e., flood control). There is little opportunity for the pricing mechanism to be used in diverting water from irrigation or power generation to recreation purposes (Heady and Timmons, 43).

The fact that the pricing mechanism is an insufficient basis for final control of water use and allocation does not imply that the principle of this choice criterion should be discarded. Stucky asserts that "economics indicates that the market system, based on supply, and demand (and price), can be depended upon and should be depended upon to allocate these waters to their future uses, whether they stay in their present or move to some other use" (97, p. 78). If a most efficient use or control of water is to be effected, the pricing mechanism must be retained--with some qualifications and modification, of course. Problems associated with the pricing mechanism (in its attempt to measure and reflect the relative value of water in its different uses) are discussed in Chapter 4.

What constitutes an efficient allocation of productive services or resources depends upon the objectives of the economic system or community. Though many objectives have been suggested or appear implicit in some public water programs,[1] yet to date economic evaluations of public agencies have been concerned primarily with the increase in national income. This is all the more so for a developing economy, like that of Ghana, where the main emphasis of resource use is put upon increasing the gross national, as well as per capita, income. The following discussion will therefore be confined to the problem of how an efficient allocation of water resource investment can be approached, given that the objective is to increase national income.

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[1] See Heady, E. O. and J. F. Timmons (43): "Planning and legislation in respect to water resources should have one dominant goal: to maximize long-run social welfare from these resources," (p. 49). Also see Maass, A., *et al*. (69, Chapter 2).

## Plan of Work

This thesis is concerned with efficient use of water to maximize national income. It purports to do this by, first, bringing into focus the consequences of alternative water projects and selecting those projects which attempt to achieve the society's objectives with minimum of available resources. Then, we must consider all the alternative uses of water and select those which are in line with the relative demand of water to society. A third consideration--which is usually of great importance when the goal of the society is to maximize economic welfare--is equitable distribution of the product or income of the water resource among potential users and beneficiaries.

The treatise will, therefore, be divided into two main sections as follows. Part one will be concerned with allocation of water resource investment among alternative water supply projects--a review of the general principles and applications of cost-benefit techniques. In Part Two we shall take as given the major investments that have been made in dams, irrigation canals and other water facilities, and consider the efficient allocation of the available water supply between the competing uses to maximize social product or net income. In taking these investments as given, we assume that the river has been quite fully developed by them--as will be the case of the Volta River very soon. For less developed river systems this approach is potentially helpful in the planning of investments.

A short chapter will be devoted to the allocation of the income and benefits derived from water in an equitable fashion among individuals within the society. And we shall conclude with a bibliography.

# PART ONE. INVESTMENT DECISION MAKING

# CHAPTER 2. GENERAL CRITERION PROBLEMS

## Introduction

There is no price mechanism within government which points the way to high-level economic efficiency, that is, to the correct allocation of resources among "industries" or broad governmental functions. In fact, "the only market that exists for most government products is a political process" (McKean, 74). Again, there is no competitive force that induces lower level efficiency, that is, the adoption of methods and equipment which carry out each function at minimum cost. Because of the lure of profits and threat of bankruptcy, private firms are under pressure to seek out profitable innovations and efficient methods. This search has led to an increasing use of formal quantitative analysis--mainly the various techniques in the field of Operations Research, such as Linear Programming methods and models based on the Theory of Games. Even in the absence of systematic analysis, some firm is likely to discover more efficient methods through trial and error. Other firms copy the innovation, and those that fail to do so begin to suffer losses, and the process of "natural selection" tends to eliminate them (3, pp. 211-221).

In government, however, there is no profit lure, and promotions or salary increases do not depend upon profits. Most of the cost of poor decisions does not fall on those who make them. The incentive to seek profitable innovations and efficient methods is, therefore, not a strong one.

Thus because of the government's lack of a competitive market mechanism, formal analysis of alternative actions may be especially rewarding in the public sphere. Choosing among alternatives entails the use of rules or criteria, which are simply the application of the formal quantitative analysis. In the field of water resources development, the criteria most commonly encountered are (i) the "Requirements" approach, (ii) Maximum Gains minus costs methods, (iii) Either Gain or Cost Fixed, and (iv) Cost-Benefit analysis. Of these, the Cost-Benefit (or Benefit-Cost) analysis is the most important in the evaluation of water resources programs--hence it will be treated in full (Chapters 3 through 5), while the others will only receive a summary treatment.

## The "Requirements" Approach

This technique is used by government agencies at various levels of decision-making. Officials inspect a problem pertaining to water usage and set up a "required" task or performance characteristic. Cost, that is, what is to be sacrificed in order to obtain the requirement, is given little or no explicit consideration: the requirement is set on the basis of "need" or payoff alone. "Requirements are often set by looking at 'need' without regard to cost not only when selecting broad programs but also when choosing the means of carrying them out" (74, p. 12). The defects of this procedure are apparent, the most important being that, by ignoring the cost of a course of action, the requirements approach ignores the worth of all other alternative possible actions. As Paul Douglas puts it, "with this approach, it is not unnatural for a military service to procure, for example, all-hair wrestling mats even though they cost about twice as much as the half-hair-half-wool mats that are used in most gymnasiums" (19, p. 175).

A water resource program only had to pass the following feasibility tests: "Can the performance characteristic be achieved? Can the necessary budget be obtained? Does the nation have the necessary total resources?" (74, p. 11). If the program passes the feasibility tests it is adopted; if it does not some adjustments must be made.

The "Requirements Approach" is an inefficient criterion for evaluation of water resource programs--the "optimum" program, the one that is regarded as the requirements, is derived by disregarding fund limitations. In Ghana fund limitations are everywhere visible and places an upper bound not only on water resources development but also on all economic activities. Hence, it is obviously unwise to ignore fund limitations (which will very likely remain with us for some years to come); nor shall we have to ignore the payoffs and the costs of alternative programs in the selection of the optimum program.

## Maximum Gains Minus Costs

If gains and costs can be measured in the same unit, to maximize gains-minus-costs can be considered an acceptable criterion for choosing some investment projects over others. By the costs of a project is meant the gains that could be realized if the water resource were used in its next best alternative employment. Thus suppose three water resource programs are being compared: A yields 100 units of gain, B yields 75 units, and C yields 50 units. Then for project A, gains and costs are 100 units and 75 units respectively. When costs are viewed in this way--as opportunity costs in next best alternative employment--it becomes obvious that to maximize gains-minus-costs is equivalent to maximizing total gains. With reference to the three programs in the example above, project A is the one that maximizes gains-minus-costs (100 minus 75) and it is also the project that yields the greatest total gain in the circumstances postulated.

Although this procedure provides us with a suitable way of 'making the most of whatever actions can be taken,' its application is limited only to the comparatively few occasions when gains and costs are commensurable.

## Either Gain or Cost Fixed

These two criterion-forms are especially useful when costs and gains cannot be measured in the same unit. As McKean puts it, "what would be the meaning of the ability to destroy ten targets minus one billion dollars?" (74, p. 47). In such a situation, where it is impossible to maximize gains minus costs, the next-best procedure is to 'constrain' or 'set' either the costs or gains and try to get the most for a given cost or to achieve a specified objective at least cost.

These two criterion-forms are equivalent, if size of either gain or cost is the same in the two tests. If the maximum gain criterion leads to a policy which yields $Y from a fixed budget or cost of $X, then the minimum cost criterion will also suggest the same policy for a prespecified gain of $Y--that is, the policy which achieves the prespecified gain of $Y at a cost of $X. According to McKean, the two criterion-forms also yield the same amount of information "if calculations are carried out for many different scales of cost and gain." As a result of their equivalence, the choice between these two tests depends largely upon whether it is gain or cost which can be fixed with the greater degree of "correctness."

How is the 'correct' gain or cost fixed? In other words, how does one go about fixing the right achievement or budget? If the achievement or budget is set uncritically, the test criterion degenerates into the .... "requirements approach." Using Paul Douglas' example again, it might be taken as given that we "need" all-hair wrestling mats; and the analysis would seek the cheapest way to achieve that "requirement."

To set the achievement or cost critically, the following procedure has been suggested. Several tasks or scales of effectiveness are estimated by assuming several budget sizes. If a particular 'system' is preferred for all tasks or budgets, that system is dominant and is chosen. If no particular system is dominant, then the decision-maker has to draw on further information in order to set the right task or budget.

Whether there exists a dominant system or not, the decision-maker, in order to make use of the analysis, must select the scale of the task or budget. He has to know the cost of achieving different tasks or the potential achievements with different budgets--herein lies the importance of estimating the results for a variety of budgets or tasks. However, it is not always possible to experiment with all possible scales of achievement or cost, because the computations would be too expensive and voluminous to provide any net assistance. Hence, the analyst should do more than simply estimate several tasks for given budget sizes or several budgets for given tasks. He should make some inquiry into higher-level criteria for the society or community and also establish their relationship with lower-level criteria. For example, he has to ask (and must try to answer) the questions: what task (or budget) is consistent with higher-level criteria? Is a capability of supplying 100 million Kwh. of hydro-electric power too much or too little in view of the over-all aims of the industrial development program? If the analyst can obtain reasonable answers to these questions, the analysis can then be easily converted into a higher-level sub-optimization problem. At some higher level, the appropriate criterion is taken as given--that is, to carry out the higher-level task at minimum cost, or to get the most out of the higher-level budget. This acceptance of a task or budget as given at some high level is completely different from, and far more efficient to, setting "requirements" uncritically all the way up and down the line (74, p. 48).

The above criteria have been described only briefly, and so the several complications in the criterion problem have been ignored. Prominent among these complications are uncertainty, costs or gains occurring in different periods, secondary benefits or costs, and "intangibles." In most cases, costs or gains which occur in different time periods are not of equal value. Intangibles and the degree of uncertainty about a project's cost and gain cannot be priced--they cannot be expressed in terms of the principal or common unit that is being used,[*] and hence must somehow be taken into account "on the side." If enough weight is attached to intangible effects, the neatness of any analysis is likely to

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[*] If gains are measured in terms of dollars, those effects which cannot be so measured are intangibles. If no single unit is used extensively enough to be regarded as a common denominator, there is no basis for distinguishing at all between tangible and intangible effects.

be greatly marred, and the relationship between the estimates of gain and cost cannot reveal the preferred policy. Because of uncertainty,* the estimates of costs and benefits are usually average or expected outcomes. It is known in advance that estimates may be off the mark: benefits of irrigation projects, for instance, depend upon such factors as technological innovations that affect relative prices, and the actual fertility of the soil; and these things cannot be perfectly foreseen. A suggested method of treating uncertainty as well as intangibles is "to avoid concealment and to present some quantitative indicators."

Secondary, or indirect, benefits and costs, on the other hand, can be evaluated in the market place. The complication these secondary effects introduce into the analysis is whether or not, and for what purpose, these indirect effects should be considered and added to the primary (or direct) ones. Direct costs are defined to be the value of the goods and services needed for the establishment, maintenance and operation of the project and to make the immediate products of the project available for use or sale. Direct benefits are the value of the immediate products and services for which the direct costs were incurred. Indirect benefits are the values added to the direct benefits as a result of activities "stemming from" or "induced by" the project.

The complications considerations will be taken up again later and fully treated in connection with the cost-benefit analysis, to which we now turn. Unlike the summary treatment given to the other criteria, the

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*In a sense, uncertainty can be regarded as an intangible, but as an especially "ubiquitous" and significant one.

cost benefit analysis will be extensively discussed. It is the criterion most commonly used by water resource development agencies and other agencies of the government--for various reasons: e.g., the lessons of cost-benefit analysis are relevant to the use of quantitative analysis (for example, operations research) for private firms, the most direct connection being to the comparison of net profits to the agricultural firm from different operations. Moreover, whatever can be learned from cost-benefit analysis has a direct applicability to the comparison of alternative actions in other governmental activities. The general methodological problems encountered in the estimation of damage reduction due to flood control projects are essentially the same as those for the estimation of potential damage reduction attributable to certain defense operations. (For further discussion, see 74, pp. 16-18).

# CHAPTER 3. COST-BENEFIT ANALYSIS

## Introduction

Cost-benefit analysis is a practical way of assessing the desirability of projects, where it is important to take a long view in the sense of looking at repercussions in the nearer and further future, as well as a wide view in the sense of allowing for side-effects of many kinds on many persons, industries, regions, etc. That is, it implies the enumeration and evaluation of all the relevant costs and benefits. This involves drawing on a variety of traditional sections of economic study--production economics, public finance, welfare economics--and trying to weld these components into a coherent whole. Although the subject matter of cost-benefit analysis has appeared as long ago as 1844 in Dupuit's classic paper on the utility of public works (20), the procedure has come into prominence only within the past three decades. In the United States one of the first uses to which the cost-benefit analysis was put was the evaluation of navigation projects. The River and Harbor Act of 1902 required a board of engineers to report on the desirability of Army Corps of Engineers' river and harbor projects, taking into account the amount of commerce benefited and the cost. At this time the cost-benefit analysis was considered to be purely "an administrative device owing nothing to economic theory and adapted to a strictly limited type of Federal activity--the improvement of navigation" (37, p. 3). Consequently, valuation techniques were confined to tangible costs and benefits.

In the 1930's, with the New Deal, the idea of a broader social justification for projects developed. The Flood Control Act of 1936 thus authorized Federal participation in flood-control schemes "if the benefits to whomsoever they may accrue are in excess of the estimated costs." The practice of making analyses then spread to the other agencies concerned with water development projects. The purpose was not only to justify projects but also to help to decide who should pay. By the end of World War II, agencies had broadened their approaches by including intangibles as well as secondary or indirect benefits and costs. Since the war, great advances have been made in the development and application of reasonably sophisticated techniques of economic analysis in the design of water resources projects which are effective in preventing the construction of many uneconomic projects, yet no single technique occupies such a favorite position with economists as the "traditional" cost-benefit analysis--this is evidenced by the great number of books and journal articles written about this procedure. A noteworthy contribution to the literature on cost-benefit analysis is the "Green Book" (49) (a work of an inter-agency committee set up in 1950). The book is an attempt to codify and agree on general principles which are couched in the language of welfare economics.

Like any other technique or criterion, the cost-benefit analysis can be used inappropriately as well as appropriately. There are two general limitations of principle (as distinct from the many more of practice, referred to as "complications" or weaknesses--to be discussed later) which easily come to light. First, cost-benefit analysis as generally understood is only a technique for taking decisions within a framework which has to be decided upon in advance and which involves a wide range of considerations, many of them of a political or social character. Secondly, cost-benefit techniques in their present form are least relevant and serviceable for large-size investment decisions. If investment decisions are so large relative to a given economy (for example, a major dam project in a small country, as is the case with the Volta River Project in Ghana) that they are likely to alter the constellation of relative outputs and prices over the whole economy, the standard cost-benefit technique is likely to be inadequate, for nothing less than some sort of general equilibrium approach would suffice in such cases. This means that the applicability of the technique to underdeveloped countries is likely to be less than is usually thought to be, since so many investment projects involve large structural changes in such areas. But, as Prest and Turvey (82) argue, this limitation should not rule out all applications of the cost-benefit technique in such countries. In fact, given the shortage of capital resources in such countries, the cost-benefit analysis play an important role as a "starter" in the appraisal and selection of particular projects. The point to be understood is simply that one must be aware of the limitations of the technique when applied to underdeveloped countries.

## The Marginality Principle

It has already been pointed out that cost-benefit analysis is a way of setting out the factors which need to be taken into account in making certain economic choices. Most of the choices to which it has been applied involve investment projects and decisions--whether or not a particular project is economically justifiable, which is the best of several alternative projects, or when to undertake a particular project.

It is the expressed policy of the federal water resources agencies to undertake only those activities or projects for which the incremental benefits exceed the incremental costs. The criterion of the cost-benefit analysis that is used to indicate the relative merits of alternative projects is the ratio of benefits to cost. According to the "Green Book," "the ratio of benefits to cost reflects both benefit and cost values and is the recommended basis for comparison of projects" (49, p. 14). The rule is not to maximize the ratio, or even rank projects according to benefit-cost ratios, but is simply to exclude projects with ratios that are less than unity. That is, the benefit-cost ratio, assuming proper measurement of alternative costs, must be over one for the whole project and for each of its subprojects. There will be a net loss if substandard projects are combined with justifiable projects. If a project A, yielding positive net benefits of 10 is combined with project B, yielding a net benefit of -5, the total is +5 all right, but the net gain to the economy can be increased to +10 simply by transferring productive services from project B to other uses where the value of their marginal product will equal their costs.

In practice, it often happens that projects with the higher benefit-cost ratios are regarded as preferable to those with lower ratios (neglecting intangible considerations). The number of projects with relatively high ratios influences the size of the budget, and the ranking of projects according to the benefit-cost ratios helps determine the particular measures to be undertaken with a given budget.

A proper application of the marginal principle requires that the marginal net benefits be zero. This means that it must not be possible to increase total net benefits by making the size of the project larger or smaller. For example,[*] the dam must be neither too high nor too low; the channel must neither be too deep nor too shallow. Ordinarily it is impossible to tell whether the size of a project is "just correct," since data on the costs and benefits of marginal increments usually are not given in project reports. In general, however, engineers seem to be motivated to build projects which utilize the "full physical potentialities of the site" (that is, build up to the point where incremental costs rise sharply) rather than to be governed by a comparison of incremental costs and benefits. An adoption of a technique or practice which would compare marginal costs and returns would be very helpful.

## The "Right" Criterion in the Comparison of Projects

Choice involves maximization and we have to discuss what it is that decision-makers want to maximize. The formulation which best covers most cost-benefit analyses is as follows: the goal is to maximize the present value of all benefits less that of all costs, subject to specified constraints (82, p. 686).

In order to arrive at the "right" criterion, it is necessary that the nature of the projects (or the appropriate alternatives) which are to be submitted to cost-benefit analysis should be made clear. If projects A and B are to be compared, they have to be fitted into their appropriate contexts. Thus if the alternatives are the procurement of machines A and

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[*] The example is taken from Fox and Herfindahl (26, p. 201).

B, each machine has to be fitted into a context that includes all other currently used equipment, various decisions and operations in the firm and all relevant man-made and natural features (such as communications network and climate) (74, p. 50). We then compare the alternatives A and B by comparing the gains and costs of a system that includes A with those of a system that includes B.

However, if one authority is responsible for producing A goods and B goods and the choice is restricted to judging between A goods investment projects of different sizes, then it must take into account the effect of producing more A goods on its output of B goods. Many complications are encountered here: relationships between A and B goods may be on the supply or demand side, they may be direct (in the sense of A influencing B) or indirect (in the sense of A influencing C, which influences B) and etc. An illustration is the operations of an authority responsible for a long stretch of river: if it puts a dam at a point upstream this will affect the water level, and hence the operations of existing or potential dams downstream.

Another problem associated with formulation of appropriate alternatives is that of interdependence. Suppose we want to compare three interrelated proposed actions A, B and C--that is, the results of A depend upon whether or not, say, B is in existence. This interdependence poses no difficulty, other than increasing the computational burden, if only one of the three proposals is to be undertaken. In this case, the comparison between proposals A, B, and C resolves to simply comparing, as before, rest-of-the-system-plus-A, rest-of-the-system-plus-B, and rest-of-the-system-plus-C; the choice is based on the gains and costs associated with these. But sometimes two proposals are to be chosen, or projects are to be ranked for future references, with a view to proceeding down the list as far as the budget will go. In these circumstances, there may be trouble ahead, because as soon as one of the projects is to be constructed, the other evaluations may change. McKean (74) gives the following example. We want to compare three projects: A (a watershed plus a reforestation project), B (the watershed plus a forest-fire control program), and C (the watershed plus downstream levees). Suppose project A turns out to be the best, with project C as the second-best. The question posed here is: "Will project C continue to be the second-best after project A has been put into operation?" Not necessarily, because reforestation (project A) will reduce the worth of the levees (a "competing" project) and increase the worth of forest-fire control (a "complementary" project).

The upshot of the discussion on appropriate alternatives is that it is necessary to recognize interdependencies in calculating benefits and costs. When projects are interrelated, the correct procedure is to compare the systems that are actually being considered: A, B, C, A plus B, B plus C, A plus C, and A plus B plus C. There is no clear-cut or correct independent ranking of projects that are themselves interdependent.

Also involved in the selection of the "right" criterion is the choice of an appropriate discount rate. The literature on the choice of appropriate interest rates for public investment projects is voluminous; but there is a widespread agreement among economists that from an efficiency point of view a rate is required which is more comparable with private rates than those used currently or in the past. But on examining the rates that are used in the private sector, one becomes confronted with various questions. Even if one can select a single or average risk-free long-term interest rate, what significance can be attached to it? Straight away we run into the old arguments about whether market rates of interest do bear any close relationship to the marginal productivity of investment and time preference or whether the relationship is so blurred as to be imperceptible. Both pure theory and imperfections in the capital market are thus involved; and it is not within the scope of this thesis to examine the conceptual aspects of choosing a discount rate for water projects.

In computing gains and costs for each project, we must allow for time differences, because we attach different significance to the same amounts if they occur at different times. This allowance is often made by discounting future amounts and converting each stream to its present value. Our choice criterion then becomes one of maximizing of "present worth", a term which means the present value of gains minus the present value of costs.

