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PLANNING NATURAL RESOURCE DEVELOPMENT

An Introductory Guide

U.S. DEPARTMENT OF AGRICULTURE ECONOMIC RESEARCH SERVICE

ABSTRACT

This guide describes and illustrates principles for making rational decisions on the scope, content, and scale of natural resource development programs. Its five main parts correspond to distinguishable phases of actual resource planning. The first part outlines some concepts and procedures for selecting feasible components of development programs. The second part presents a suggested criterion for identifying an initial array of feasible project proposals. Methods are then explained for formulating preliminary single-purpose or multipurpose programs. Concluding sections reexamine the preliminary programs for further possibilities of integrating program purposes and show how a recommended "final" program might influence the income and other economic accounts of an economic system.

The guide is introductory in nature, although some terminology and examples are technical when accuracy requires it. Its main purpose is to help public officials and others who do no actual planning, but who make important decisions regarding projects, better understand and judge the comparative merits of development programs.

Keywords: Systems analysis, cost-benefit analysis, economic evaluation, resource development, economic planning, evaluation.

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FOREWORD

Research efforts in the Economic Research Service have been intensified and broadened in recent years in support of public programs designed to improve the management of land and water resources. These efforts are directed toward a twofold objective: (1) to clarify and sharpen conceptual and procedural issues relating to the impact and effectiveness of public investments; and (2) to assist in the development of systematic approaches to planning and evaluation. The present study on planning methodology is intended to contribute toward the achievement of both objectives, especially the latter one. The report reflects one of several possible perspectives and emphasizes certain technical aspects of the larger problem of resource management.

This report was prepared under special arrangements within ERS that enable a researcher to undertake a short-term assignment and devote uninterrupted time to the development of new concepts or new methodology to improve understanding of selected economic phenomena and the decisionmaking process for resource allocation. The author recognized the need for a document that illustrates how economic principles can be applied to the planning process for natural resource investment decisions. The report is primarily intended for the reader who is concerned with how resource development plans are formulated but who can be better served by an introductory guide rather than a more detailed or more technical treatise or planning manual. This document presents steps that can be followed in appraising the scope, content, and scale of resource development projects. It is not intended to be a comprehensive report of all aspects of or approaches to the complex planning process.

At the time this guide was prepared, new principles and standards for multiobjective planning were being proposed for adoption by the Water Resources Council. The principles and standards, if adopted, will go far in prescribing both the purposes and the methods for future water resource planning by Federal agencies. Concepts and approaches suggested in this guide, along with results of studies now underway in ERS, will be helpful in the establishment of new agency procedures in implementing the multiobjective planning approach.

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SUMMARY

Basic economic concepts and principles can be applied in evaluating and deciding on the scope, content, and scale of natural resource development programs. To show how these principles can be applied, this guide follows step-by-step phases of actual resource planning. The analysis shows how priorities are assigned to preliminary development projects or components according to their feasibility, based on tangible benefits; environmental or other kinds of intangible benefits, including social values; or other considerations. The application of a suggested criterion for identifying an array of feasible project proposals is described. The hypothetical example given includes an irrigation project, a flood-control levee, and an urban water supply project. Development of the final project is planned according to the amount of money available. Methods are given for the formulation of single-purpose and multipurpose programs.

Finally, preliminary programs are examined to see if objectives can be combined. The example shows how the irrigation project mentioned above could also be used for flood control, at a one-third saving in cost and for 75 percent more in net benefits. Concluding parts of the guide describe how projects can influence the total economy of the area for which they are planned and also the national economy.

PLANNING NATURAL RESOURCE DEVELOPMENT
An Introductory Guide

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BACKGROUND

This guide illustrates some basic concepts and principles for making rational decisions on the scope, content, and scale of natural resource development programs. The guide follows step-by-step phases of actual resource planning. These phases include: (1) deciding on the concepts and procedures for identifying alternative components of development programs; (2) identifying through cost-benefit analysis or other methods an initial array of feasible project proposals; (3) formulating preliminary programs and ranking projects according to their prospects for achieving net benefits, considering environmental or other intangible costs or benefits; and (4) formulating revised programs as individual purposes or projects carried to a scale equalizing their marginal benefits and costs, again with consideration for intangibles. Phases 3 and 4 use examples for varying levels of capital availability.