Once the relevant alternatives have been clearly identified, the choice of a test criterion then becomes dependent upon what interest rate is used to discount the future benefits and costs (neglecting uncertainty). It has been suggested that if there is no capital rationing or if resale value is relevant, the market rate of interest should be used for discounting. Hence, if the investment budget can be varied by borrowing money at some market rate of interest (--i.e., "no capital rationing"), one should undertake all projects which have positive present worths when discounted at the market rate; or, in the case of interdependent projects, one should choose those which have the highest positive present worths when the streams are discounted at the market rate. This criterion implies that we should invest until the internal rate of return from incremental investment is no higher than the market rate of interest. Internal rate of return of an investment project is defined as the rate of discount which makes the present value of the project's receipt stream equal to the present value of its cost stream; that is, the rate of discount which makes the present worth zero. If a $100 investment provides a yield of $5 per year in perpetuity, its internal rate of return is 5 percent. The above criterion, therefore, states that if one can borrow money to finance investment projects at a market rate of interest of 4 percent, he should undertake all projects which have internal rate of return greater than, or equal to, 4 percent. Hence, in general, with no capital rationing, the "right" criterion for the correct set of investment projects is "maximum present worth when the streams are discounted at the market rate." This does not imply that "the" market rate is an unchanging rate or an unambiguous concept. But it simply means that if the size of the agency's investment budget can be adjusted to the conditions in the general investment market, then the discount rate should reflect those reinvestment opportunities.

In many countries (and more true of the underdeveloped countries) capital is a scarce resource, so that investment projects are considered under the conditions of capital rationing. In Ghana, where the water resources development program (which led to the selection of the Volta River Project) is considered in the framework of capital rationing, the water development agency has no reason to use the market rate for discounting; the available capital or investment budget is fixed and it might either fall short of, or go beyond, the point where the "marginal" internal rate of return equaled the market rate of interest. Under this circumstance, it is suggested that the appropriate discount rate should be the "marginal" internal rate of return, that is, the rate of return from the project's marginal investment. This discount rate, therefore, is the same as the yield that could be earned in the next-best alternative project. In order to obtain the preferred set of investment projects, we must know the marginal internal rate of return. The important question here is how in practice is the marginal internal rate determined. One method is to discount the streams of net benefits at various rates and find the discount rate at which the budget is exhausted by projects with a positive present worth, that is, with gain streams whose present values exceed those of their cost streams (1, p. 48). The lower the rate used for discounting, the larger the number of projects which are "economically justified"--that is, which have positive present worths. Hence, at some rate of discount, the amount of "economically justified" investment is equal to the budget. This rate is the marginal internal rate of return, the rate that makes the marginal project have a zero present worth. These projects with positive present worths that exhaust the budget constitute the correct set--the set that yields the maximum present worth with the given investment budget when the streams are discounted at the marginal internal rate of return. Thus in the more general case of allocating a fixed budget (i.e., under conditions of "capital rationing"), the "right" criterion for selecting the economically efficient set of investment projects is the "maximization of present worth for a given investment budget when the streams are discounted at the marginal internal rate of return." The basic idea of this criterion is to keep high-valued capital from being put to low-valued uses.

In dealing with interdependent projects (under conditions of capital rationing), only rough results can be obtained. If we are prepared to accept rough results, the analysis can be done in two parts. First, the best project set (i.e., the best mix of interrelated projects) is selected by using a discount rate which is believed to be "about right"--that is, the discount rate closest to the marginal internal rate of return). Secondly, the projects contained in the best mix are ranked on the basis of their internal rates of return. The higher-ranking projects can then be accepted until the budget is exhausted. As already mentioned, this procedure is rough in that there is always the danger that the combinations of interrelated projects may be wrong in terms of the marginal internal rate of return which finally emerges from the analysis. But if a ranking is to be made, the internal rate is an acceptable basis provided that the interrelationships are properly taken care of "on the side", and provided that the net receipt stream can be reinvested perpetually at that rate[*] (74, p. 91; and 2, p. 941). The rate of return is a ranking device only; the "right" criterion, as already stated, is the maximum present worth for the given investment budget with the marginal internal rate of return as the discount rate.

Eckstein, while agreeing with McKean that the "right" investment criterion for selecting projects should be able to choose a set of

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[*] Margolis (71) argues that McKean's assumptions that the benefits are reinvested is unwarranted. The benefits are not available to the government for investment. The benefits are incomes received by irrigation farmers, inhabitants of flood protected cities, etc., who will invest or consume the benefits (p. 105).

projects which would give the maximum present value to the nation, differs from McKean in his statement of the investment criteria. Eckstein proposes as a discount rate, the rate at which the taxpayers privately value the funds which they provide through taxation to finance the project--this rate is referred to as the "social cost of federal capital" and has been estimated at 5 to 6 percent (21, p. 99). Eckstein defends this use of a private rate by urging that government agencies should accept the ethical judgment that consumers' sovereignty with regard to intertemporal choice should dominate. A private rate of interest should, therefore, be used in determining the choice of projects and the size of public investments.

This discount rate obviously assumes that the preferences of current population should dominate the preferences of future generations. Eckstein (21) and Krutilla and Eckstein (60) recognize this underlying assumption and argue that in the political process the future is not valued solely in terms of the preferences of the current population: the beneficiaries should be future generations as well as the current one. But they use the time preferences of the current generations of taxpayers as the basis for the choice of a discount rate--arguing that the selection of the particular generation or generations whose preferences should be considered is a purely arbitrary one. Though the economist cannot decide which generation's welfare should be maximized and therefore he cannot "scientifically" choose a discount rate, he can be helpful in the selection of an appropriate social rate of time preference. In the field of water resources the economist can carry through the analysis at several rates, one of which would be Eckstein's social cost of federal capital, and he can then advise the government on the time implications of the different rates.

Eckstein's investment criterion--maximize present value by valuing income streams in terms of preferences among pairs of future years--yields results (a set of projects) which may be quite different from those obtained by McKean's "right" criterion. For example, in the Krutilla-Eckstein study of the Hells Canyon case the government's high dam has a higher benefit-cost ratio than the Idaho Power Company's three-low-dam proposal when an interest rate (marginal internal rate of return) of .0025 is used. When they use an interest rate of 0.055, the social cost of federal taxes, the three low dams are judged more efficient.

In practice, however, McKean's "right" criterion of "maximum present worth for a given investment budget, with marginal internal rate of return as the discount rate" still commands a much superior respect among government agencies than does any other investment criterion.

# CHAPTER 4. THE "COMPLICATIONS" AND CONSTRAINTS OF COST-BENEFIT ANALYSIS

## The "Complications"

Thus far the selection of the appropriate criterion has been accomplished by abstracting from time and uncertainty. Of the many issues in economic evaluation of water projects one of the most discussed and least clarified is the problem (or problems) associated with time. Government agencies as well as various economists treat time very differently. These differences among economists has often been cited as a sign of immaturity of the state of economic science when dealing with time.

Whatever decision is made about the beneficial consequences which should be attributed to the goal, the benefits must be aggregated over a great many years. If the benefits in different years are not equivalent, and everyone assumes they are not, then weights must be assigned so as to permit addition and comparison, that is, there is involved the selection of a discount rate for pairs of years. We have seen that to select the discount rate the identification of the characteristics of the goal over time is not enough; imperfections in the capital market, uncertainty and the planning horizon create constraints on the actions of both government agencies and private parties. Should uncertainty enter into the specification of the goal, i.e., are two expected values with different variances to be differently valued; or should it enter into the criteria, i.e., should we use a rule which gives greater weight to more certain consequences; or should it be avoided by arbitrary and often hidden assumptions?

## Uncertainty

In the sphere of private decision-making, "nonoptimal" criteria such as payout periods have been used for the choice of investments. Use of these criteria would be inefficient if the entrepreneurs had full knowledge, but they are resorted to because they give greater weight to more certain consequences.

Eckstein distinguishes between uncertainty related and unrelated to time. If unrelated to time, as in water resource problems (e.g., uncertainty stemming from technological change, and major unexpected modifications in the character of demand), he defends safety allowances on the cost side. Experience with this kind of uncertainty underscores the desirability of maintaining flexibility in meeting future demands. This can be encouraged by such means as a higher discount rate or a shorter assumed life for projects (26, p. 202). Either action should in theory have the effect of reducing the number of projects which are "economically justifiable." However, Eckstein proposes to add a risk premium of only 1/2 to 1 percent to the interest rate to allow for this type of uncertainty; this adjusted interest rate is then used to calculate the expected values of the various projects. This is a mild adjustment, especially for projects with an expected life of well over 50 years. He justifies this low risk premium which is uniform for all projects by treating the government as a firm, projects as one of its investments, and then asks what risk the government program as a whole incurs because of the one project. This argument results in an adjustment for uncertainty in the correct direction, the reduction in present value increasing with the life of the project, but it misses the major problem. Margolis (71) argues that the government and its agencies must choose among projects and this choice should be affected not only by the expected values but also by the probabilities of a range of benefits and costs. Uniform risk premiums hide the diversity in projects which range from watershed treatment with uncertain hydrology and product demand, to urban water supply where the engineering techniques and markets are far better known.

McKean believes that it is desirable to reduce uncertainty, but that not enough is known about the probabilities of the range of outcomes or the utilities of the different ranges for the analyst to develop a certainty equivalent. He, therefore, suggests a supplementary table which would sum the uncertainties of the parts of the analysis into one grand statement giving the subjective probabilities of the range of outcomes. It is then left to the government to evaluate the risks. This explicit treatment of uncertainty is preferable to the sole presentation of expected values or to a uniform adjustment for all projects.

Because of uncertainty, it is also important that serious consideration be given to project designs which retain flexibility of action--for example, by using general purpose rather than specialized design or by using less durable structures in some cases. Uncertainty can also be allowed for in the assessments of annual levels of benefits and costs. The various ways in which uncertainty impinges upon cost-benefit analysis have been well discussed by Dorfman (69, Chapter 3), Eckstein (22, Section 5), Hirshleifer (46, pp. 139-41) and McKean (74, Chapter 4) and need not be elaborated here.

Though it is generally recognized that the appraisal of the goal should include consideration of uncertainty, yet neither the various economists nor the government alter the "right" investment criteria because of uncertainty.

## Intangibles

Benefit-cost analysis requires quantification both in physical and economic terms. Quantifying in economic terms involves evaluating on the basis of a common denominator or weight. In practice this means money, although other denominators are conceivable and are used in economic theory. The necessity of quantifying in terms of money is frequently pointed out as a weakness of benefit-cost analysis.

At first glance, one portion of benefits and costs appear rather obvious and simple to evaluate. These are the products which can be sold for money and are referred to as "tangible" benefits, e.g., value of cotton produced by an irrigation project; and "tangible" costs are those associated with such products, e.g., the costs of cotton, the dam and the productive agricultural areas flooded by the reservoir. In addition to these products to which monetary values can be assigned, there is a set of products which enter into the individual valuations but for which no market price is available. These are usually called "intangible" benefits. The intangibles are poorly named. They are not elusive, just difficult to add into a sum along with bales of cotton and gallons of water. Intangibles include items like lives saved in floods, regional growth, and recreational use. Intangible benefits and costs are quite substantial for some projects. However, the benefit-cost ratios concern only tangibles. All of the tangible benefits (discussed below) are summed up to provide a single number, the numerator of the benefit-cost ratio. Intangibles are discussed in supplementary documents, that is, are taken into account "on the side". It is then up to the government to decide (on the basis of some nebulous utility functions) among projects with different combinations of tangible and intangible benefits and costs.

Four classes of tangible benefits can be distinguished. Their definition is relatively clear but their measurement remains poor. (1) Irrigation benefits are valued as the increase in farm income which could be attributed to the water. (2) Flood control benefits are the mathematically expected losses averted because of the project. (3) The navigation benefits are the differences between the costs of shipping by water and those by the cheapest alternative. Eckstein points out that the cheapest alternative is usually rail and its costs are estimated at the rates charged rather than by marginal costs. In Ghana, because of the lack of railway communication between the North and the South of the country, the cheapest alternative to navigation on the Volta Lake is motorway. (4) Power benefits are the costs of generation of equivalent power by a private steam power plant.

The use of the costs of the cheapest alternative as a benefit can especially overstate benefits when it is assumed that the lowered costs, because of public investment, would lead to an increase in activity. For example, if people were inhibited from shipping because of high rail (or road) rates, or if they did not locate in an area because of the high power rates, then the price of the cheapest alternative is more than they would in fact pay. Thus, the tangible benefits are far from certain. There have been steady improvements in the concepts of benefits and costs but these have not overcome the difficulties of measurement and especially the projection of the estimates into the future.

In general, the intangible benefits are of a different order. It is not simply the difficulty of finding market evaluations, such as in the case of recreation benefits. Most of the intangible benefits are concerned with social evaluation of such matters as conservation, the family-sized farm, mobility of resources, income redistribution, implications for public health, or balanced regional development. It is possible that through some ingenious means monetary values can be found which may make intangibles comparable to the tangibles, but as yet no guides have been developed for this research. Until that time, the proposals of McKean and others to quantify the intangibles as much as possible and present them in supplementary documents may be all that is possible.

## Externalities

McKean discusses spill-over effects, Eckstein discusses interdependencies, which are forms of external economies or diseconomies. Despite this lack of an accepted name, it is clear from the authors' analyses that they refer to the wide class of costs and benefits which accrue to bodies other than the one sponsoring a project, and the equally wide issue of how far the sponsoring body should take them into account.

McKean (74, Chapter 8) discusses at length the distinction between pecuniary and technological external economies (or spillovers). He argues that progenitors of public investment projects should take into account the external effects of their actions in so far as they alter the physical production possibilities of other producers or the satisfactions that consumers can get from given resources; they should not take side-effects into account if the sole effect is via prices of products or factors. The distinction really rests on the following basis: "technological spillovers affect the physical outputs that can be obtained from other producers' physical inputs, while pecuniary spillovers do not." One example of technological spillovers is when the construction of a reservoir by the upstream authority of a river basin necessitates more dredging by the downstream authority. An example of pecuniary spillovers is when the improvement of a road leads to greater profitability of the garages and restaurants on that road, employment of more labor by them, higher rent payments to the relevant landlords, etc. In general, this will not be an additional benefit to be credited to the road investment, even if the extra profitability and any net rise in rents and land values is simply a reflection of the benefits of more journeys being undertaken than before, and it would be double counting if these were included too. Consequently, we have to eliminate the purely transfer or distributional items from a cost-benefit evaluation: "We are concerned with the value of the increment of output arising from a given investment and not with the increment in value of existing assets" (Prest and Turvey, 82). In other words, we measure costs and benefits on the assumption of a given set of prices, and the incidental and "consequential" price changes of goods and factors should be ignored.

This distinction is obviously not a simple one to maintain in practice; there are some results from investment which are partially technological and partially pecuniary. It is sometimes difficult to unravel them because some of the transfers occasioned by investment projects may affect the distribution of income significantly, and hence the pattern of demand. But as a general guiding principle the distinction is most valuable.

The application of this principle implies that an investing agency must try to take account of obvious technological spillovers, such as the effects of flood control measures or storage dams on the productivity of land at other points in the vicinity. In some cases no explicit action may be needed, e.g., these effects may be internal to different branches of the same agency, or some system of compensation may be prescribed by law. But in others there should at least be an attempt to correct for the most obvious and important effects. Although in principle corrections are needed whatever the relationship between the interacting organizations, it must be expected that in practice the compulsion to take side effects into account will be much greater if a small number of organizations are involved than if the external benefits (or costs) are spread over a large multitude of individuals. The conclusion reached in this section is that technological spillovers should, and pecuniary spillovers should not, be taken into account in the comparison of projects, even if all are economic.

### Secondary benefits and costs

Arguments about secondary benefits are based on the notion that some pecuniary spillovers can be properly included in benefits. McKean (74), Eckstein (21) and Margolis (71) all note that secondary benefits are "indubitably a species of spillover," though they do not fall squarely into any one of the categories already discussed.

There are two major classes of secondary benefits and costs considered in the practice of benefit-cost analysis. The first comprises those which accrue in connection with the processing of the immediate products; this class is referred to as "stemming from." The second class comprises those benefits and costs alleged to accrue because expenditures by the producers of the immediate products stimulate other economic activities; this class is referred to as "induced by." The essential principle can be made clear by taking the case of irrigation which results in an increase in grain production, where the direct or primary benefits are measured as the value of the increase in grain output less the associated increase in farmers' costs.

The increased grain output will involve increased activity by grain merchants, transport concerns, millers, bakers, etc.; that is, it finds expression in the demand by processors for the immediate products of the irrigation project, and hence will involve an increase in the processors' profits. If the ratio of total profits in all these "processing" activities to the value of grain at the farm is, say, 30 percent, then secondary benefits of 30 percent of the value of the increase in grain output are credited to the irrigation project. These are the secondary benefits "stemming from" the irrigation project. Ciriacy-Wantrup (15) asserts that if these "stemming" secondary benefits are (by some more or less arbitrary accounting procedure) determined and added to the primary benefits, a portion of primary benefits is counted twice. Secondary benefits from processing may also arise from the fact that the goods produced by a public project may lower market prices. Since the immediate products are available to processors at lower prices, the project then should receive a credit for secondary (net) benefits equal to the price differentials times the quantities produced. However, though the quantities produced by a public project may be large enough to have effects upon prices, such a situation per se does not indicate additional profits from processing. At best, such additional profits are short-lived. The quantities produced by the product should be evaluated with the prices at which these quantities can be absorbed.

"Induced" secondary benefits, on the other hand, are the extra profits made from activities which sell to farmers. The argument for including this class of secondary benefits is supported on the academic level through analyses based on Keynesian economics. In the practice of benefit-cost analysis, however, this class of benefits is computed regardless of underemployment among productive services in the course of general fluctuations of investment, saving and income. Dealing with this class under two main assumptions, McKean (74) and Ciriacy-Wantrup (15) reach the conclusion that (a) when there is full employment there really are no secondary benefits at all, and (b) if in the absence of the project, certain resources would be involuntarily unemployed throughout the time period, usually as much as fifty years, then the incomes of these resources throughout the time period can be regarded as a secondary benefit "induced by" the project. More realistically, these resources would be unemployed over only part of the relevant period, so that their incomes (that is, the value of their products) can be counted as a benefit over only that part.

The implications of this distinction for cost-benefit measurements are that the extent of unemployment and underemployment must be projected and that the secondary benefit must be calculated as the net incomes of productive factors with the project minus their net incomes without the project. Thus if any productive factors are pulled into full use from idleness or submarginal employment, the increased value of the product would be counted. In practice, it is not only difficult to predict the unemployment which would exist without the project, but it also requires "some boldness" to predict the effects of a project upon unemployment when "we have no foreknowledge of the rest of the Federal Budget." As a result of these and other reasons, one is forced to conclude from this analysis of secondary benefits and costs that all classes of secondary net benefits be dropped from consideration if the problem area is project selection; this is the most important problem area in which benefit-cost analysis is presently used.

### Relevant prices

The foregoing discussions have been based upon the assumption that the immediate products or outputs of the public project are to be put to their best uses, and that the actual pricing system will not prevent this. What happens if the analyst can foresee that actual prices charged will differ from marginal cost? Should this affect the procedure for valuing benefits and costs?

If marginal cost declines until suddenly the expansion of output "hits a stone wall", the price should be adjusted so as to ration that output among the most valuable uses. When we are dealing with costs and benefits which can be expressed in terms of money it is generally agreed that adjustments need to be made to the expected prices of future inputs and outputs to allow for anticipated changes in relative prices of the items involved, including expected changes in interest rates over time. Sometimes, when an output is particularly hard to value, benefits are assumed to be equal to the cost of the cheapest alternative means of producing the same service.

Another problem posed for cost-benefit measurements by the pricing procedure is deliberate under-pricing, that is, deliberate setting of price below marginal cost. If this policy is foreseen (e.g., in an irrigation project) or predictable, it must be remembered that the price set is too low to ration the irrigation water to its best uses, so that the water may not be devoted to the acreage where it would be most productive. In such circumstances, the benefits should not be estimated on the assumption that the output (water) will be used in any particular way.

Though adjustments are needed for expected prices of future inputs and outputs, yet most economists feel that movements of the general price level are irrelevant in the comparison of projects and should be kept out of the cost-benefit calculations; that is, no adjustments should be made for expected changes in the general price level. The purpose of cost-benefit estimates is that they should help us to see which choices would take us nearer to maximum production. So far as efficiency in this sense is concerned, movements of the general price level are beside the point: "the essential principle is that all prices must be reckoned on the same basis, and for convenience this will usually be the price-level prevailing in the initial year" (82, p. 691). Thus, if the price level rises from 100 to 300 by the time the benefits occur, it is simply incorrect to say that benefits have trebled.

## Indivisibilities

With some few exceptions, market prices are used to value the costs and benefits of a project. So long as investment proceeds by small increments, the value of the output attributable to the investment is simply the price of an extra unit, or that price multiplied by a small number of units. This amount satisfactorily measures what people will be willing to pay for the additional product. Suppose, however, that investment can be provided only in a "large lump", such as a big reservoir or a canal, and that the extra units of output are large enough to affect these prices. Difficulties arise when one tries to measure benefits and costs. In the case of final products, the benefits accruing from the investment project cannot be measured by multiplying the additional units of output either by the old or the new price. The former will give an overestimate and the latter an underestimate. What is needed is a measure of the addition to the area under the demand curve (area ABCD in Figure 2), which, on the assumption that the marginal utility of money remains unchanged, is an appropriate measure of the money value of the benefits provided, in the sense of assessing what the recipients would pay rather than go without them. When the demand curve is linear an unweighted average of before and after prices will suffice; but more complicated techniques are necessary for other forms of demand function--when they are known. In the case of intermediate products, the demand curve is a derived one, and so it "can only be a perfect reflector of social benefit" if the optimum welfare conditions are met "all along the line". If this condition is satisfied the gross benefit arising from a project concerned with intermediate products is measured by the market value of sales plus any increase in

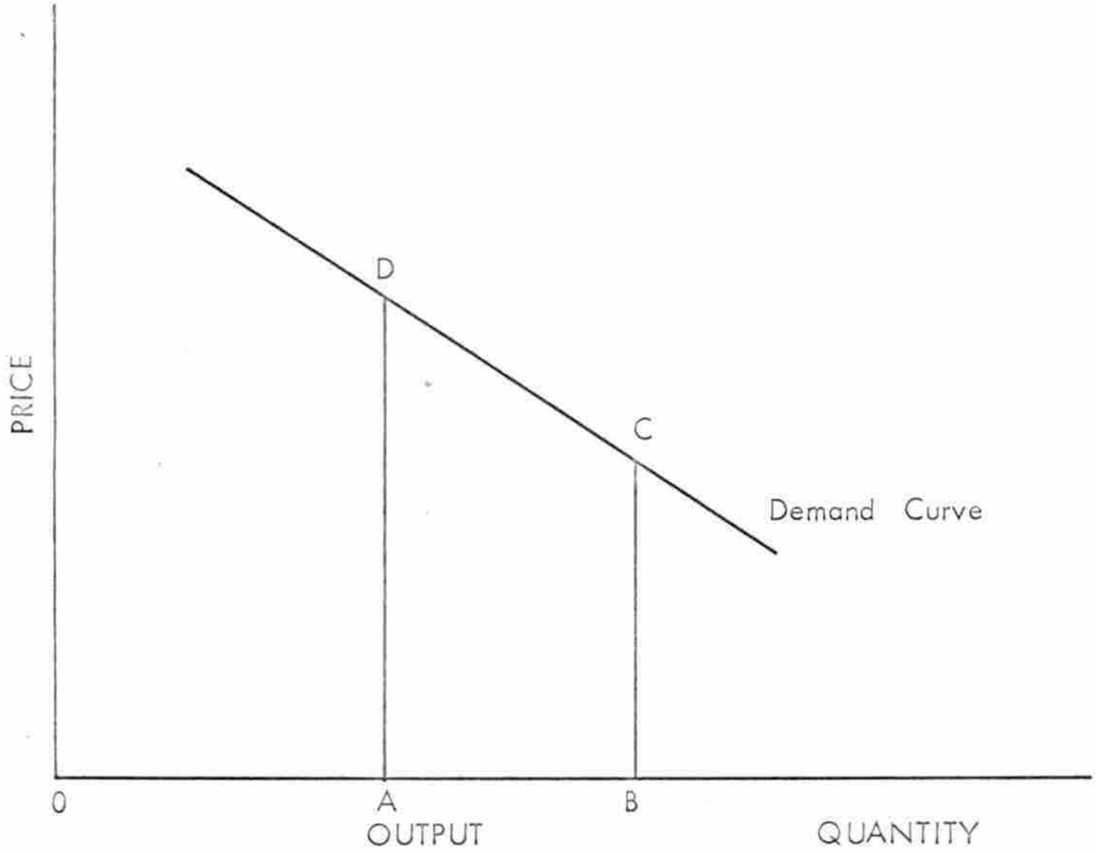

Figure 2. Valuation of benefits when indivisibilities exist

consumers' and producers' surplus with regard to any final product based on the intermediate products.

If the indivisibility is of any consequence, so far as costs are concerned, it will raise the prices of the inputs used to build the chunk of equipment. Would the extra units of input multiplied by this higher price correctly measure their cost? No. On the costs side there is a double problem, distinguished by Lerner in his treatment of indivisibilities (65). First, it is necessary to adjust prices of inputs so as to eliminate any rental elements, which will be measured by excesses over transfer earnings in their next best alternative use. Second, analogous to the problem of the demand side, as more and more of a factor is absorbed in any one line of output the price of the alternative product which it might have been making rises further and further. We, therefore, have to make a choice between valuation of the inputs at the original price, the ultimate price, or some intermediate level. If we, again, make the assumption of linearity, a price halfway between the original and the ultimate levels will suffice. In practice, the adjustments for indivisibilities on the costs side may be necessary at any particular time, and hence are likely to be more complex than those on the benefit side.

## Market imperfections*

Departures from Pareto optimum conditions arise when monopolistic elements or other imperfections in inputs or outputs markets are such as to twist relative outputs away from those which would prevail under

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*This section is based largely on Prest and Turvey (82, pp. 692-693).

competitive conditions. In such cases, investment decisions based on valuations of costs and benefits at market prices may not be appropriate; failure to correct for these distortions is likely to lead to misallocations of investment projects between different industries.

The relevance of this point for public decisions concerning investment is several-fold.

> "First, if a public authority in a monopolistic position behaves like a private monopolist in its pricing and output policy its investment decisions will not comply with the principles of efficient allocation of resources unless the degree of monopoly is uniform throughout the economy.
>
> "Secondly, complications may arise when there is monopolistic behaviour at a later stage in the production process ...
>
> "A third illustration is in respect of factor supplies. If the wages which have to be paid to the labour engaged on an investment project include some rental element and are greater than their marginal opportunity costs, then a deduction must be made to arrive at an appropriate figure; conversely, if wages are squeezed below marginal opportunity costs by monopsony practices.
>
> "Fourthly, there may be an average over marginal costs. This raises the well-known difficulty that if prices are equated to short-run marginal costs, as they must be to ensure short-period efficiency, the enterprise will run at a loss." [1]

With respect to the fourth point, various ways of getting over the problem have been suggested (e.g., two-part tariff system, discriminatory charges, voluntary subscriptions), but there are snags in all of them. If none of these suggested "solutions" are acceptable one must be prepared

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[1] Prest and Turvey (82, p. 692).

to countenance losses. Investment decision are here based on notions of what people would be willing to pay or what the project "ought to be" worth to customers, as Hicks (45) puts it.

The above examples point to the inapplicability of investment decision rules derived from a perfectly competitive state of affairs to a world where such a competitive situation no longer holds. There are two possible ways of making the necessary measurement adjustments: either a correction can be made to the actual level of costs (benefits), or the costs (benefits) arising from the market can be taken as they stand but a corresponding correction has to be made to the estimation of benefits (costs). The first of these two methods is, generally, the less complicated to compute.

### Taxes and controls

Another case of divergence between market price and social cost or benefit is that of taxes on expenditure. There is a standing controversy pertaining to the inclusion of taxes and duty in the cost-benefit calculations, either as reductions of project benefits or as additions to project costs. Most economists prefer to measure taxed inputs at their factor cost rather than at their market value. On the opposite end of the pole are those who believe that "in computing the annual costs of Federal water developments, for determining economic justification or for any other purpose, there should be included amounts equivalent to the taxes which would have to be paid were the lands, physical improvements and business, if any, not exempt from taxation, whether Federal, State or local" (24, p. 192). Which position is correct?

While private profit-making decisions should allow for income and profits tax payments, this should not be the case in the public sector. Cost-benefit estimates, it should be recalled, are supposed to be guides to the set of efficient projects, and should, therefore, reflect all tangible costs and benefits to the economy. What one is concerned with here, therefore, is a measurement of cost which corresponds to the use of real resources but excludes transfer payments.* On the whole, tax payments are not closely correlated with the costs to the economy that can be attributed to a particular investment. In fact, many tax payments represent a transfer from one group to another. Hence, profits or income taxes on the income derived by a public authority from its project are irrelevant if government proposals are to be compared only with each other in order to select the best set of projects for a given budget.

Collective goods

Market prices clearly cannot be used to value benefits which are not capable of being marketed. This leads us into the collective goods issue, see Samuelson (85, 86, 88) and Head (40). The essential point is that some goods and services supplied by government are of a collective nature in the sense that the quantity supplied to any one member of the relevant group cannot be independently varied. For example, all members of the population benefit from defense expenditure, all the inhabitants of any given district benefit from an anti-malaria program, and all ships in the vicinity benefit from a lighthouse. Bowen (8) differentiates between separately marketable

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*Transfer payments do not represent genuine additions to cost (or, alternatively, reductions in benefit) to the nation.

goods and such collective goods by the use of Figures 3(a) and 3(b). Whereas aggregation of individual demand curves is obtained by horizontal summation in the Figure 3(a) case, it is obtained by vertical summation in the case of collective goods (Figure 3(b)). This reflects the fact that though individuals may differ in their marginal valuations of a given quantity of a commodity, they all consume the same amount, in that each unit is consumed by all of them. For example, flood control afforded to different individuals is a joint product.

No one has yet succeeded[*] in getting consumers to reveal their preferences regarding collective goods; any rational individual consumer understates his demand, in the expectation that he would thereby be relieved of part or all of his share of the cost without affecting the quantity obtained.

The implication of this for cost-benefit estimates is that where commodities are supplied at zero prices or at non-market clearing prices which bear no relationship to consumer preferences, there is "no basis for arriving at investment decisions by computing the present value of sales." Of course, the problem does not apply to collective goods alone; a whole range of goods and services may be supplied free (or at nominal prices) by government for a whole variety of reasons.

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[*] Some attempts have been made to find ways out of this impasse, but these have not been fruitful. Samuelson (85, 86, 88) and Musgrave (77) have shown that even if the "nonrelation of preferences" problem is ignored, there is still another major snag, in that there is no single best solution but rather a multiplicity of optimum solutions.

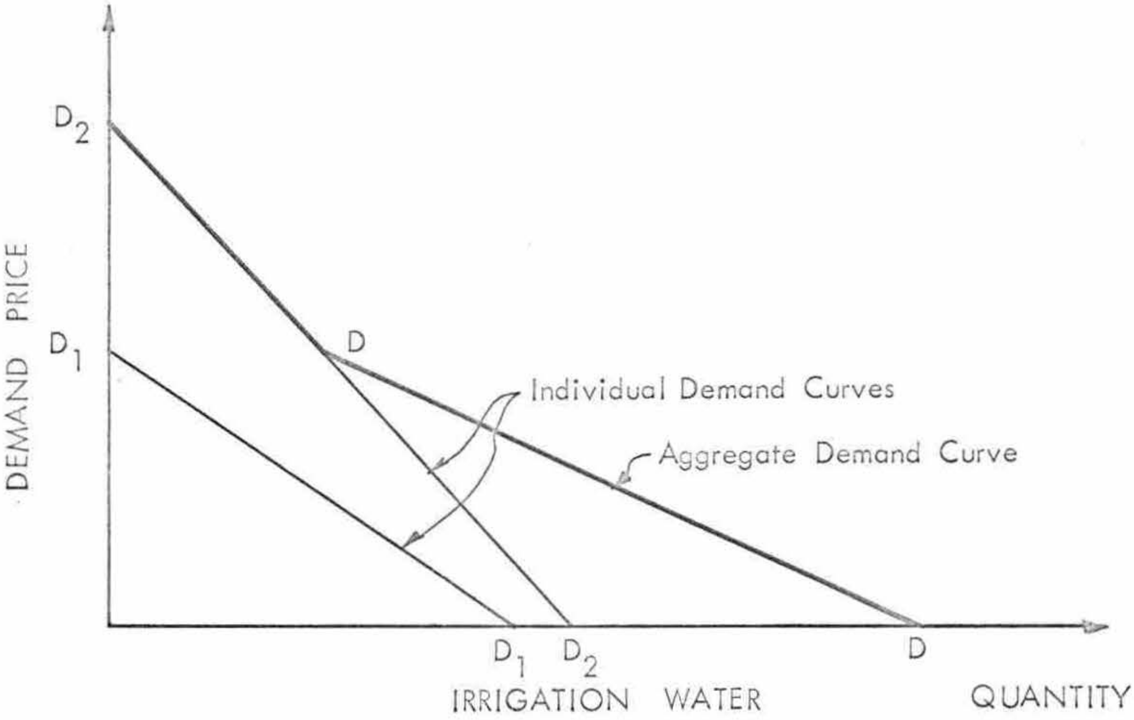

Figure 3(a). Marketable goods

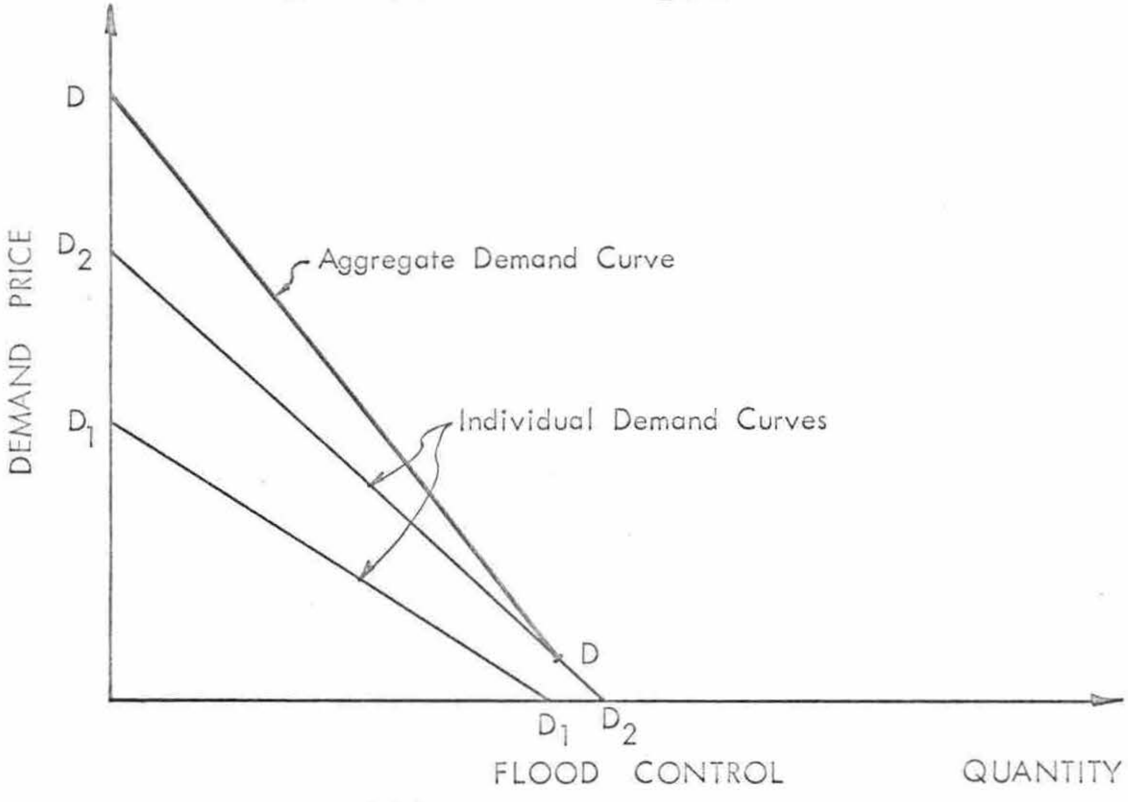

Figure 3(b). Collective goods

## The Constraints

Investment criteria are rules for the public agencies to follow in order to maximize the goal, subject to constraints. The constraints are the institutional environment which limits the choices they can make. Were it not for incompatibilities among projects and for budget limitations, choosing all projects for which the present worth is positive would assure a maximum. Given a budget constraint but neglecting incompatibilities, it would be sufficient to rank projects according to the size of their present worths and move down the list until the budget was exhausted. But the combined existence of both budget constraints and incompatibilities are central practical problems of choosing an optimal expenditure program.

Eckstein (22) has an excellent classification of constraints. First, there are physical constraints. The most general of these is the production function which relates the physical inputs and outputs of a project, but this enters directly into the calculation of costs and benefits. Where choice is involved between different projects or regarding the size or timing of a particular project, external physical constraints may also be relevant. Thus, one particular input may be in totally inelastic supply, or two projects may be mutually exclusive on purely technological grounds. These external physical constraints also include the incompatibility restraints which are based on the recognition that (a) of all the included public projects that could provide a particular output or service, not more than one can be chosen, and (b) the same facility (e.g., dam site) can be used only once. This last restraint, however, does not mean that the dam (or the facility) can be used to provide only one function (see Steiner, 96).

There are also legal constraints--what is done must be within the framework of the law. This may affect matters in a multiplicity of ways, e.g., regulated pricing, time needed for public inquiries, limits to the activities of public agencies, etc. We also encounter administrative constraints, related to limits to what can be handled administratively. Uncertainty can be introduced by constraints, for example, by the introduction of "some minimum regret requirement." There are the distributional constraints, which are concerned with income distribution and based on the compensation principle (of Kaldor, 52, and Scitovsky, 89) in the New Welfare Economics. The notion that the choice between projects can be made solely on the grounds of "economic efficiency", because any unfavorable effects on income distribution can be overcome by making some of the gainers compensate some of the losers, is rarely applicable in practice.

Prest and Turvey state that it is "perfectly possible" to compensate property owners not only for property which is expropriated but also for property which is reduced in value. Similarly, it is possible to levy a charge in respect to property which has been enhanced in value. These payments of compensation and charges, being lump sums, are not likely to have any direct effects upon resource allocation. In general, however, attempts to get beneficiaries to pay more than the marginal social cost of the project outputs they consume will affect the allocation of resources. Whatever the reason for such attempts, the pricing policy adopted will affect project outputs, and hence project costs. Thus, costs and benefits are not independent of pricing policy.

Income distribution requirements may, thus, affect cost-benefit analysis in either of two ways. First, when pricing rules are laid down in advance in the light of political or social notions about income distribution, then the task is to maximize the present value of benefits less costs subject to certain specified financial requirements, i.e., subject to one or more constraints. The second way occurs when the authorities have not laid down any specific financial rules but do clearly care about income distribution. In this case the task is to maximize the excess of total benefits over total costs subject to constraints on the benefits less costs of the particular groups whose economic welfare is of interest to the decision-maker.

Finally, we have the budgetary constraints. Hirshleifer (46) argues that such constraints ought not to exist: if the budgeting authorities "are worth their salt" the amount allocated to the sub-budgets will take account of the productivity of the projects available to them and the costs of obtaining the necessary funds. If this is not done, he asserts, the answer is to recast the whole system of budget allocation. However, in the light of past and present experience with planning in Ghana and elsewhere, Hirshleifer's argument is rather unrealistic. Many decisions relating to projects selection (and planning, in general) are taken within the framework of a budget constraint, and the economist would be rendering the nation a greater service by helping to sub-optimize within this framework, even if, as a long-run proposition, he thinks in his private capacity that it should be changed.

# CHAPTER 5. SUMMARY AND APPLICATION OF ANALYSIS

## Summary

The most common maximand or goal where projects involve only costs and benefits expressed in terms of money is the present value of benefits less costs.

Investment criteria are rules for agencies to follow in order to maximize the goal, subject to constraints. Where no projects are interdependent or mutually exclusive, where no time considerations are relevant and where no constraints are operative, the choice of projects which maximizes the present value of total benefits less total costs can be expressed in any of the following four equivalent ways enumerated by Prest and Turvey (82):

> "(1) Select all projects where the present value of benefits exceeds the present value of costs;
>
> (2) Select all projects where the ratio of the present value of benefits to present value of costs exceeds unity.
>
> (3) Select all projects where the constant annuity with the same present value as benefits exceeds the constant annuity (of the same duration) with the same present value as costs;
>
> (4) Select all projects where the internal rate of return exceeds the chosen rate of discount."

Once the various complications are introduced, more complicated investment criteria are required. McKean states that there is no single criterion which can put into proper perspective all the problems associated with different time paths. He suggests supplementary tables to show uncertainty and time paths. He advocates as the most significant partial test, which he refers to as the "right" criterion, "the maximization of present worth for a given investment budget, when the streams are discounted at the marginal internal rate of return." This proposal is directed towards selecting the set of best projects given a budget limit. However, the government (e.g., Congress) usually deliberates on the individual projects, not the set. Therefore, an index of worthwhileness, a rank of preference, must be assigned to a project. If this is needed, McKean suggests that the projects be ranked by the internal rate of return. It is then better to select the alternatives with the highest present values, proceeding down the list until the limited budget is exhausted.

The impact of the complications on cost-benefit analysis in terms of the present value approach[*] can be summarized as follows: Where the costs and/or benefits of two water-resource projects A and B are interdependent in the sense that the execution of one affects the costs or benefits of the other, they must be treated as constituting three mutually exclusive projects, namely, A alone, B alone, and A and B together.

Mutual exclusivity can also arise for technological reasons. Thus, a large or a small dam, but not both, may be put in one place. Whatever the reason for mutual exclusivity, its presence must be recognized and allowed for in formulating investment criteria.

Where there is a choice of starting date it must be chosen so as to maximize the present value of benefits less costs at the reference date.

Given a constant budget limitation, an investment schedule which shifts with time so that each year similar worthwhile investment

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[*] This does not imply that the present value approach is always the most convenient goal or maximand. Other maximands are possible, such as capital stock at a final date.

alternatives are available, and benefits which do not result in funds for the agency, then the choice of projects should be affected by the levels of future operating costs. The greater the future operating costs, the less funds will be available for later investments, and therefore, the larger will be the number of future projects not adopted even though they are better than currently marginal products. McKean avoids this complication by assuming that the benefits provide funds which cover operating costs (and therefore the level of operating costs is not relevant), and that only current investment funds are rationed.

Constraints cause the biggest complications, particularly when there is more than one of them and when mutual exclusivity and optimal timing are also involved. Indivisibilities also complicate matters when constraints are involved. The existence of more worthwhile projects in later years, coupled with the assumption of a comparable budget constraint, makes it important to consider the future constraints explicitly.