The guide includes a number of numerical examples, but no econometric models. Such models have their uses in planning, but the objective of this guide is to present the elements of planning in an introductory form. Its primary intended audience is legislators or public officials who may do no actual planning but who must often approve or disapprove policy decisions on competing development proposals. Such persons cannot be expected to become familiar with complex models using advanced mathematical programming, input-output, and simulation methods. Nor can they use official policy documents as a totally adequate basis for evaluating the comparative merits of the many different proposals they must act upon.

A related audience might be the interested citizens and organizations who frequently ask legislators and public officials to intercede for them and for their ideas about development proposals that can affect them. In these circumstances, where some persons will have to compromise, this guide may be useful in explaining resource planning in a way that shows planning itself to be a series of compromises and a process of identifying and balancing alternatives. All concerned—legislators, policymaking officials, and interested citizens—then could more readily evaluate alternatives and their own ideas, using somewhat the same thought processes and steps that trained planners might use.

In addition, aspiring planning specialists may find that this guide can serve as an introductory text, particularly the relatively more complex and detailed parts on specific procedures that refine the planning process.

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FEASIBLE COMPONENTS OF PROJECTS AND PROGRAMS

SOME INITIAL CONSIDERATIONS

A first step in planning is to specify the geographic area intended to benefit from development. Resource development potentials in the area can then be examined as possible sources of benefits. This should be done before specific project proposals are advanced. Planners should not assume that development problems can be solved entirely or that potentials can be exploited fully. Solution of all problems would be possible only if the wisdom, skill, capital, and other resources required were limitless and without cost in the sense of having no alternative productive uses. Since this is never the case, an important next step in planning is to determine the range of development proposals that show promise of being socially feasible; that is, that are expected to result in benefits exceeding the costs involved. While the problem of identifying alternatives may involve considerable subjectivity and uncertainty, this does not mean that such identification and subsequent other choices cannot be rational. Also, economic science does not require that resources always be allocated in a strict monetary context.

Another early essential in planning is to specify the context—local, regional, or national—in which analysis and decisionmaking will be done. If decisions are to be made with national considerations taken into account, a national viewpoint is required for adequate specification of the data or relationships among the data, even if the ultimate decision allows purely local development. Similarly, if decisions are to be made on local considerations only, local data and relationships will suffice for proper evaluation. But broader regional or national consequences may be assessed here also, especially if useful in resolving situations where evaluations of local consequences are indecisive.

Whether particular projects should be evaluated in a national context can also depend on particular local situations, current social priorities, and the availability of techniques for linking local or regional economies to the national economy. Unless the project is a major one or deals with particularly pressing national policy problems like poverty and serious unemployment, it is probably "economic" and therefore relatively safe not to attempt a national level of analysis.

With the planning area, the level for planning and decisionmaking, and the range of development possibilities identified, development proposals can come from any disciplines involved in preplanning investigations or subsequent planning efforts. Disciplines may include engineering, natural sciences, law, social work, and political science.

Following these preliminary steps, the economics of each proposal need to be evaluated against the overall objectives of a development program, and within a common set of feasibility criteria. These criteria are reviewed at some length later in this report because they determine the array of specific proposals surviving the test of social feasibility. While feasibility in terms of economic efficiency may appear to be stressed in the discussion, efficiency considerations can be a guide to considering other dimensions of social justification, such as the provision of services having intangible, environmental, or other nonmarket values.