The achievement of our specified goal--namely, the maximization of present value subject to fixed investment budget--can be shown graphically by the use of Margolis' diagram reproduced here as Figure 4. Instead of selecting the best set of projects by the usual benefit-cost ratio method, here a slightly different procedure is employed. $\alpha$ is the ratio of operating costs to capital (referred to simply as "capital intensity") and is constant over time. $\beta$ is the ratio of benefits to capital, and is constant over time. The projects under consideration are ordered by $\alpha$. Given a constant investment appropriation (i.e., fixed government allocation for water resources development which is constant over time), the investment option is a choice among alternative projects with different

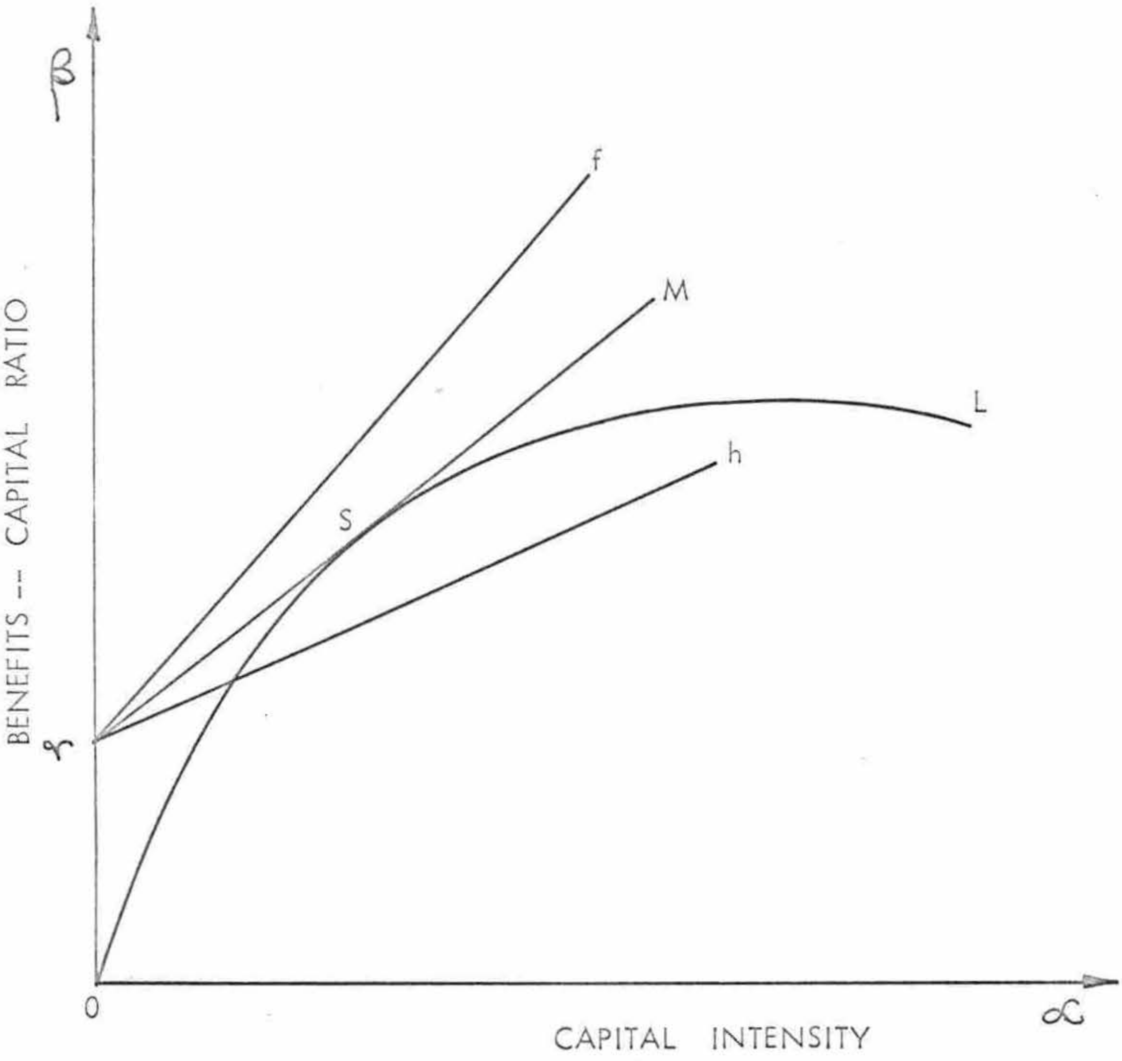

Figure 4. Maximization of present value

degrees of capital intensity, $\alpha$.

OL is the production opportunity curve and it represents the highest $\beta$, the benefits-capital ratio, of any project at a given $\alpha$. In order to choose the best project (or best set of projects) we must maximize the present value with respect to $\alpha$. After some algebraic manipulation, Margolis arrives at the following equation as the maximization condition for the present value:

$$\frac{d\beta}{d\alpha} = \frac{\beta}{\alpha + r}$$

where r is the level of the discount rate; rM, rf, and rh are some of a set of rays from r, each ray representing a different benefit-cost ratio. In graphical terms, this maximization condition is the tangency of rM with OL. The benefit-cost ratio line tangent to OL gives us the optimal ratio in order to maximize the present value of the investment budget. S, its point of tangency, tells us the best $\alpha$, or capital intensity. With this knowledge of $\alpha$, we can then choose the best project or the best set of projects.

## Applications to Water Projects

The principles set out in this section (Part One) of the thesis have been most commonly employed in cost-benefit analysis relating to two particular areas--water resource projects studies and transport projects studies. These techniques also have great applicability in land-usage schemes (urban renewal, recreation and land reclamation), health, education, research and development, and defense.

Our interest is presently focused on water resource projects. Water projects take many different forms; they may differ purely on engineering characteristics. The purposes of water investments are also different and many--provision of more water for an industrial area, provision of irrigation water, prevention of flood damage, etc. In some cases there may be only one such purpose in a particular project; in others it may be a case of multipurpose development. The details of cost-benefit analysis inevitably differ from project to project.

This study was prompted by the construction (1962-66) of the Volta River Project in Ghana. After several years of consultations and feasibility studies, the Government of Ghana and the Kaiser Engineers of the United States agreed to erect a dam at Akosombo on the Volta River, Ghana's largest river. The principal purpose of the Volta River Project was to provide abundant and cheap hydropower to the expanding industries and thereby facilitate Ghana's drive toward economic diversification. The next most important benefits from the scheme were envisaged to be irrigation, flood control and navigation. Other benefits were envisaged (such as industrial water to the Accra-Tema areas and inland fishing), but these did not feature much in the cost-benefit estimates. How were the benefits (and costs) of these "purposes" arrived at? This is the question I want to address myself to in this last section of Part One of the thesis.

Since the Volta River Project is a multipurpose scheme, we shall look only at a few of these "purposes" for which it was intended. We shall consider hydroelectric schemes, irrigation and flood control schemes--treating them, first, as separate individual projects, and then as parts of one multipurpose project.

The discussion is not necessarily based on the methods of evaluation actually used for the Ghana project. In fact, I intend to employ in this thesis only the standard methods of measuring the benefits (and costs) as previously discussed.

### Hydroelectric power scheme

The standard way of measuring the value of the extra electricity generated by a public hydroelectric scheme is to estimate the savings realized by not having to buy from an alternative source. This may sound simple, but a closer examination reveals all sorts of complicated issues.

Considering the simple case of a single public hydroelectric source versus a single private steam plant, it is easy to see that benefits can be measured by the costs of the most economical private alternative. As Eckstein (21) shows, this raises a number of issues; e.g., a private sector station will not be working under competitive conditions, and so its charges may not coincide with opportunity costs; private sector charges will not be directly relevant to public sector circumstances in that they will reflect taxes, private sector interest rates, etc. Another point arises when a new hydroelectric station provides a proportionately large net addition to the supply in a region. In this case (which is the case with Volta River Project's electricity generation) the alternative-cost principle would produce an overestimate of benefits, and we are forced back to a measure of what the extra output would sell for plus the increased consumers' surplus of its purchases. (See discussion on indivisibilities, *supra*). Presumably a survey of the potential market for the power will provide some of the needed information, but the difficulties of making reliable estimates remain enormous.

Let us consider a second case where a new hydroelectric station has to be added to a whole supply system. We want to measure the amount of power produced by the new hydroelectric station. The amount of power produced and the times of the year at which it will be produced depend not only upon the physical characteristics of the river providing the power but also upon the cost characteristics of the whole electricity supply system and upon the behavior of the electricity consumers. "The supply system constitutes a unit which is operated so as to minimize the operating costs of meeting consumption whatever its time pattern happens to be." Therefore, the way in which the hydroelectric station is operated may be affected by alterations in the "peakiness" of consumption, the bringing into service of new thermal stations, etc.

Now applying the principle of measuring benefits by the cost savings of not building an alternative station, we see that, because of the system interdependence just described, "the only meaningful way" of measuring this cost saving is to "ascertain the difference in the present value of total system operating costs (in the two cases) and deduct the capital costs of the alternatives." A simple comparison of the two capital costs and the two running costs will give the right answer only if the level and time pattern of the output of each would be exactly the same, a condition which is almost never achieved in practice. As a result, in general, a very complicated exercise involving the simulation of the operation of the whole system is required (Turvey, 105). Simulation models for other water resource projects can be found in Maass _et al_. (69).

Finally, Krutilla and Eckstein (60) point out that even if two or more hydroelectric stations are not linked in the same distribution and consumption network, there may be production interdependence. An example is that when upstream stations in a river basin have reservoirs for water storage, this is highly likely to affect water flows downstream, and hence, the generating pattern of stations in that area:

> "Once there is a steady flow of water from the Akosombo dam (the main dam of the Volta River Project), it is planned to construct a weir and power station at Kpong, twelve miles downstream, which will create a net addition to the project's power capacity of 86,000 kilowatts. . . ." (In a footnote): "The actual capacity of the Kpong station will be 140,000 kw, but its operation will reduce the capacity at Akosombo by 54,000 kw" Killick (58, p. 394).

If technological interdependence of this type is not internalized by having both types of station under the same authority, it will be necessary to have some system of compensatory arrangement if we want to cut down resource misallocation.

## Irrigation

Prest and Turvey contend that since it is seldom possible to ascertain directly the price at which water could be sold upon the completion of a proposed irrigation project, and since this price would in any case give no indication of consumers' surplus, the "direct" benefits of an irrigation project have to be estimated by:

> "(i) forecasting the change in the output of each agricultural project, leaving out those outputs which, like cattle feed, are also inputs;
>
> (ii) valuing and summing these changes; and
>
> (iii) deducting the opportunity cost of the change in all farming inputs other than the irrigation water

in order to obtain the value of the net change in agricultural output consequent upon the irrigation of the area" (82, p. 706).

In many countries with reasonably well-developed agricultural extension and advisory services, forecasts can be made for additional output, whether sold in the market or consumed on the farm. Some difficulties are encountered in trying to obtain these forecasts. Even in the absence of any delay in the response of farmers to new methods, it often takes some years for the full effects of irrigation to be felt in the economy. Since, in addition, farmers will take time to adapt, what is required is not just a simple list of outputs but a schedule showing the development of production over time. But this is too complicated to achieve in practice and usually "the best that can be done is to make estimates for about two benchmark dates and extrapolate or, alternatively, postulate a discrete lag in the response of farmers" (ibid). This difficulty in preparing forecasts of additional output is due to the fact that we are dealing with the behavior of a group of people (viz., farmers), and hence the forecasts will depend as much upon the agronomic conditions as also upon peasant conservatism, superstition, etc.

Forecasts are further complicated by the ever-present probability that farmers may not follow an income-maximizing course of action. If this happens, we have to substitute or supplement the projections based upon the assumption of maximizing behavior with projections based upon the assumption that the behavior of other farmers elsewhere constitutes a useful precedent.

With respect to valuation, all the complications already discussed become evident. The amount the farmer gets for his crops may differ markedly from their value to the community where agriculture is protected or subsidized, as in Ghana by the Marketing Boards for the various crops, or in the United States (Eckstein, 21). This proves the point made in the text that when the conditions for optimal resource allocation are not fulfilled in the rest of the economy, market prices become a poor guide to project costs and benefits. The indivisibility problem also arises when the increment in the output of any crop is large enough to affect its price, so that there is no unique price for valuation purposes. Though output should be valued at a given price level consistent with valuations of other benefits and costs, future changes in relative prices must be taken into account. Hence, price projections are required and, as before, anything from simple extrapolation to highly sophisticated supply and demand studies may be employed.

Subsistence output still forms a not insignificant part of Ghana's total agricultural output, and this raises the age-old problem in social accounting about the appropriate valuation of subsistence output. (For a complete discussion on this subject, see Prest and Stewart, 81).

The secondary benefits associated with an irrigation project are those which reflect the impact of the project on the rest of the economy, both via its increased sales to farmers ("induced" benefits) and via its increased purchases from them ("stemming" benefits). The appropriateness of including these benefits has already been discussed elsewhere in this thesis. Secondary effects (costs or benefits) may also arise because of technological interdependence among many irrigation schemes--for example, the effects on the height of the water table in one area may spill over to another district.

Any irrigation project will have a number of other (minor) effects; these will vary from case to case. Some examples of these effects (taken from an ex-post study of the Sarda Canal in India, 78) are:

> Canal water is also used for washing, bathing, and watering cattle.
>
> Silt is deposited at the outlet heads, which necessitates constant and laborious cleaning of the channels.
>
> Some plots of land have been made untillable by unwanted water.

Many such effects will be unquantifiable, but must nevertheless be remembered in any analysis.

## Flood control

The major benefits of flood control are the losses averted. The losses can refer to different types of assets--property, furnishings, crops, etc.; or to different types of owners--individuals, business firms, government, etc. In all these cases, the general principle is to estimate the mathematical expectation of annual damage ("on the basis of the likely frequency of flood levels of different heights") and then regard such sums as the maximum annual amounts people would be willing to pay for flood control measures. Other benefits which must be taken into account include avoidance of death by drowning, avoidance of temporary costs (e.g., evacuation of flood victims, epidemics), and the possibilities of putting flood land to higher uses if the risk of inundation is eliminated.

On the costs side, the initial costs of the flood control works and their repair and maintenance charges must be included. Since we do not find a free land market in many, if not all countries, the cost of land acquisition for reservoirs, etc., is bound to be arbitrary.

Principles of private investment alternatives do not have much applicability in the case of flood control projects--for many reasons. Protection for one inhabitant in a district inevitably implies protection for another, and so we run into the collective goods problem; protection for one district may worsen flood threats to another, and so this brings up technological externalities; flood works often have to be on a large scale and of a complex nature, and this brings us up against the indivisibilities and imperfect competition problems. As a result of these, one has to try to estimate willingness to pay for flood protection by the "roundabout devices" already described--market principles fail to help us.

### Multipurpose schemes

In practice, many river projects have a number of purposes in mind--navigation, fishing, recreation, etc., in addition to those discussed above. For such projects, we not only consider the cost-benefit data for, say, different-sized hydroelectric stations, but also we have to consider different combinations of, say, irrigation and navigation improvements. Because of greater possibilities of interdependence, the benefits and costs calculations become even more complicated. We, therefore, have to take seriously the problems of complications already dealt with above (which list is, incidentally, by no means exhaustive).

## Concluding Remarks

As is to be expected from the foregoing discussion, wide divergencies of view have been expressed about the role and usefulness of cost-benefit analysis. Some people look upon it as "a practical revolutionary concept of economic planning" (Hall 38, p. 173 and McKean 74). Others like Arthur Smithies (94) make a skeptical appraisal of the usual evaluation methods and conclude that "judgment plays such an important role in the estimation of benefit-cost ratios that little significance can be attached to the precise numerical results obtained" (p. 344).

Whatever the view one takes, it is important to note that cost-benefit analysis causes questions to be asked (e.g., the justification of existing pricing policy) which would otherwise not have been raised.

The case for using cost-benefit analysis is strengthened, not weakened, if its limitations are openly recognized and indeed emphasized. We cannot expect this technique to be of any use if a project is so large as to alter the whole complex of relative prices and outputs in a country. It is no good expecting those fields in which benefits are widely diffused, and in which there are manifest divergences between accounting and economic costs or benefits, to be as easily amenable to cost-benefit analysis as others. Nor is it realistic to expect that comparisons between projects in entirely different branches of economic activity are likely to be as meaningful or fruitful as those between projects in the same branch. The technique is more useful in the public-utility area than in the social-services area of government.

Lastly, it must be emphasized that even if cost-benefit analysis cannot provide the right answers, it does play the role of screening projects and rejecting those answers which are obviously less promising. Insistence on cost-benefit analysis, therefore, can help in the rejection of inferior projects, which are nevertheless promoted for empire-building reasons.

# PART TWO. ALLOCATION OF WATER BETWEEN ALTERNATIVE USES

# CHAPTER 6. ECONOMICS OF WATER IN GHANA

## Introduction

Ghana lies in a central position in West Africa. The country is roughly rectangular in shape and has a total area of about 92,100 square miles (238,537 square kilometers). It is bordered on the north, east and west by the states of Upper Volta, Togoland and the Ivory Coast, respectively; its coastline of about 344 miles extends southwards into the Gulf of Guinea (see Figure 1). From its extreme southern point lying at latitude 4° 44' North of the Equator the country extends about 420 miles to a northernmost point at latitude 11° 10' North. The extreme eastern point is given by longitude 1° 12' East and the extreme western point by longitude 3° 15' West. The Greenwich Meridian passes through the new harbor and township of Tema, which is 15 miles to the east of Accra.

The estimated population of Ghana at the end of 1963 was about 7,400,000. This gives a population density for the whole country of about thirty-one per square kilometer. Ghana is by no means a densely populated country but by comparison with conditions prevailing in other parts of Africa, Ghana's population density is fairly high (Omaboe, 79). Comparable figures (for 1962) for some selected African countries are 5 for Algeria, 18 for Ethiopia, 39 for Nigeria, 28 for Morocco and 106 for Rwanda (cf. United Nations Demographic Yearbook, 1963). Africa as a continent is sparsely populated. Its average density of population of nine persons per square kilometer compares with 10 for America, 64 for Asia, 87 for Europe excluding the Soviet Union, and a world-wide average density of 23.

Although Ghana's population is at the moment relatively low, the population is growing rapidly--at an estimated annual rate of growth of 2.6 percent. If this rate is maintained the population will be about 11 million by 1980 and close to 19 million by the turn of the century, giving an average density of 79 persons per square kilometer.

By size and population, Ghana is a small country. This has its advantages and disadvantages in terms of the economic and social development of the country. One advantage is "the compactness of the country which enables it to escape the troubles and difficulties facing the development of many of the large countries of Africa, Asia and South America." On the other hand, with a population of only about 7 million a serious limitation is imposed on the size of the domestic market for a wide range of commodities and this in turn may have serious repercussions on the tempo of economic growth and development. The escape from this, as Ghanaians see it, is through the formation of an African Common Market. The first step toward achieving this objective was taken in May, 1967 when representatives from all West African countries (except Guinea) met in Ghana under the auspices of the United Nations Economic Commission for Africa to draw up a plan for an Economic Community of West Africa--considered to be a forerunner of the continent-wide African Common Market.

## Economic Geography of Ghana

R. Szereszewski (100) states that the foundations of the existing structure of Ghana's economy were laid during the last decade of the nineteenth century and the first decade of the twentieth century. This was the period during which the export economy of the forest belt of the country was developed and transformed. Prior to this the country had a small export trade but this was based largely upon the collection of naturally-occurring forest produce such as palm fruits and kernels, kola nuts and wild rubber. These two decades saw the replacement of this export trade by the products of two major economic activities, gold-mining and cocoa-farming. These two products have dominated the economy of the country for more than half a century now and they have dictated the pace of economic growth and the present structure of the economy. A significant fact is that cocoa-growing has been closely integrated into the subsistence agriculture. This has had the effect of greatly reducing subsistence production in the country. Generally, the existence of a large sector of subsistence is a normal feature of most underdeveloped countries; in the rural areas the impact of money is not great and most of the farming communities produce for their own consumption. Information available (in 1963) on the pattern of household consumption in Ghana reveals a relatively small degree of subsistence production. It was estimated then that the consumption of their own produce by producers in Ghana as a whole represents about 20 percent of total household expenditure. This is not a particularly high figure considering that Ghana has over two-thirds of her working population engaged in rural activities. "The proportion of their own produce consumed by producers in urban communities is only about 7 percent although in the rural communities it is as high as 31 percent. Even so the rural households show a relatively high degree of sophistication in their consumption patterns" (Omaboe, 79).

The economic transformation to a modern export economy and the degree to which subsistence economy is now being changed, by commercialization of its resources, into an exchange economy, have been duly reflected in the growth of the Gross Domestic Product. Szereszewski has estimated that over the twenty-year period, 1891 to 1911, there was a growth rate of about 1.8 percent per annum in the Gross Domestic Product _per capita_ in real terms. This represents a relatively high rate of growth in the standard of living.

Ghana's expenditure on the Gross National Product in 1960 was estimated at about N₵ 940 million (i.e., $1,316 million). This is a _per_ capita national income of $200 which provides Ghana with a high level of living relative to other underdeveloped countries. It can be compared with the $90 of Nigeria, the $120 of the United Arab Republic (Egypt) and the $73 of India. Although the Ghana figure appears to be high by the standards of the underdeveloped countries, it is still low compared with the levels which have been achieved in the developed and industrialized countries. Comparable figures for some of the developed countries are:

| | | |
|---|---|---|
| United Kingdom | $1,244 | (1958) |
| Sweden | $1,592 | (1958) |
| Canada | $1,310 | (1954) |
| United States | $1,870 | (1954) |

These figures reveal the great magnitude of the differences in the standard of living between the underdeveloped countries and the developed countries of the world.

The low per capita national income of Ghana (compared with the developed countries) creates a number of difficulties concerning the mobilization of savings within the economy and the rate of economic growth which the country is able to generate through its own resources. The raising of the per capita national income is therefore the main objective of all development planning in Ghana. In order to achieve this the annual rate of growth of the economy should exceed the annual rate of growth of the population. The rate of growth per annum of the population thus sets a lower limit to the real annual economic growth that must be obtained if the standard of living is not to be allowed to fall. Szereszewski (99) analyses the performance of the Ghana economy between the years 1955 and 1962 and shows that the Gross Domestic Product showed a relatively high real rate of growth of almost 40 percent in those seven years. This was an average compound annual real rate of growth of 4.8 percent, "a rate which is high by the standards both of the developed countries and of most of the less developed countries." When the increase in Gross National Product is considered against the estimated annual increase in population of 2.6 percent, we find a substantial rise in the average levels of living during the period--over 2 percent per annum.

This well advanced state of affairs has been made possible principally by cocoa-growing and mining with its associated construction works. As with most underdeveloped countries, farming is the major occupation in Ghana, accounting for the livelihood of over 60 percent of the working population. Eleven percent of the farmers grow cocoa. The economic dominance of this crop, Ghana's leading export commodity, is the main reason for the diversification of the economy. Ghana is the world's largest supplier of cocoa;--one-third of the world's entire supply of cocoa comes from Ghana.

It is estimated that about 80 percent of the capital stock in Ghana consists of investment in construction and cocoa. Capital investment in cocoa has enabled the country to take a high place among the underdeveloped countries in terms of _per capita_ national income (as well as capital stock _per capita_) and investment in construction has succeeded in providing the country with an infra-structure which is advanced even by the standards of some of the developed countries.

Such a one-crop economy is obviously an obstacle to industrial growth, and always is subject to market fluctuations, a potential source of financial instability. Ghana resolved to break this financial dependence on the cocoa market by broadening the nation's economic base. (It must be noted that the infrastructure of Ghana is capable of supporting economic activity far above the level presently attained. Moreover, the quality of the managerial and administrative machinery which Ghana possesses is of a relatively high standard; the quality of the senior civil service is high and compares well with that of the developed countries--that is a fact which is accepted by all those who have had much to do with the Ghana Senior Civil Service. Unfortunately, the same tribute cannot be accorded the junior civil service. In commerce Ghanaians hold important managerial and administrative posts in both domestic and foreign enterprises.) The first step in diversifying the economy was to determine what resources the country could develop and what the sequence should be for long-term sustained growth.

One of the basic measurements of any nation's economic well-being, productivity and strength is the amount of its power generation and consumption, and the development of water resources. Over the past seven years the pace of industrialization has been very rapid. But unfortunately, or of necessity, the Government has been the largest single body concerned with such industrial progress, because indigenous private enterprise has been confined mainly to agriculture and its associated activities. The need for cheaper and increased volume of electric power for new and growing industries has been discussed several times over the past two decades. Then again, although Ghana is often regarded as a well watered country, the problem of conservation and utilization has always been of major importance everywhere except, perhaps, in some parts of the forest zone where there is little agricultural activity. In the dry season the greater part of the country (especially the northern savanna districts and some coastal areas including the whole of the Accra Plains) suffers a chronic shortage of water for all purposes--notably water for domestic use and for irrigation. Improved and greatly increased volume of water supplies are essential if those areas are to increase their population and agricultural activity.

Thus, after Ghana became independent in March, 1957 (it was, prior to this date, known as the Gold Coast), the government called for new studies of earlier British investigations (1952 to early 1956) of the feasibility of constructing a dam and powerhouse on the Volta River. The Volta Project was conceived as a multipurpose scheme providing abundant hydroelectric power and also water for the irrigation of the area below and adjacent to the Volta River and the development of an inland fishing industry. This project was compared with some other projects, both multipurpose and a series of single-purpose projects, all of which had the objective of "progress in the development of Ghana's natural resources, industry and agriculture." These alternative projects were subjected to formal quantitative analysis described in Part One.

The Government of Ghana had long been convinced of the desirability of the Volta River Project; in February, 1959, an appraisal of all the alternative projects (with costs assessed at current prices) saw the selection of the Volta River Project. The project was started in January, 1962 by the Kaiser Engineers of Oakland, California, U.S.A. and completed in January, 1966; first commercial power from the project was produced in August, 1965.

To make the large hydroelectric power available from the project economically feasible, it was essential that there be a consumer for a major block of the power generated. Studies had indicated that this point of the feasibility could be met by construction of an aluminium smelter, an industry which requires large amounts of power. This was to form the nucleus of an integrated aluminium industry utilizing hydroelectric power from the project to refine deposits of bauxite in the vicinity of Akosombo. The hydroelectric project and the aluminium smelter are financially separate. The construction of the Valco smelter at Tema was begun in December, 1964 and is nearing completion now.

The principal source of revenue from the Volta River Project will be sales of power. The demand for the power will come from three groups of consumers: the Valco Smelter, the mines (Ghana has a natural endowment of exploitable mineral deposits--gold, diamonds, manganese and bauxite), and the general public. The minimum revenues from sales of power to the smelter are known with a high degree of assurance, since they are written into the power contract signed by the Volta River Authority and Valco. (The Volta Aluminium Company (Valco), owner of the Smelter at Tema, is a partnership of two aluminium producers headed by Kaiser Aluminium and Chemical Corporation of the United States of America.) Under this contract the Authority is obliged to make available, and Valco is obliged to consume or to pay for, certain minimum quantities of power. The minimum quantities are specified for each year--starting from the first year of the "Permanent Delivery Date", a date which in all probability seems to be April 1, 1967. The price at which the power will be sold to the smelter is fixed for the first thirty years at 2.625 mills, equivalent to 0.187 pesewas[*], per kilowatt hour. This price is by any standards a cheap rate indeed; it is about one-ninth of the estimated cost of producing power from the most efficient of Ghana's present power stations. Thus, although the smelter demand was essential to the viability of the hydroelectric project, because an alternative project of a dam with a substantially smaller generating capacity would have much higher unit costs, very little direct profit will be obtained from sales to the smelter--at least for the first thirty years.

A large demand for power from consumers other than the smelter at remunerative prices is thus essential to the hydroelectric project. The Kaiser Engineers' Reassessment Report of 1959 calculated maximum and

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[*] A mill is one-tenth of a U.S. cent. 1 pesewa = 1.40 cents (U.S.). N₵ 1.00 (one new cedi) = $1.40 (U.S. dollars).

minimum costs of power delivered to the general public for domestic and industrial uses as 7.12 mills and 4.75 mills respectively. Based on estimates of average daily demand for the Electricity Division's power and the Reassessment Report's projections of past trends in the consumption of electricity in Ghana, Killick (58) asserts that revenue from sales to other consumers is expected greatly to exceed revenues from the smelter, even though for a long time the smelter will be taking the larger part of the total power generated at Akosombo. He then sounds an optimistic note that "subject to the qualification that it is difficult to estimate the growth of non-smelter power demand, there seems every reason to believe that the hydroelectric project will in itself prove a wise investment. And this is quite apart from any external economies that it may create" (58, p. 401).

## Water Use

Apart from hydroelectric power generation, some of the more important alternative uses to which the waters of the Volta Lake can be devoted are irrigation, inland transportation, recreation, fishing and domestic and industrial water. Of these uses, irrigation and inland water transportation are receiving considerable attention of the Government of Ghana. Lake Transportation Survey and Accra Plains Irrigation Survey were undertaken in 1965 and 1966 at the expense of the government.

### Domestic use

Use of domestic water has grown steadily over the past decade and will keep on growing as the standard of living rises for the country as a whole. There are wide variations in domestic water use in different regions due to great regional inequalities in terms of standards of living. Price has little effect on use since water costs are normally modest and have minor constraints on use.

In the cities and towns the population is served with piped water by the Water Supplies Division. In the rural areas where there are no piped water supplies, the Water Supplies Division provides clean water from wells, boreholes and ponds (principally from wells) under the Rural Water Supplies Scheme. Over the past decade the number of piped water supplies has increased steadily from 43 in 1957 to 119 in 1965. Comparable figures for other types of water supplies are: from 45 to 98 for ponds, from 367 to 790 for boreholes, and from 2,915 to 3,833 for wells. In 1965 the total water production from Water Works in the country was 10,992 million gallons. The population served by the Water Supplies Division with piped water, ponds, boreholes and wells was estimated at 2,537 thousand in 1965. "This shows that only 32 percent of the population was served with water by the Water Supplies Division" (30, p. 86). Per capita municipal use for cities in the United States varies from 50 to 500 gallons per day but of this some is for industrial and commercial use. The 1965 figures indicated that the average municipal use of water for the City of Accra was of the magnitude of only 40 gallons per capita per day.

During the dry summer months of July, August and September there is a shortage of water for domestic use not only in the Accra municipality but also in the whole of the arid Accra Plains area. It might seem that the low level of per capita consumption of domestic water is due to lack of water supplies facilities. However, notwithstanding the shortage of domestic water during the summer months, one cannot offhand assert that domestic water demands will have a fortuitous phasing with dependable and improved supplies, because the use is sometimes wasteful in some other months. This phase of the problem requires detailed studies for each region before intelligent water allocation to domestic use can be made.

In conclusion, the following observation will be made: although the use of water for domestic needs will increase with population increase and a rising standard of living, there is no reason to expect any revolutionary change in the per capita consumption for domestic purposes. Consequently, the amount of water from the Volta Lake which will be allocated to domestic use will not be of any substantial magnitude at least within the next decade.

### Industrial use

Use of water for industrial ventures varies not only between products but also between different plants producing identical products. The nature of the use is variable and the effects of the use on the waste water may vary likewise. A few industries such as the soft-drink plants and breweries actually use water in their products, as well as in processing. The two major industrial uses of water are for condenser water and in manufacturing processes. In the latter use, there is a wide range. For example, a canning plant may need only wash water, while paper mills require large amounts of water to suspend pulp fibers and steel mills may require large amounts of water to quench and descale the steel in rolling mill. Industrial use of water is, therefore, a complex matter and cannot be easily defined. It is customary to use water circulated per manufactured unit as a measure of industrial water use. As seen above, the present water use is very small indeed.

With respect to future industrial water use, we find uncertainty of changing economic factors to be a major effect on the future use patterns. The use of water in the future appears certain to increase at a greater rate than the level of industrial production. Consideration of future industrial water use cannot be divorced from that of the selection of industries that (a) might profitably locate in the industrial southern Ghana which is expected to absorb most of the water allocated for industrial purposes, (b) would utilize the raw materials produced in the country, and (c) would absorb a maximum of the available working force. It is difficult, if not impossible, to adhere to all three of the above principles. For instance, some industries that would utilize Ghana's natural resources may require large quantities of water and employ relatively few people, while other industries would employ a large number of people, require a minimal amount of water and utilize very little of our natural resources. With due consideration for the effect of various patterns of industrial water use on Gross National Product, and considering the fact that problems of unemployment and underemployment are real in Ghana, the Seven-Year Development Plan gave preference to industries that would absorb the growing labor force and that would require some minimum amount of water for industrial purposes. Among the industrial groups selected for study in developing the patterns mentioned above are food and kindred products, textile mill products; stone, clay and glass products, and electrical machinery and equipment. Thus, the suspended Seven-Year Development Plan intended to pursue the following "five important economic objectives" to achieve the goal mentioned above:

> "(a) To the largest degree possible domestic substitutes should be produced for those manufactured staples of consumer demand for whose supply Ghana is now entirely dependent on foreign sources and expends large sums in foreign exchange each year.
>
> (b) The agricultural and mining commodities that are at present exported mostly as unprocessed primary products should be progressively processed and manufactured before export.
>
> (c) The building materials industry should be expanded and modernized to enable it to support the inevitable increased activity in construction and a start should be made on the development of other basic industries in the field of metals and chemicals.
>
> (d) In the development of basic industries particular attention should be paid to preparing the economy for further stages of industrialization envisaged under subsequent plans. A beginning should therefore be made in a small way in the field of machine industries, electrical equipment and electronics.
>
> (e) Industries will be developed in such a way that they fit in with development in other African countries" [1]

In late February, 1966 there was a change-over of Administration in Ghana. The new Administration charged the old regime with, inter alia, serious economic mismanagement and suspended the Seven-Year Development Plan which, it was alleged, "existed only in name during the year (1965) and it was no wonder that the 5.5 percent target rate of growth for the economy it contains proved to be an unattainable rate in 1965. Quite apart from the fact that government expenditure was running at a level much higher than is indicated in the Plan, the composition of this expenditure was also terribly out of tune with the Plan estimates. . . . All the

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[1] Seven-Year Development Plan 31, p. 93.

efforts (by the new Administration) to stabilize the economy have resulted in an increase in unemployment levels. This should give the government some worry as it poses both a political and a social problem. The new budget of the Administration makes provision for a number of labor-intensive projects which can go a long way to minimize the unemployment problem" (30, pp. 105-106). It is not difficult to infer from these pronouncements that the new Administration will very likely be guided in their industrial program by the "five important economic objectives" outlined above, and that in case of any major deviations from these "objectives" it is not unreasonable to assume that the new emphasis will be put on industries which will go a long way to solving the problems of unemployment and underemployment while requiring some minimum amount of water for industrial purposes.

Mineral resources of present known economic importance found in Ghana are gold, diamond, bauxite and manganese. All these minerals as well as stone, sand and gravel are in active production. Some other minerals which are known to exist in Ghana, and are likely to come into production within the foreseeable future are clay, beryllium, iron and white lime (cf. Killick, 57). Sand-gravel and stone are being exploited by the local building industry. Clay suitable for brick-making and pottery is found in many parts of the country, but these (especially brick-making) will become of importance only when heavy industries become the order of the day, or cheap transportation becomes available. A more recent and unexploited discovery is the large deposit of iron ore near Shiene in the Northern region. The future of iron apparently lies with the increased activity of the construction industries and cheap transportation. The Shiene iron ore fields is within reach (only 30 miles away) of the Volta Lake and thus water transportation is possible for the products of any mine that might be constructed there. Beryllium probably will be the last of the minerals to be exploited. It nevertheless constitutes a valuable source of imparting great strength and resistance to fatigue to alloys with aluminium and iron which are producible in Ghana.

Mining operations and mineral processing, however, do not require large amounts of water. For most open pits water is required only for cooling radiators on internal combustion engines and for domestic use. In large open pit mines water is required for churn or rotary drilling. Underground mining operations require considerably more water than open-pit mining because of the necessity to reduce dust. All drilling underground is done wet; that is, a stream of water is kept on the drill bit. After blasting, the broken rock is sprayed with water to reduce the dust hazard. The amount of water consumed underground varies within wide limits, but on the whole the average figure for the volume of water per ton of ore mined is very small indeed. Processing of ores generally requires large quantities of water in comparison to those required for mining operations.

Hence, as greater emphasis is placed upon "progressively processing and manufacturing" our agricultural and mining commodities before export, the industrial water demand can be expected to increase very sharply, percentage-wise. However, it must be noted that water uses for industrial purposes have developed in an environment of relative abundance of water and uses have been very generous. In the future, such uses will seem wasteful and we can anticipate more restrictive uses. Taking into consideration the above analysis of manufacturing and mining industries, it seems doubtful if this percentage increase in demand for industrial water can be translated to any substantial increase in the volume of water going into industrial ventures. Consequently, at least in the foreseeable future, the amount of water from the Volta Lake allocated to industrial use will not be of any significant magnitude.

## Recreation

In Ghana recreation business is still in its infancy and is very small, in terms of visitors to public recreation areas. But with a rising *per capita* income and with an increased activity of the Ghana Tourist Board, the demand for all types of outdoor recreational activities is likely to increase greatly in the coming decade--with demand for fishing and swimming taking precedence. There is therefore a great need for the Ghana Tourist Board to cordinate and aid in the planning and use of outdoor recreation activities. At present the data accumulated by the Board are very sketchy and incoherent. It is hoped that in the near future the Board will be able to provide such basic data as recreational benefits (in terms of cedis per visitor-day) to be used in comparing the costs for determination of economic justification of proposed recreational developments, and also the number of visitors (per a unit period, say a year) to the various recreational areas.

As mentioned elsewhere, recreation has become a big business in Ghana. Water recreation activities are currently confined to the coastal areas (e.g., Biriwa Beach, near Cape Coast, and Labadi Beach near Accra) and Akosombo, the southernmost tip of the Volta Lake. Water recreation activities are expected to be on the increase in the future but this will have very little effect on water use.

An important question that comes to mind is whether the traditional institutions of supply, demand and market pricing system can be depended upon to serve as a basis for allocating water to recreation. This is a valid question because with growth in urban population and per capita income, and the resulting growing demand for outdoor recreation, "what was once virtually free for the asking--e.g., access to a desirable fishing stream--is now in increasingly short supply" (cf. Wollman 110, p. 220). Whereas the industrial user of water is a well-defined personal or corporate entity that can protect the vital raw materials of its activity, the recreational "industry" is disorganized and itself depletes very little water. As Wollman puts it, for the most part, it is not the businessman in the "industry" but the ultimate consumer who makes contact with water. The interest of the industry in an adequate water supply is, therefore, more indirect than that of farmer or processor, even though water may be just as essential for the industry's welfare. "Because of this indirect nature and the fact that the recreation industry is, in fact, composed of a wide variety of trades, services and government facilities, no well-defined user interest--except that of the consumer himself--can readily be mobilized. For this reason one might suspect that in order to provide for an allocation of water to recreation that gives due consideration to the 'demand', some public or public-private arrangement may be required, the rationale of which is not directly derived from private, market-price processes" (Wollman 110, p. 221).

## Water transportation

One of the potential benefits of the Volta Lake is that of inland water transportation or navigation. Technically there is no major difficulty but economically the viability of such water transport system will depend on the volume of traffic. Because of great regional inequalities, there is at present a very limited flow of goods between the North and the South. Killick (58) has suggested that a major expansion of North-South trade will occur if the iron ore deposits at Shiene in the Northern region were found to be worth exploiting. The observation has also been made that many of the new communities on the shore of the lake will develop into prosperous fishing and trading centers. Low-cost water transportation will, obviously, play an important role in the development of both developments--providing dependable and cheap transportation of the iron ores to the South for processing, and also providing access to a broad trading area for the inland fishing industry.

Engineering and preliminary design has been undertaken by the Kaiser Engineers for structures and facilities that would be required for a passenger and cargo transport system on the Volta Lake, and a Lake Transportation Survey was conducted by the government to study all transport system from the lake downstream to the coast. The survey was not only an exercise at determining the feasibility of the water transport project but also an attempt to determine where the proposed inland ports of the Volta Lake are to be located. It is needless to say that any policy intended to reduce regional inequalities or stimulate trade from the South to the Northern regions of Ghana and thence into Upper Volta must take into account water transportation on Lake Volta--subsidizing such a transport system, if necessary.

The new Administration has committed itself to developing the Volta Lake water transport system and work is to begin soon. It therefore seems clear that a considerable amount of water of the 120-million-acre-feet-capacity Lake Volta will be devoted to water transportation.

## Irrigation

The possibility of drawing water from the Volta Lake to irrigate the areas below and adjacent to the Lake has been the subject of a good deal of investigation. The two principal studies were undertaken by the Food and Agricultural Organization of the United Nations and the Kaiser Engineers. Because of the fairly heavy capital costs involved, the irrigation studies have so far been confined to the relatively arid and potentially more productive soils of the Accra Plains. It is hoped that as the financial position of the economy improves the adjacent areas of Ho-Keta Plains and Kpandu district will also be brought under irrigation.

The lowest rainfall values in Ghana for any particular year are recorded over the Accra Plains with the capital (Accra) itself having an average annual rainfall of only 28 inches. Since 1960 some experiments have been conducted on the black soil of the Accra Plains to determine the feasibility and advisability of an irrigation scheme for the area and also to determine what crops are best suited to the soil conditions. One such pilot scheme (the Dawhenya Dam Project) proved to be a great success with 500 acres of rice. In the last couple of years the State Sugar Products Corporation, in an attempt to increase its activity, sponsored a research project on the plains and the result was astonishingly good.

Modest successes have also been recorded in experiments with other crops--this was done to replace the high starch foods of maize and cassava which enjoy natural immunity in the plains with more highly profitable crops as vegetables, cotton, tobacco and fruits.

Both the FAO and the Kaiser Engineers Studies agreed on the technical feasibility of the Accra Plains irrigation project--it would be possible to take off from the Volta Lake a sufficient volume of water to irrigate the plains without reducing the power generating capacity of the dam. The Accra Plains irrigation scheme is likely to affect the agricultural economy in ways comparable to that of the hydropower development. Under the scheme, an irrigation system has been designed by the Kaiser Engineers (though not yet constructed) to bring water from Lake Volta and the Volta River to the Accra Plains. When completed, the Accra Plains project will enable Ghana to produce major quantities of industrial raw materials for the local industries--cotton and sugarcane--and will provide an abundant supply of consumer staples, including rice, other grains, vegetables and citrus fruits. A reconnaisance study by Lewis G. Smith (done on behalf of the Volta River Authority) indicated that a financially profitable scheme of irrigation would be possible at a capital cost of N₵ 51.6 million or $72.24 million (92). The Smith report estimates that the annual value of the rice crop should exceed the total cost and, at 30,000 tons a year, would greatly reduce the country's need to import this food.

The relative dryness of the Accra Plains requires some comment. The Accra Plains covers an area of about 935 square miles; it extends as a strip about 15 miles wide from 6 miles west of Accra to the vicinity of Ada. (It is separated from the Ho-Keta Plains, to the east, by the Volta

River--see Figure 5). The Accra Plains make up the vegetation zone known as the Coastal Savanna Grassland--"with a variable development of thicket scrub and scattered trees" (Lane, 1957). In the western part of the plains grassland with clumps of potentially evergreen thicket is typical; this area has an average annual rainfall of about 35 inches. However, the eastern part of the plains comprising about 700 square miles (or about 450,000 acres) has an average annual rainfall of only about 30 inches--the lowest in the country. It is this eastern part of the Accra Plains (east of Accra and Aburi) that will be covered by the irrigation scheme.

The principal features of rainfall in this region, as is the case all over Ghana, are its seasonal character and its variability from year to year. The average distribution of rainfall during the year does not vary much over the area--from about 35 inches in the west to about 28 inches in the east. These average figures are low compared with the national average figure of between 40 and 70 inches. The average annual rainfall is greatest in the Western region where Esiama (near Axim) has an average of 86 inches. The seasonal variability is more pronounced for other areas than for the Accra Plains area. The seasonal distribution and its variability for typical stations are illustrated in Figure 6. (Compare the seasonal distributions of Axim in the West, Kumasi in the central area, Accra in the Accra Plains area, and Ho to the East.) Most of the central and southern parts of the country have two clearly defined rainy seasons, the principal reaching its maximum in May and June and the subsidiary in October. Though this affects the whole coastal plain, yet in the Accra Plains the subsidiary season is scarcely in evidence. January is a dry month throughout the country, but the driest month in the

**Figure 5. The Volta Lake**

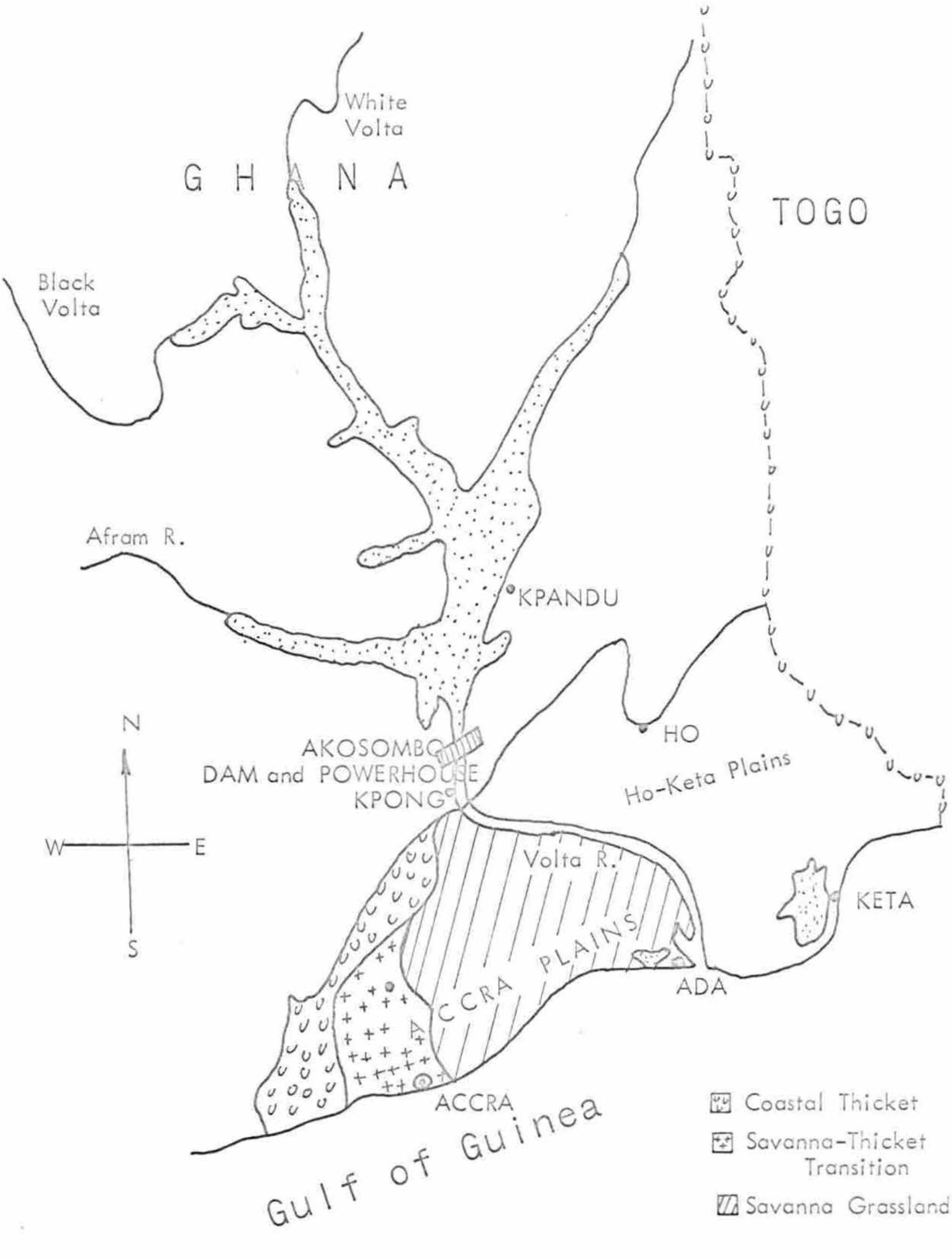
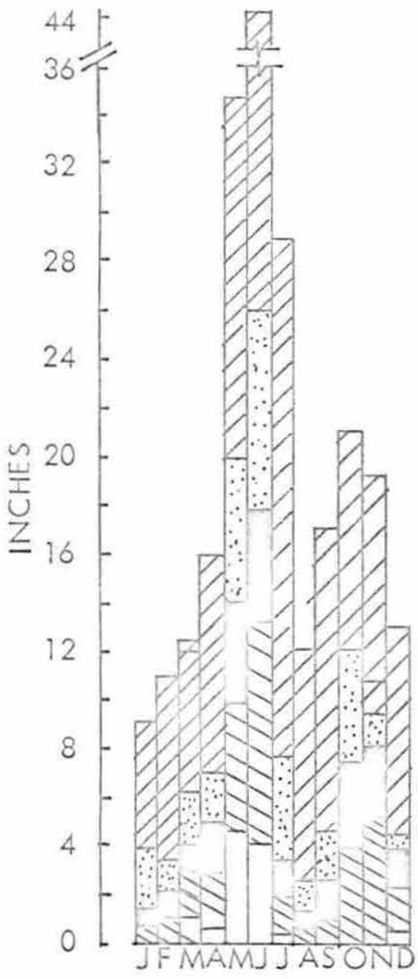
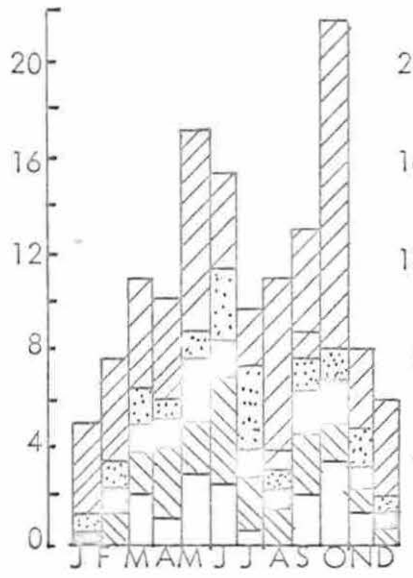

White Volta
GHANA
TOGO
Black Volta
Afram R.
KPANDU
N
W
E
S
AKOSOMBO
DAM and POWERHOUSE
KPONG
HO
Ho-Keta Plains
Volta R.
ACCRA PLAINS
ADA
KETA
ACCRA
Gulf of Guinea
Coastal Thicket
Savanna-Thicket Transition
Savanna Grassland

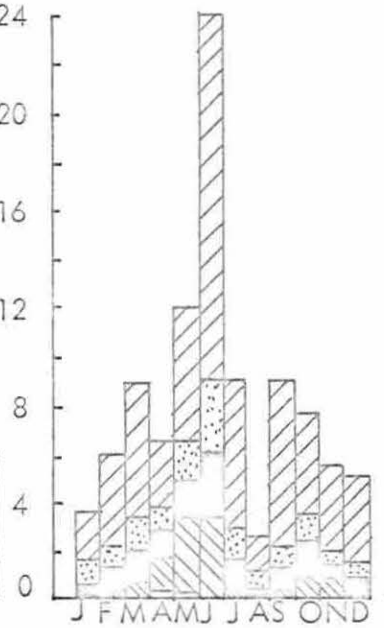
Figure 6. Seasonal distribution and variability of rainfall
Source: (108, p. 12)



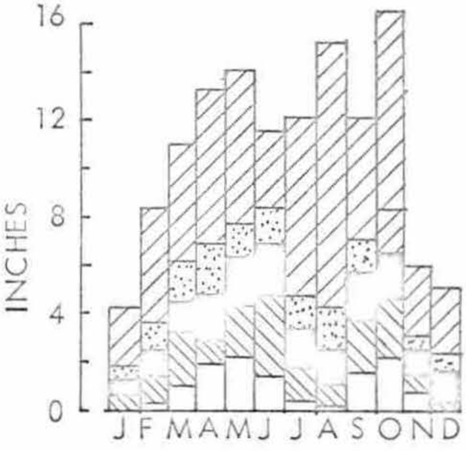
AXIM(1915-1954)



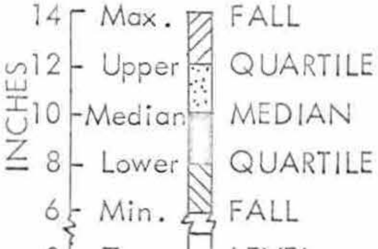
KUMASI (1906-1954)



ACCRA(1910-1956)



HO (1915-1954)



GLOSSARY

Accra Plains is August. This accounts for the "chronic shortage of water" during the summer months in the capital, Accra, and its environs. The result of seasonal variations is variability in monthly rainfall totals and also in yearly totals. Figure 6 presents values of the median monthly rainfall totals, the greatest and least values recorded in each month and the quartile values. It will be noted that, while June in the southern part of the country is expected to be wet with average monthly values between 6 and 10 inches, values at Accra range from 24 inches to just under 5 inches.

The savanna grassland of the Accra Plains is one of the least-farmed regions of the country, the grassland being mainly used for grazing of cattle. The black soils do not support good grazing land, water supplies are hard to obtain and the soils are extremely difficult to cultivate with the hoe. The result is that the land they underlie is practically unused except for occasional grazing when nearby grassland has been overgrazed.

# CHAPTER 7. MODELS FOR WATER RESOURCES ALLOCATION

## Introduction

Efficient utilization of the water resources within a river system requires a knowledge of the net social benefits derived from various quantities of water allocated to each of the many potential users. The difficulties in quantifying these benefit functions have already been discussed in Part One. For further discussion, McKean (74) and Eckstein (21) are suggested.

The Volta River Project, when fully completed, will take on the character of a highly developed river system, in that the water levels in the reservoirs, the flows in the streams and canals and the quantity of water allocated to each of the many water uses can be at least partially controlled. The operation of the many control structures in such a way as to best satisfy all these demands poses a problem.

Problems of allocation often involve the simultaneous determination of a number of variables. Consider the allocation of the waters of Lake Volta. Because of the seasonal variation of rainfall over all regions in Ghana, the amount of water in the lake will obviously vary from season to season. We also have a number of alternative uses to which this water can be put, each use having different seasonal requirements. The problem here is that of selecting the best alternatives;--that is, the determination of the solution of the variables which yields the greatest product or income from the given volume of water. If there were no positive interaction between the variables, an "optimum" solution would eventually be found by consecutively holding all variables constant but one, each time calculating incremental (or marginal) costs and returns. However, most planning agencies do not have sufficient resources for this laborious procedure.

Activity analysis appears promising as an aid in water resources allocation, in view of the large number of interdependent variables that may be involved. The most important optimization technique developed in the field of activity analysis is linear programming, a method which attempts to prescribe optimum courses of action for a given (linear) objective. The general problem of linear programming is the search for the optimum (minimum or maximum) of a linear function of variables constrained by linear relations (equations or inequalities) called restraints.

Two linear programming models are discussed in this thesis. The first corresponds to the present situation in which the principal demands for water are for electricity generation and irrigation of only one area, the Accra Plains. Irrigation of the area adjacent to the lake is not considered here; the amount of water for domestic uses is taken as a constant; no provision is made for other uses of water* (cf., discussion of Chapter 6).

The second model is a method for determining rational water-allocation policies when the Volta River Project is fully completed and is functioning as a "highly developed" river system--with all the fixed physical plant (e.g., reservoirs, dams, power plants, irrigation canals, etc.) completed and operating. This model thus abstracts from fixed

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*Industrial uses of water, water for recreation, and uses by fish are small in relation to the agricultural uses of water.

capital costs and allows for several consumptive uses of water in the Volta river system. Consumptive use, in this context, means any use that makes water unavailable for other users.

The policy objectives of the two models, while remaining essentially the same (that is, efficient utilization of the water resources among the users), give rise to different objective functions.

## Model I

### The objective function

The capital costs associated with electricity generation (that is, the building of the Volta Dam and power plant at Akosombo) will not be introduced into the function since these costs cannot be manipulated. The capital costs of building the reservoir R to capacity Z and the irrigation system to capacity I million acre-feet (m.a.f.) per year, however, while also are given data, must be introduced into the objective function since these capital costs are yet to be incurred. The total amount of water removed for irrigation of the Accra Plains is denoted by I, and E denotes energy generated in any period (t = 1, 2, ..., 50 years) in thousands of kilowatt hours (kwh).

The objective function is given by

$$\pi = B_1(E) + B_2(I) - K(Z, I)$$

where

$B_1(E)$ is the present value of an output of E kwh per year, in millions of cedis (N₵),

$B_2(I)$ is the present value of an irrigation supply of I m.a.f.

per year, in millions of N¢,

K(Z, I) is the total capital cost of building reservoir R to capacity Z and the irrigation system to capacity I, in millions of N¢.

K(Z, I) has been estimated and fixed (a given datum) at N¢ 51.6 million. The benefit terms (gross of capital costs) are obtained as the present value of the annual net benefit. Assuming an average discount rate of 2½ percent, we obtain a present value factor of 28.4 for the assumed 50 years life of the project--that is, the present value of a net benefit of N¢ 1.00 per year for fifty years is N¢ 28.40.

$B_1(E)$: The price at which the power will be sold to the Valco aluminium smelter is fixed for the first thirty years at 2.625 mills (or 0.187 pesewas) per kilowatt hour, while "a rate of 10 mills (or 0.715 pesewas) per kilowatt hour is assumed for non-smelter consumers" (Killick 58, p. 398). The gross benefit then is

$$\frac{1}{100}\left[0.187E_s + 0.715(E - E_s)\right]$$

millions of cedis, where $E_s$ is the amount of power available to the smelter. Operating and maintenance costs are taken as 0.002E. We, therefore, obtain annual net benefit from electric power as

$$\frac{1}{100}\left[0.187E_s + 0.715(E - E_s)\right] - 0.002E$$

and the present value of electric power operations is

$$B_1(E) = (0.00515E - 0.00528E_s) \times 28.40$$

$$= 0.146E - 0.150E_s$$

The amount of power available to the smelter, $E_s$, is known (cf. The White Paper No. 1 of 1961, 32, p. 22).

$B_2(I)$: The marginal value of irrigation water is not constant. We assume the marginal gross benefit to be of the form

$$\alpha + \frac{c}{1 + \beta I}$$

in cedis per acre-foot, where $\alpha$, $\beta$, and c are known parameters. Integrating this form 0 to I, we obtain the total gross benefit in millions of cedis as

$$\alpha I + c' \log(1 + \beta I) , \qquad c' \neq c .$$

Subtracting operating and maintenance costs of $\mu I$, we obtain an annual net benefit of

$$\alpha' I + c' \log(1 + \beta I) , \qquad \alpha' = \alpha - \mu$$

$\mu$ is a parameter,

which yields a present value of irrigation water of

$$B_2(I) = \left[\alpha' I + c' \log(1 + \beta I)\right] \times 28.40$$

The objective function can thus be written as

$$\text{(1)} \qquad \begin{aligned} \pi = {} & 0.146E - 0.150E_s + 28.40\alpha' I \\ & + 28.40c' \log(1 + \beta I) - 51.6 . \end{aligned}$$

The constraints

The year is broken up into two seasons: the wet rainy season and the dry season. Figure 7 shows the mean flows in the two seasons in million

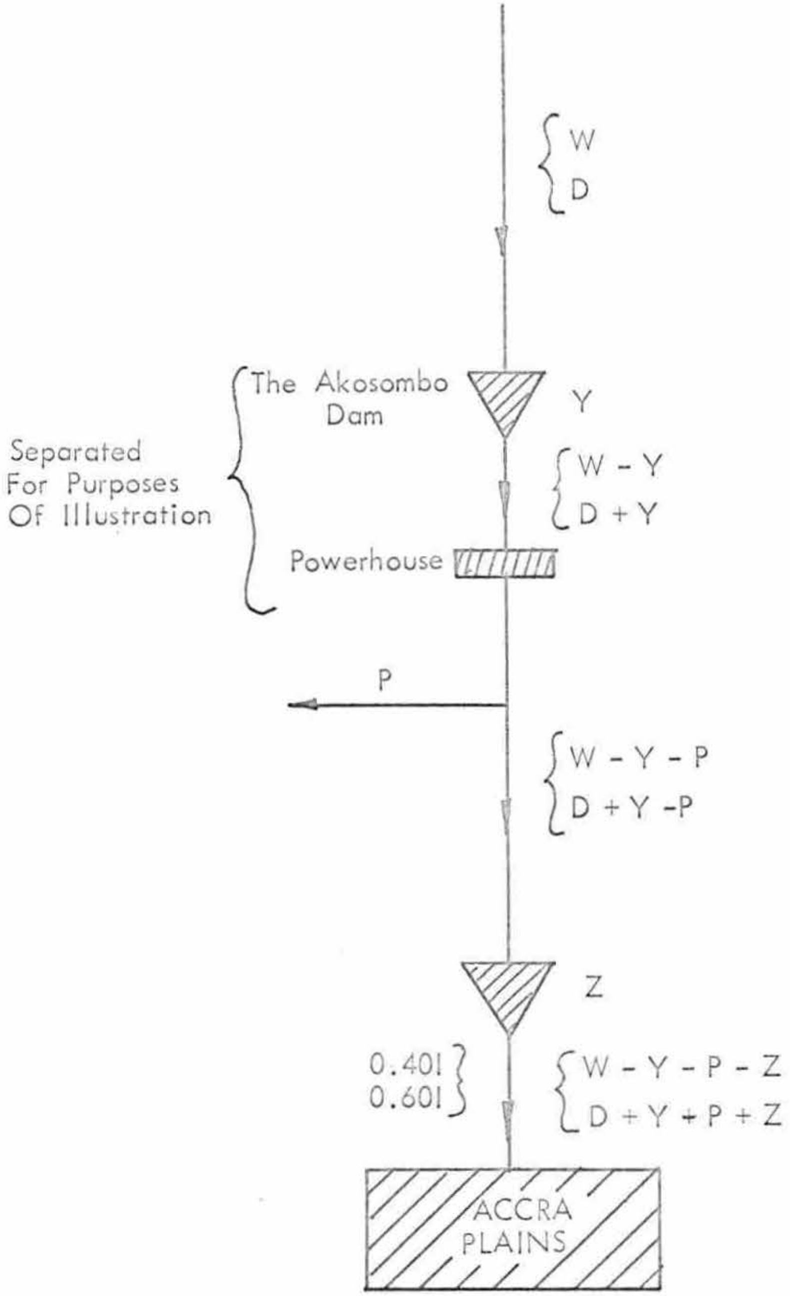

Figure 7. A simplified Volta River system

acre-feet, with the wet season flow written above the dry season flow. W is the amount of water flowing into Lake Volta from the many tributaries of the Volta River during the wet season, and D is the inflow during the dry season. The amount of water flowing into the Volta Lake in the two seasons (W and D), the amount of water for domestic consumption (P), as well as the capacity (Y) of the now-completed dam, are all given data. We assume that 40 percent of I is required during the rainy season and 60 percent in the dry season. We also assume there is no significant inter-seasonal variation in energy consumption, so that half the energy generated will be consumed in the wet season and half in the dry season.

The policy constraints are given as (see Figure 7):

$$
\begin{aligned}
W - Y &\geq 0 \\
W - Y - P &\geq 0 \\
D + Y - P &\geq 0 \\
W - Y - P - Z &= 0.40\ 1 \\
D + Y - P + Z &= 0.60\ 1 \\
I, Z &\geq 0
\end{aligned}
\tag{2}
$$

We assume a linear technical relationship between flow and energy output:

$$E = \lambda F \tag{3}$$

where E denotes energy generated in any period in kwh; F denotes flow through the turbines in m.a.f. in the same period. Under the assumption that half the energy is consumed in wet season and half in dry season, the policy constraints for energy generation are:

$$
(4) \qquad \begin{aligned} W - Y &\geq \frac{0.5}{\lambda} E \quad \Longrightarrow \quad Y + \frac{0.5}{\lambda} E \leq W \\ D + Y &> \frac{0.5}{\lambda} E \quad \Longrightarrow \quad -Y + \frac{0.5}{\lambda} E \leq D \end{aligned}
$$

## Model II

This model concerns itself with the formulation of operating policies for an already developed river system. I have assumed a system design in which targets are well established--i.e., each user knows exactly the quantity of water he will receive during each time period during the year. Users plan their activities expecting to receive these target allocations but at the same time realizing that because of the uncertainty of inflows W and D, their actual allocation may be greater or less than their target. An optimal operating policy is, therefore, likely to be that which minimizes the total losses associated with any deviation from the target allocations.

### The objective function

Buras (10) has constructed two net benefit functions for irrigated land in California. More recently, Hufschmidt and Fiering (48) have developed many benefit functions for domestic and industrial water supplies and for hydroelectric power in the Lehigh River Basin in Pennsylvania. Maas, *et al*. (69), McKean (74), Dorfman (17), Kelso (56), Ciriacy-Wantrup (13) and Wollman (110) have also discussed some methods of constructing these benefit functions. Loucks (68) considers Figure 8 as a "plausible net benefit function"; associated with this is a loss function (Figure 9) obtained "by revolving the benefit function of Figure 8 about the horizontal

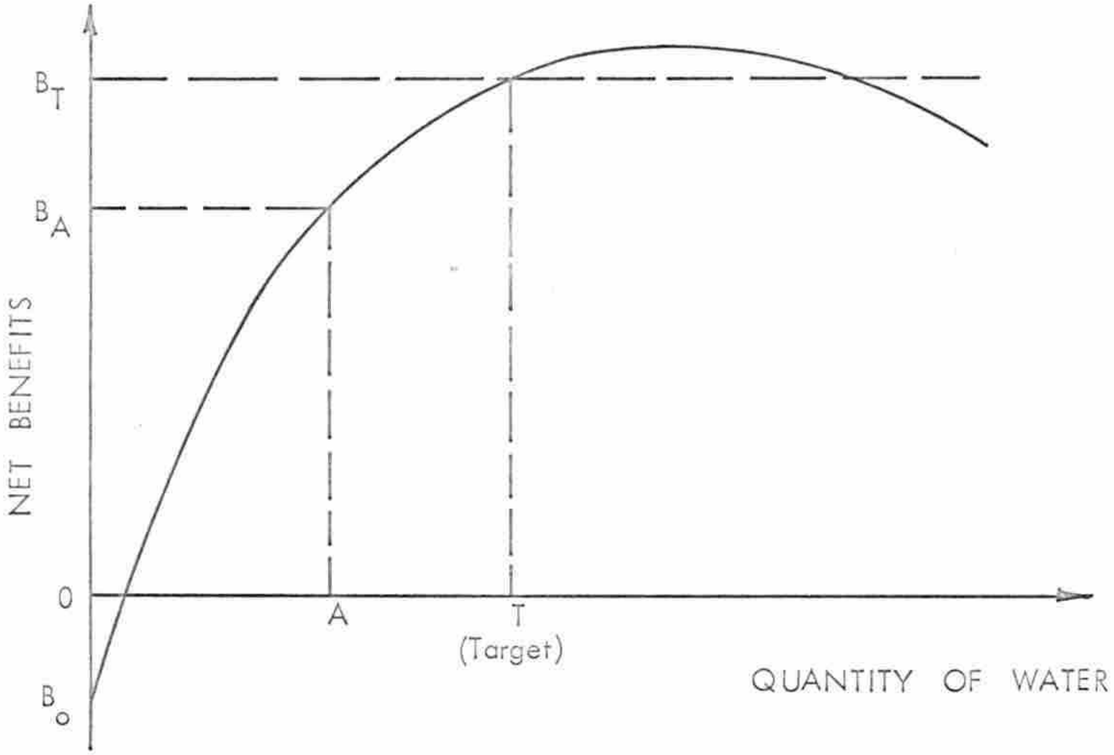

Figure 8. Net benefit function

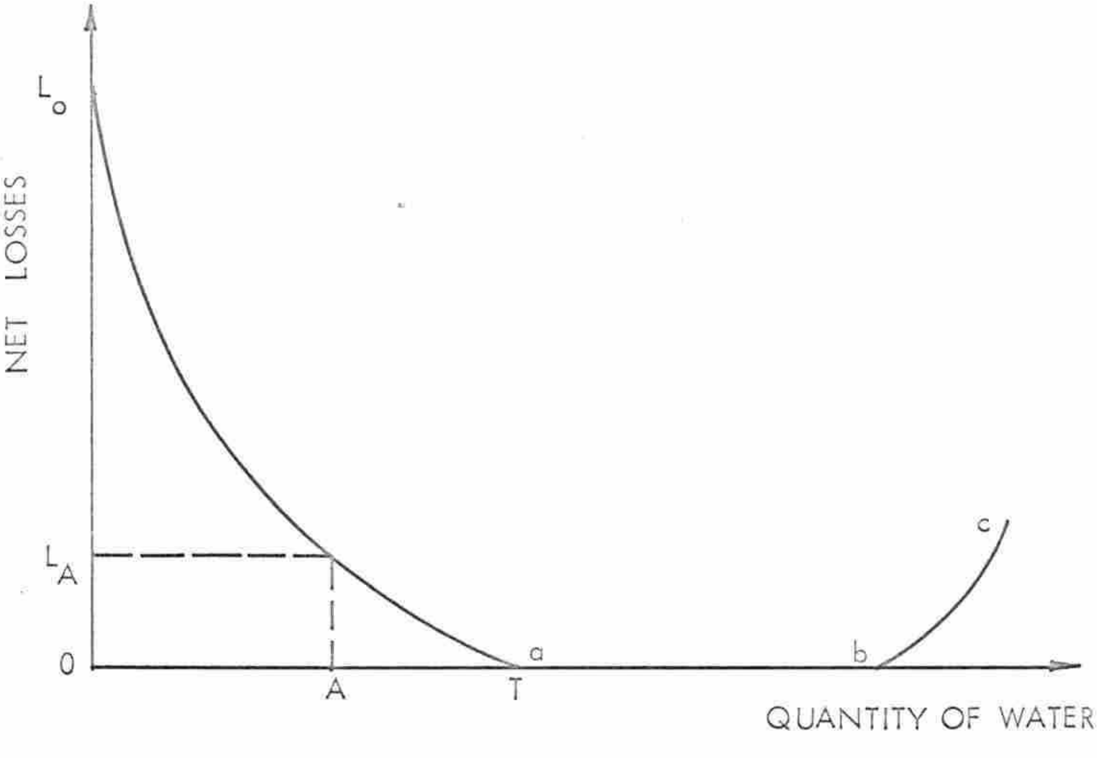

Figure 9. Net loss function

line" going through the point $B_T$, where $B_T$ is the level of benefits achieved when the actual allocation equals the target allocation. In Figure 8, the benefits are near a maximum at the target allocation. A flood or drought relative to the target allocation will often decrease the benefits received. An allocation of A units of water would reduce the expected net benefits by $B_T - B_A$. The benefits occurring from a zero allocation, $B_O$, may be negative (as shown) or positive. A decrease in the expected net benefits represents a loss to the water user (measured in money terms, cedis). For a farm firm the loss might represent the decrease in profits resulting from underproduction or from flood damage. For many other industries (e.g., manufacturing, recreation, water transportation) the loss from water shortage would be the cost of doing without the water or obtaining water elsewhere, whichever is less. The least costly alternative can be expressed as a function of the allocation. The alternative cost or loss function is of the shape shown in Figure 9.

If the actual allocation is O-A, then the reduction in benefits $B_T - B_A$ in Figure 8 equals the loss O-$L_A$ in Figure 9. The user's target will be somewhere in the region of no losses*, i.e., between a and b in Figure 9.

Almost all the uses to which the waters of Lake Volta will be put--irrigation, power generation, recreation, fishing, water transportation, municipal consumption (50, 58)--have convex loss functions similar to $L_O$-a-b-c.

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*Negative losses are not considered.

The problem now is to express the objective function mathematically and then minimize the total net losses. Let the subscript u denote a particular consumptive use in the river system (u=1, 2, ... U).* Let the subscript r represent a particular reservoir in the river system (r=1, 2, ... R).

We now linearize the loss function associated with any particular use within the river system in Figure 10. The slopes of the linear segments, $L_{utj}$ represent the net loss per unit of water within segment j allocated to use u in period t. $L_{uto}$, therefore, represents the net losses resulting from an allocation of a zero quantity of water to use u in period t. $M_{utj}$ is the maximum quantity of water that can be allocated to all segments up to and including segment j within period t. Thus $M_{ut2}$ represents the maximum amount of water that can be allocated to segments 1 and 2. Let $N_{ut}$ be the maximum number of loss-function segments j for use u in period t. Replacing subscript u with subscript r, we obtain similar notations for any reservoir r. These notations represent given data, in that, since we are dealing with a "highly developed" river system, the total number of consumptive uses (U), the total number of reservoirs (R) as well as the number of segments $N_{ut}$ (for consumptive uses) and $N_{rt}$ for reservoirs are <u>all</u> known. Similarly for $M_{utj}$ and $M_{rtj}$.

The variables or unknowns are:

$Q_{utj}$ = the quantity of water within segment j allocated to use u in period t, and

---

*We now consider 3 different kinds of irrigation projects: $I_A$ represents irrigation of Accra Plains, $I_H$ represents irrigation of Ho-Keta Plains, $I_K$ represents irrigation of Kpandu and adjacent area. Each irrigation project is taken to be a different consumptive use, u.

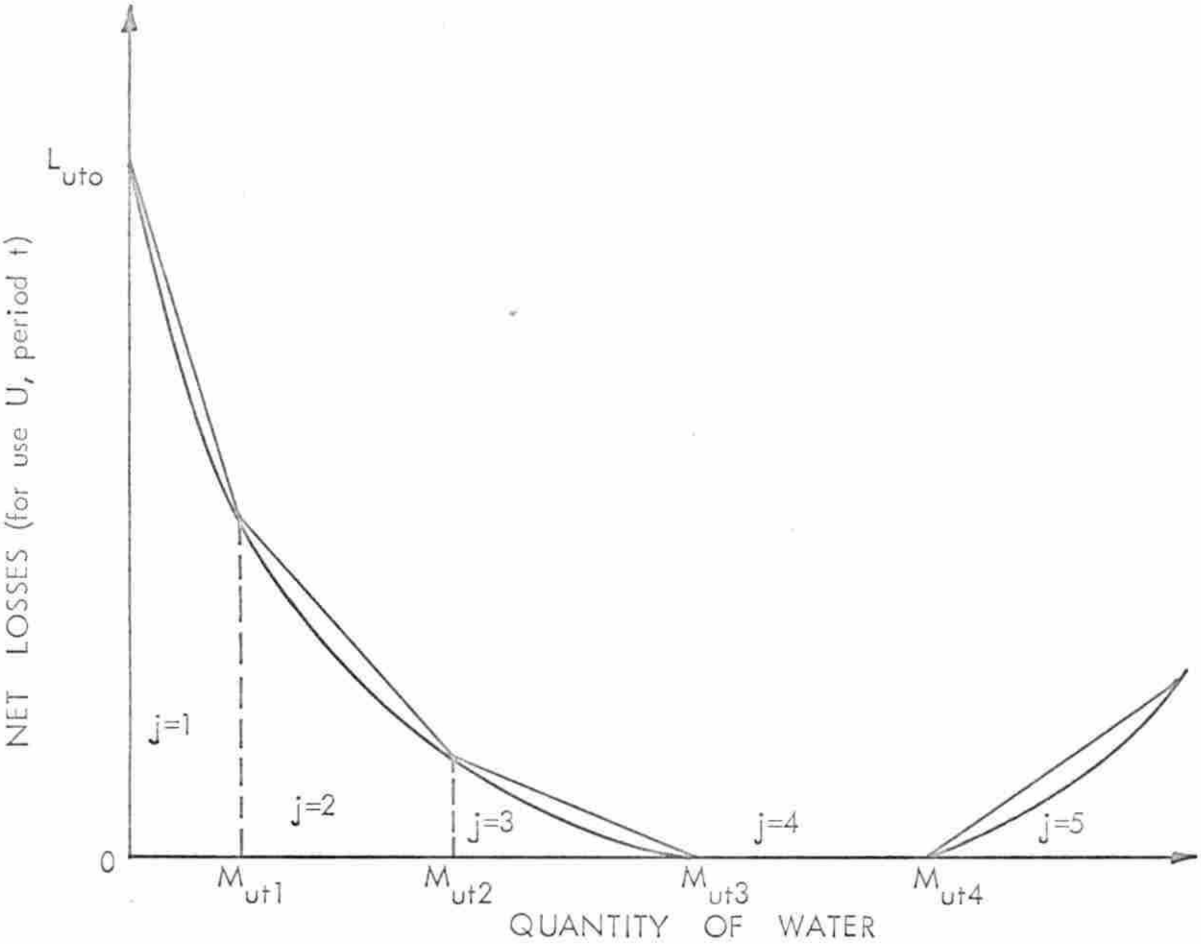

Figure 10. Linearized net loss function

$S_{rtj}$ = the quantity of water within segment j stored in reservoir r in period t.

Therefore, the total quantity of water allocated to use u in any period t is

$$(5) \qquad Q_{ut} = \sum_{j=1}^{N_{ut}} Q_{utj}$$

Similarly, the water stored in any reservoir r at the end of any period t is:

$$(6) \qquad S_{rt} = \sum_{j=1}^{N_{rt}} S_{rtj}$$

We encounter some difficulty in measuring the net losses from a reservoir r if the final water storage level j at the end of a period is different from the initial level at the beginning of the period. Thus, if during a particular period t the initial storage were in segment j=2 and the final storage in j=5, how do we calculate the net losses for period t? By using net losses occurring at the beginning of the period, at the end of the period, or some average of these two losses? For this reason, some writers (39, 68) divide the period t into subperiods. Here we divide period t into equal subperiods p:

$$p = 0, 1, 2, \ldots, P_{rt} \qquad (p \epsilon t)$$

where period t begins at subperiod p=0 and ends at subperiod p = $P_{rt}$; the total number of subperiods, $P_{rt}$, will depend on the reservoir r and period t.

Let $S_{rtjp}$ be the quantity of water within segment j stored in reservoir r at the end of the subperiod p ($p \in t$). Then

$$(7) \qquad S_{rt} = \sum_{j=1}^{N_{rt}} S_{rtjp}$$

The net losses resulting from the amount stored in reservoir r at the end of the subperiod p is:

$$(8) \qquad L_r^+ = L_{rto} + \sum_{j=1}^{N_{rt}} L_{rtj} S_{rtjp}$$

Therefore, the average net losses during period t from the water stored in reservoir r is:

$$(9) \qquad L_r = L_{rto} + \frac{1}{P_{rt} + 1} \sum_{p=0}^{P_{rt}} \sum_{j=1}^{N_{rt}} L_{rtj} S_{rtjp}$$

The loss function associated with energy produced by a hydroelectric plant e is similarly obtained as

$$(10) \qquad L_e = L_{eto} + \sum_{j=1}^{N_{et}} L_{etj} E_{etj}, \qquad e = 1, 2, 3$$

where $E_{etj}$ = electrical energy produced within segment j by plant e during period t.

The net loss to any particular use u is defined similar to equation 10.

The policy objective then is to minimize the total net losses to all uses u, all hydroelectric plants e and all reservoirs r over all periods t($t = 1, 2, \ldots, T$):

Minimize

$$(11) \quad F = \sum_{t=1}^{T} \left\{ \sum_{u=1}^{u} \left( L_{uto} + \sum_{j=1}^{N_{ut}} L_{utj}\, Q_{utj} \right) + \sum_{e=1}^{3} \left( L_{eto} + \sum_{j=1}^{N_{et}} L_{etj}\, Q_{etj} \right) \right.$$

$$\left. + \sum_{r=1}^{R} \left( L_{rto} + \left[ \frac{1}{P_{rt} + 1} \right] \sum_{p=0}^{P_{rt}} \sum_{j=1}^{N_{rt}} L_{rtj}\, S_{rtjp} \right) \right\}$$

<u>The constraints</u>

The first group of constraints comprises the definition of the variables $Q_{ut}$, $S_{rt}$ and the quantity of water stored in reservoir r at the end of subperiod p, $\sum_{j=1}^{N_{rt}} S_{rtjp}$. Equations 5 and 6 are therefore part of the policy constraints, and

$$\sum_{j=1}^{N_{rt}} S_{rtjp} = \begin{pmatrix} \text{initial storage} \\ \text{in period t} \end{pmatrix} + \frac{p}{P_{rt}} \begin{pmatrix} \text{final storage minus} \\ \text{initial storage} \end{pmatrix}$$

$$(12) \quad = S_{r,t-1} + (p/P_{rt})\,(S_{rt} - S_{r,t-1})$$

$$= (1 - p/P_{rt})\, S_{r,t-1} + (p/P_{rt}) S_{rt}$$

The second group of constraints states that each allocation within segment j cannot be greater than the maximum for that segment:

$$(13) \quad \begin{aligned} Q_{ut1} &\leq M_{ut1} &;\quad S_{rt1p} &\leq M_{rt1} \\ Q_{utj} &\leq M_{utj} - M_{u,t,j-1} &;\quad S_{rtjp} &\leq M_{rtj} - M_{r,t,j-1} \end{aligned}$$

for all u, r, t, p, j; $j \neq 1$.

The third group of constraints are related to water allocations and reservoir releases. The quantity of water allocated to any of the consumptive uses, $Q_{ut}$, cannot be greater than the amount $A_{ut}$ available for that user:

$$Q_{ut} \leq A_{ut} \tag{14}$$

for all u and t.

Where some allocations are established by law, we insert a constraint guaranteeing at least, say, $W_{ut}$ units of water to use u in period t:

$$Q_{ut} \leq W_{ut} \ . \tag{15}$$

The quantity released, $X_{rt}$, from any reservoir r during any period t cannot exceed the storage at the end of the previous period plus the inflow, $I_{rt}$, during the present period:

$$X_{rt} \leq S_{r,t-1} + I_{rt} \ ; \tag{16}$$

and the reservoir storage, $S_{rt}$, at the end of any period t cannot exceed the reservoir capacity, $C_r$:

$$S_{rt} \leq C_r , \tag{17}$$

for all r and t. Also the storage at the beginning of period t plus the net inflow minus the release, $X_{rt}$, must equal the storage, $S_{rt}$, at the end of the period:

$$S_{rt} = S_{r,t-1} + I_{rt} - X_{rt}$$

or

$$S_{rt} + X_{rt} - S_{r,t-1} = I_{rt} \ . \tag{18}$$

Finally, we consider the hydroelectric power constraints. The main hydroelectric plant of the Volta River Project is associated with one reservoir (the Akosombo Dam) and is a fixed head plant which draws water at an average height of 213 feet above the Francis turbines.* The head is therefore a constant. However, it is planned to construct two more power stations.** Let us assume a linear technical relationship between flow and energy output:

(19) $$E_{et} = K_e Q_{et} H_{et} , \qquad e = 1, 2, 3$$

where

$E_{et}$ = electrical energy produced by plant e during period t.
$K_e$ = a constant for efficiency and conversion of plant e.
$Q_{et}$ = the flow through the turbines of plant e during period t.
$H_{et}$ = average head above the turbines of plant e during period t.

Assuming a known average head, $H^*_{et}$, the constraints for power are easily recognized as:

(20) $$E_{et} = (K_e H^*_{et}) Q_{et}$$

(21) $$Q_{et} \leq X_{rt}$$

where reservoir r is associated with hydroelectric plant e.

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*Four 203,000-hp Francis turbines are in use now (two more will be added as power demand grows). Design operating head is 213 feet.

**A power station at Kpong (twelve miles downstream from Akosombo) will have a "net" capacity of 86,000 kilowatts. A smaller dam at Bui in the Brong-Ahafo region will have a capacity of 190,000 kilowatts (58).

## Policy Formulation

For Model I, the problem is one of maximizing the objective function 1 subject to the constraints of equations 2 and 4. Since all the parameters and variables are known data except for Z, I and E, the programming problem is a very simple one. The solution to the problem can be obtained by the use of a computer or by trial-and-error iterative method suggested by Dorfman (17), whereby E and I are made functions of Z.

With respect to the generalized Model II, the programming problem is one of minimization: minimize the objective function 11 subject to the constraints 5, 6, and 12 through 21, where applicable. This linear programming model can be solved by the use of computers. The capacity of computers is such that the number of variables may not be a major obstacle, once problems are formulated adequately.

The Volta River Project is controlled by the Volta River Authority, a statutory corporation owned by the Republic of Ghana. The "Authority" is responsible for establishing a policy which minimizes the total expected losses to all users over all future time periods. The Authority will, therefore, naturally like to know the reservoir releases per subperiod p ($p \epsilon t$) and user allocations which minimize the expected total loss to all users.

The solution will specify the reservoir releases and user allocations in all periods t based on the best estimates available for future net inflows and economic losses. Only the current period t's reservoir releases and user allocations are made, so that a continual updating of the input information and the solution will result in a closer realization of the Volta River Authority's policy objective--that over many periods the policy will result in an efficient use of Lake Volta's water resource.

# CHAPTER 8. WELFARE CONSIDERATIONS

## Introduction

Mishan defines welfare economics as "that branch of study which endeavours to formulate propositions by which we may rank, on the scale of better or worse, alternative economic situations open to society" (75, p. 5). The "new" welfare economics (1939 and after) has developed "elaborate structures of thought" attempting to specify the conditions, concepts, and principles of economic welfare maximization. The question as to whether welfare propositions are capable of being tested has always been asked. The ultimate test of any theory lies in its ability to specify operations which, if carried out in the real world, will lead to tests of its workability (i.e., its validity). Unless means can be found to clothe welfare with measurable attributes or to replace it with a measurable indicator, the usefulness of welfare maximization as a criterion for project selection remains questionable.

A commonly accepted criterion of a social change that leads to increase of economic welfare is the Pareto criterion, which states that "a situation in which no individual can be made better off without making another worse off" represents an increase of welfare (Abba P. Lerner, 64). Because of the difficulty of measurement introduced by the implicit assumption of interpersonal comparisons of utility, this criterion is usually stated in a modified form (the Kaldor-Hicks compensation test): welfare is increased by a change that renders it possible to make at least one person better off and leave no individual worse off by compensating the losers.[*] An increase in national income resulting from a water resource project is sufficiently close with the Pareto criterion "with compensation": "An increase of national income may be regarded as a practical, first approximation to the (Pareto 'with compensation' criterion), provided that the policy under consideration does not appreciably increase inequality of income distribution" (16, p. 307). Increases in national income resulting from increases in economic efficiency can thus be taken as indicators of increases in economic welfare if certain restrictive assumptions are accepted and if the resulting distribution of income from the use of the water resources is not substantially altered toward inequality.

## Equitable Distribution of the Income of Water Use

From the discussion above it follows that in order to obtain the most enhancement of national income from the waters of Volta Lake there is the need to spell out quite clearly not only the efficiency considerations involved in water resource allocation among uses but also the income redistributive consequences of such an allocation. An equitable distribution of the income or product of water thus needs some consideration.

A resource such as water can be used to directly produce want-satisfying services; as in human consumption, recreation and absence of floods. "Obviously, we want an equitable distribution of these services: some people should not die of thirst while others have water which goes

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[*] The compensation principle asks only whether losers could be compensated: it does not require that they should be compensated. The declared aim of the compensation test, as Kaldor (52) stresses, is to separate the question of "efficiency" from that of distribution.

to waste. But aside from such obvious examples, an equitable distribution of the benefits of water also is needed where the product of water is sold in the market and generates income which is used to purchase other consumer goods (i.e., the water itself is not consumed but it gives rise, through the income it generates, to the opportunity of purchasing other goods)."[1] The water resource could be devoted to only a few (say, one or two) uses; so that the total income from water use accrues to these few "firms" while others receive nothing. From the viewpoint of obtaining the greatest income from the water resource, such a distribution of the product or income is undesirable. The satisfactions derived from the last cedi (or dollar) of water-generated income to the person receiving one million such cedis would very likely be less than for the person with only five such cedis. To obtain a large income from water would be quite ineffective if this income were not reasonably or equitably distributed.

However, these two major conditions necessary for the attainment of "most enhancement of national income"--the efficiency or allocation problem and the income distribution problem--may not always complement each other; in fact, they quite often interfere with the attainment of each other. For example, as an attempt at equity in distribution of water benefits, the government may enact a law allowing each person in the country a certain proportion (say, 1/7.4 millionth) of the total water supply. As Heady and Timmons point out, some of the persons in the country would have only unproductive uses of the water; the same water would have a

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[1] Heady and Timmons 43, p. 58. This section has drawn greatly from this single page. To avoid frequent footnote references, the very extensive use which has been made of the Heady-Timmons paper is acknowledged here.

greater marginal value productivity if added to the "use share" of another person and purpose. Hence, equity in the distribution of water would interfere with efficiency in the allocation of water in production. Such a conflict between efficiency in production allocation and equity in distribution can be resolved in a number of ways, the most commonly practiced of these being that via the price mechanism. A price is set on water in accordance with the supply and productive uses (demand). The industries and firms would then channel the water into those productive uses which have the highest marginal value productivities in line with consumer demands. The revenue from water then could be used to provide general public services for people in the country--thus guaranteeing equity in distribution of income or other water benefits. If necessary, certain prior uses for human consumption, recreation, etc. might have to be first established before the price mechanism is applied. From the foregoing discussion and illustrations, it becomes clear that legislation must recognize the income (or benefit) distribution problem as well as the water allocation problem if the country's supply of water resource is to be used most effectively.

## Welfare Principles and Allocation Techniques: Conclusion

The difficulty of measuring recreation and other intangible benefits in the same way as other project benefits suggests that the cost-benefit analysis may be so qualified by the intangibles as to be of questionable value in the decision-making process. This implies that water allocation decisions may need a stronger economic footing than the monetary benefits that could be estimated for any project purpose.

Welfare considerations pose the question of how satisfied the opposing potential users might be made and what price they would be willing to pay for recreational or other water use in order that the project cost could be recovered. This obviously states the problem a little differently than conventional studies, which frequently accepts costs or prices actually paid as indicators of recreational benefits, with the result that benefits can be easily underestimated but not likely to be overestimated. In welfare economics, however, monetary benefits and costs play an important but not all-important role in determining the particular allocation of water among different uses that would maximize the satisfaction of the potential users.

The core of a welfare approach to water allocation would be a series of utility (indifference) functions, each showing the dependence of a potential user's satisfaction on various combinations of all commodities or services he might consume, including such services as recreational use of leisure time. Given the costs of producing various quantities of goods and services and consumer incomes, it would then be possible to determine the quantities of each commodity or service purchased by each consumer in order to maximize his level of satisfaction, as well as the market prices paid for each commodity or service.

These points all indicate the need for allocation techniques that incorporate the objectives of maximum satisfaction and equitable price from all uses and for all users of water--in other words, a goal of making all users feel as well off as possible without making any potential user feel worse off by compensating the losers, if necessary. It seems, then, that projects and allocation programs leading to "most enhancement of national income", together with marginal notes on each concerning its income redistributive consequences, are operational goals for water resource project evaluations. In this framework, the allocation technique of Chapter 7 implies a given income distribution. The technique can be repeated for various income distribution levels, obtaining different maximum of national income for each income distribution level. The final coordination of choice must be achieved by the political and administrative decision-making process; this evaluation is done against the background of some assumed moral values of the society, i.e., value judgment plays the most important role in the final choice. The allocation programs, therefore, provide a range of objective, rational measurements that "will sharpen the efficiency of the 'partisan-adjustment process' of final decision making."

# BIBLIOGRAPHY

1. Alchian, Armen A. Economic replacement policy. Santa Monica, California, Rand Corporation. 1952.

2. Alchian, Armen A. The rate of interest, Fisher's rate of return over costs, and Keynes' internal rate of return. American Economic Review 45: 938-943. 1955.

3. Alchian, Armen A. Uncertainty, evolution, and economic theory. Journal of Political Economy 58: 211-221. 1950.

4. Arrow, Kenneth J. Social choice and individual values. Cowles Commission Monograph 12. 1951.

5. Arrow, Kenneth J., Hurwicz, L. and Uzawa, H. Studies in linear and non-linear programming. Stanford, California, Stanford University Press. 1958.

6. Baumol, William J. Economic theory and operations research. 2nd ed. Englewood Cliffs, New Jersey, Prentice-Hall, Inc. 1965.

7. Birmingham, W., Neustadt, I. and Omaboe, E. N., eds. A study of contemporary Ghana. Vol. 1. Evanston, Illinois, Northwestern University Press. 1966.

8. Bowen, H. R. Toward social economy. New York, New York, Rinehart. 1948.

9. Buchanan, James M. Fiscal institutions and efficiency in collective outlay. American Economic Review 54: 227-235. 1964.

10. Buras, N. Conjunctive operation of dams and aquifers. American Society of Civil Engineers Proceedings 3697, HY6: 111-131. 1963.

11. Castle, Emery N. Activity analysis of water planning. In Smith, S. C. and Castle, E. N., eds. Economics and public policy in water resources development. pp. 171-185. Ames, Iowa, Iowa State University Press. 1964.

12. Clawson, Marion. Methods of measuring the demand for and value of outdoor recreation. Washington, D.C., Resources for the Future, Inc. 1959.

13. Ciriacy-Wantrup, S. V. Projections of water requirements in the economics of water policy. Journal of Farm Economics 43: 197-214. 1961.

14. Ciriacy-Wantrup, S. V. Philosophy and objectives of watershed policy. In Tolley, G. S. and Riggs, F. E., eds. Economics of watershed planning. pp. 1-12. Ames, Iowa, Iowa State University Press. 1961.

15. Ciriacy-Wantrup, S. V. Benefit-cost analysis and public resource development. In Smith, S. C. and Castle, E. N., eds. Economics and public policy in water resource development. pp. 9-21. Ames, Iowa, Iowa State University Press. 1964.

16. Ciriacy-Wantrup, S. V. Concepts used as economic criteria for a system of water rights. Land Economics 32: 295-312. 1956.

17. Dorfman, Robert. Mathematical analysis: design of the Simple Valley Project. In Tolley, G. S. and Riggs, F. E., eds. Economics of Watershed planning. pp. 217-229. Ames, Iowa, Iowa State University Press. 1961.

18. Dorfman, R., Samuelson, P. A. and Solow, R. Linear programming and economic analysis. New York, New York, McGraw-Hill, Inc. 1958.

19. Douglas, Paul. Economy in national government. Chicago, Illinois, University of Chicago Press. 1952.

20. Dupuit, J. De la mesure de l' utilité des travaux publics. Annales des Ponts et Chaussees, 2nd Series, 8: 332-375. 1844.

21. Eckstein, Otto. Water resource development: the economics of project evaluation. Cambridge, Massachusetts, Harvard University Press. 1958.

22. Eckstein, Otto. A survey of the theory of public expenditure criteria. In Buchanan, J. M., ed. Public finances: needs, sources and utilization. pp. 145-164. Princeton, New Jersey, Princeton University Press. 1961.

23. Edwards, W. The theory of decision making. Psychological Bulletin 51: 380-417. 1954.

24. Engineers Joint Council. The National Water Policy Panel. Principles of a sound national water policy. Washington, D.C., The National Water Policy Panel, Engineers Joint Council. 1951.

25. Fitch, Bob and Oppenheimer, Mary. Ghana: end of an illusion. Monthly Review 18, No. 3: 1-130. 1966.

26. Fox, I. K. and Herfindahl, O. C. Attainment of efficiency in satisfying demands for water resources. American Economic Review 54: 198-206. 1964.

27. Friedman, Milton. Essays in positive economics. Chicago, Illinois, University of Chicago Press. 1953.

28. Futa, A. B. The Volta River Project. Economic Bulletin of Ghana 5, No. 1: 1-15. 1961.

29. Gale, David. The theory of linear economic models. New York, New York, McGraw-Hill, Inc. 1960.

30. Ghana Central Bureau of Statistics (Accra, Ghana). Economic Survey 1965. 1966.

31. Ghana Office of the Planning Commission. Seven-year development plan. Accra, Ghana, Government Printer. 1964.

32. Ghana Office of the Planning Commission. White Paper No. 1 of 1961. Accra, Ghana, Government Printer. 1961.

33. Golding, P. T. F. An inquiry into household expenditure and consumption and sale of household produce in Ghana. Economic Bulletin of Ghana 6, No. 4. 1962.

34. Green, R. H. The Ghana cocoa industry. Economic Bulletin of Ghana 5, No. 1: 16-32. 1961.

35. Gunaji, N. N. Municipal uses, practices, problems. New Mexico Water Conference Proceedings 7: 38-47. 1962.

36. Hadley, G. Linear programming. Reading, Massachusetts, Addison-Wesley, Inc. 1962.

37. Hammond, R. J. Benefit-cost analysis and water pollution control. Stanford, California, Stanford University Press. 1958.

38. Hall, P. Labour's new frontier. London, England, Andre Deutsch. 1964.

39. Hartman, L. M. and Seastone, D. A. Efficiency criteria for market transfers of water. Water Resources Research 1: 165-171. 1965.

40. Head, J. G. Public goods and public policy. Public Finance 17: 197-219. 1962.

41. Heady, Earl O. Mathematical analysis: models for quantitative application in watershed planning. In Tolley, G. S. and Riggs, F. E., eds. Economics of watershed planning. pp. 197-216. Ames, Iowa, Iowa State University Press. 1961.

42. Heady, Earl O. and Candler, Wilfred. Linear programming methods. Ames, Iowa, Iowa State University Press. 1958.

43. Heady, Earl O. and Timmons, John F. Economic framework for planning efficient use of water resources. In Timmons, J. F., O'Byrne, J. C. and Frevert, R. K., eds. Iowa's water resources: sources, uses, and laws. pp. 47-61. Ames, Iowa, Iowa State College Press. 1956.

44. Hicks, J. R. The foundations of welfare economics. Economic Journal 49: 696-712. 1939.

45. Hicks, J. R. Economic theory and the evaluation of consumer's wants. Journal of Business 35: 256-263. 1962.

46. Hirshleifer, J., de Haven, J. C. and Milliman, J. W. Water supply economics, technology and policy. Chicago, Illinois, University of Chicago Press. 1960.

47. Holt, C. C., Modigliani, F. and Simon, H. A. A linear decision rule for production and employment scheduling. Management Science 2: 1-30. 1955.

48. Hufschmidt, M. M. and Fiering, M. B. Simulation techniques for design of water-resource systems. Cambridge, Massachusetts, Harvard University Press. 1966.

49. Inter-Agency River Basin Committee. Sub-Committee on Costs and Budgets. Proposed practices for economic analysis of river basin projects: ("The Green Book"). Washington, D.C., Sub-Committee on Costs and Budgets, Inter-Agency River Basin Committee. 1950.

50. Kaiser Engineers. The Volta River Project. Kaiser Builder (Oakland, California, Kaiser Graphic Arts) March 1966: 1-14. 1966.

51. Kaiser Engineers. Aluminium plant in Ghana. Kaiser Builder (Oakland, California, Kaiser Graphic Arts) January-February 1967: 1-14. 1967.

52. Kaldor, N. Welfare propositions of economics and interpersonal comparisons of utility. Economic Journal 49: 549-552. 1939.

53. Kaldor, N. A note on tariffs and the terms of trade. Economica 7: 377-380. 1940.

54. Katona, G. Rational behavior and economic behavior. Psychological Review 60: 307-318. 1953.

55. Kelso, M. M. The stock resource value of water. Journal of Farm Economics 43: 1112-1129. 1961.

56. Kelso, M. M. Economic analysis in the allocation of the federal budget to resource development. In Smith, S. C. and Castle, E. N., eds. Economics and public policy in water resources development. pp. 56-81. Ames, Iowa, Iowa State University Press. 1964.

57. Killick, Tony. Mining. In Birmingham, W., Neustadt, I. and Omaboe, E. N., eds. A study of contemporary Ghana. Vol. 1. pp. 250-273. Evanston, Illinois, Northwestern University Press. 1966.

58. Killick, Tony. The Volta River Project. In Birmingham, W., Neustadt, I. and Omaboe, E. N., eds. A study of contemporary Ghana. Vol. 1. pp. 391-410. Evanston, Illinois, Northwestern University Press. 1966.

59. Koopmans, T. C., ed. Activity analysis of production and allocation. New York, New York, John Wiley and Sons, Inc. 1951.

60. Krutilla, John V. and Eckstein, Otto. Multiple purpose river development: studies in applied economic analysis. Baltimore, Maryland, John Hopkins Press. 1958.

61. Lane, D. A. The forest vegetation. In Wills, J. B., ed. Agriculture and land use in Ghana. pp. 160-169. London, England, Oxford University Press. 1962.

62. Lawson, Rowena M. The development of the lower Volta. Economic Bulletin of Ghana 7, No. 4: 81-90. 1963.

63. Lebergott, Stanley. The shape of the income distribution. American Economic Review 49: 328-347. 1959.

64. Lerner, Abba P. The concept of monopoly and the measurement of monopoly power. Review of Economic Studies 1: 157-175. 1934.

65. Lerner, Abba P. The economics of control. New York, New York, Macmillan Company, Inc. 1946.

66. Lewis, W. Arthur. Report on industrialisation and the Gold Coast. Accra, Ghana, Government Printer. 1953.

67. Little, I. M. D. A critique of welfare economics. Oxford, England, Clarendon Press. 1950.

68. Loucks, D. P. Policy models for operating water resource systems. American Water Resources Conference Proceedings 2: 232-246. 1966.

69. Maass, A., Hufschmidt, M. M., Dorfman, R., Thomas, H. A., Marglin, S. A. and Fair, G. M. Design of water resource systems. London, England, Macmillan Company, Inc. 1962.

70. Margolis, Julius. A comment on the pure theory of expenditures. Review of Economics and Statistics 37: 347-349. 1955.

71. Margolis, Julius. The economic evaluation of federal water resource development: a review article. American Economic Review 49: 96-111. 1959.

72. Margolis, Julius. Secondary benefits, external economies, and the justification of public investment. Review of Economics and statistics 39: 284-291. 1957.

73. McKean, Roland N. Divergencies between individual and total costs within government. American Economic Review 54: 243-249. 1964.

74. McKean, Roland N. Efficiency in government through systems analysis. Santa Monica, California, Rand Corporation. 1958.

75. Mishan, E. J. Welfare economics: five introductory essays. New York, New York, Random House, Inc. 1964.

76. Moran, P. A. P. The theory of storage. London, England, Methuen and Co., Ltd. 1959.

77. Musgrave, R. A. The theory of public finance: a study in public economy. New York, New York, McGraw-Hill, Inc. 1959.

78. National Council of Applied Economic Research (New Delhi). Criteria for fixation of water rates and selection of irrigation projects. London, England, Asia Publishing House. 1959.

79. Omaboe, E. N. An introductory survey (of Ghana). In Birmingham, W., Neustadt, I. and Omaboe, E. N., eds. A study of contemporary Ghana. Vol. 1. pp. 17-33. Evanston, Illinois, Northwestern University Press. 1966.

80. Pavelis, George A. Economics of water allocation. New Mexico Water Conference Proceedings 7: 80-105. 1962.

81. Prest, A. R. and Stewart, I. G. The national income of Nigeria, 1950-51. London, England, H. M. S. O. 1953.

82. Prest, A. R. and Turvey, R. Cost-benefit analysis: a survey. Economic Journal 75: 683-735. 1965.

83. Reder, Melvin. Studies in the theory of welfare economics. New York, New York, Columbia University Press. 1947.

84. Rutherford, R. S. G. Income distributions: a new model. Econometrica 23: 277-294. 1955.

85. Samuelson, Paul A. Aspects of public expenditure theories. Review of Economics and Statistics 40: 332-336. 1958.

86. Samuelson, Paul A. Diagrammatic exposition of a theory of public expenditure. Review of Economics and Statistics 37: 350-356. 1955.

87. Samuelson, Paul A. Foundations of economic analysis. Cambridge, Massachusetts, Harvard University Press. 1947.

88. Samuelson, Paul A. The pure theory of public expenditure. Review of Economics and Statistics 36: 357-389. 1954.

89. Scitovsky, Tibor. A note on welfare propositions in economics. Review of Economic Studies 9: 77-88. 1941.

90. Simon, H. A. Theories of decision-making in economics and behavioral science. American Economic Review 49: 253-283. 1959.

91. Simmonard, Michel. Programmation linéaire. Paris, France, Dunod. 1962.

92. Smith, Lewis G. Reconnaisance of irrigation potential of black soils of Accra plains. Accra, Ghana, Government Printer. 1963.

93. Smith, S. C. and Castle, E. N., eds. Economics and public policy in water resources development. Ames, Iowa, Iowa State University Press. 1964.

94. Smithies, Arthur. The budgetary process in the United States. New York, New York, McGraw-Hill, Inc. 1955.

95. Sovani, N. V. and Rath, N. Economics of a multiple-purpose river dam: report of an inquiry into the economic benefits of the Hirakud Dam. Gokhale Institute of Politics and Economics (Poona, India) Publication 38. 1960.

96. Steiner, Peter O. Choosing among alternative public investments. American Economic Review 49: 893-916. 1959.

97. Stucky, H. R. Economics of beneficial uses of water. New Mexico Water Conference Proceedings 7: 68-79. 1962.

98. Szereszewski, Robert. Capital and output in Ghana, 1955-61. Economic Bulletin of Ghana 7, No. 4: 35-43. 1963.

99. Szereszewski, Robert. The performance of the (Ghana) economy, 1955-62. In Birmingham, W., Neustadt, I. and Omaboe, E. N., eds. A study of contemporary Ghana. Vol. 1. pp. 39-61. Evanston, Illinois, Northwestern University Press. 1966.

100. Szereszewski, Robert. Structural changes in the economy of Ghana, 1891-1911. (To be published by Weidenfeld & Nicolson, London, England. Circa 1967.)

101. Theil, H., Boot, J. C. G. and Kloek, T. Operations research and quantitative economics. New York, New York, McGraw-Hill, Inc. 1965.

102. Timmons, John F. Theoretical considerations of water allocation among competing uses and users. Journal of Farm Economics 38: 1244-1258. 1956.

103. Tolley, G. S. and Hastings, V. S. Optimal water allocation: the North Platte River. Quarterly Journal of Economics 74: 279-295. 1960.

104. Tolley, G. S. and Riggs, F. E., eds. Economics of watershed planning. Ames, Iowa, Iowa State University Press. 1961.

105. Turvey, Ralph. On investment choices in electricity generation. Oxford Economic Papers 15: 278-286. 1963.

106. United Nations. Demographic yearbook, 1963. New York, New York, United Nations' Publishing Service. 1964.

107. United Nations. Yearbook of national accounts statistics, 1962. New York, New York, United Nations' Publishing Service. 1963.

108. Walker, H. O. Weather and climate. In Wills, J. B., ed. Agriculture and land use in Ghana. pp. 7-50. London, England, Oxford University Press. 1962.

109. Wills, J. B., ed. Agriculture and land use in Ghana. London, England, Oxford University Press. 1962.

110. Wollman, N., Edgel, R. L., Farris, M. E., Stucky, H. R. and Thompson, A. J. The value of water in alternative uses. Albuquerque, New Mexico, University of New Mexico Press. 1962.

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