PROGRAM OBJECTIVES AND FEASIBILITY TESTS

The importance of planning objectives in examining feasibility is shown by briefly considering resource development and development planning in an economic context. A basic goal underlying natural resource development is to improve the welfare of the members of a society that depends on or can productively employ those resources (along with labor, capital resources, and management skill) in increasing the aggregate flow of goods and services available for distribution among the members of that society. (See Ciriacy-Wantrup (*27a*) and Smith (*28*).)[2]

The aggregate flow or output of goods and services for an economic system consists of expenditures for current personal consumption, production of new or replacement capital goods, current governmental purchases of goods and services, and net domestic receipts for the goods and services exported to other economic systems. The total income or expenditure flow is the "gross national product" if a nation's economy is under study. For a particular project area, the aggregate income flow is called the "gross area product."

The net national or area product is the gross product reduced by a capital consumption or depreciation allowance to cover both normal and adverse wear and tear on the existing stock of land, buildings, durable equipment, and other physical capital assets. The net product is thus the proportion of the gross product theoretically available for present consumption without depletion of the capital stock. The net product can be broken down to national or area income (all income earned for productive service) and personal income as the national or area income actually received by individuals. Personal income is received as wages and salaries for services rendered, rental income, personal interest income, corporate dividends, and proprietary profits.

While information on these various items can be compiled or at least visualized on a national, State, regional, or local basis, the most relevant and practical measure for analyzing the changing pressure of demand on the available resources of an economic system is the gross economic product for the system or area under study. (See Smith (*28*, p. 375).) If the gross economic product or income, adjusted to remove value changes due simply to changing prices, is observed to increase from one period to another, then "real" economic growth can be said to occur. The rate of growth is the observed percentage increase in the "real" gross economic product. How this increased real product is actually distributed among the population and whether average per capita real income shows an increase are undoubtedly important too. But to avoid confusion between individual welfare, social progress, and the successful functioning of an economic system, it is best to limit the criterion for economic growth to an absolute increase in real gross economic product, and to employ other indicators for assessing welfare and social progress.

The economic essence of natural resource development is the trading of current consumption of goods and services for a greater amount of prospective future consumption, by diverting or investing some past or current income toward increasing the productive capacity of natural resources. Such investment can either compete with or complement investment for increasing the employment and productive capacity of labor and other resources of a society. Further, a particular investment in resource development has competing resource investments. The task in planning is to weigh and combine all the feasible investment alternatives in formulating a preferred development program. The program need not be limited to an economic growth objective. In fact, it might be designed only to alter the mix of goods and services flowing from natural resource use.

In this guide, the economic cost of each development proposal is considered to be the investment required to undertake and maintain it. The economic return or total benefit is the gain in real gross product obtained over the life of the proposed development. The net return or benefit is the difference between them. If that return is positive, the proposal is considered economically feasible.

In a general way, net benefit also indicates the desirability of a proposal as opposed to its alternatives, particularly those involving similar amounts of investment. Since, by definition, present consumption is being forgone for prospective future consumption, all comparisons use the "present" as the time of planning and the presumed decision point. This is done by appropriately discounting future benefits and costs for risk and time preference (*20*).

[2] Italic numbers in parentheses refer to items in Selected References on Natural Resource Planning, p. 23.

Feasible resource development programs help maximize the present value of the real net output of goods and services emanating from the employment of natural resources for the area studied. Present value is future value discounted.

Some development proposals may have to compete with others on the basis of having a qualitative or environmental kind of benefit, but not the quantitative or market-determined kind of benefit ordinarily reflected in conventional economic accounts. So net contributions are defined here for: type A proposals, which have quantitative monetary importance and therefore qualitative importance in terms of benefits and costs; type B proposals, which have only qualitative importance; and type AB proposals, which have independent quantitative and qualitative benefits. Other types, based on various qualitative and quantitative mixtures of benefits and costs, can also be imagined.

Type A proposals: Monetary net benefits are net contributions toward resource development and growth. Capitalized net benefits are computed as the excess of capitalized total benefits over capitalized total costs. Benefits and costs of all types would be discounted for future accrual and summed to present values. It is assumed that benefits are being obtained at minimum cost. Irrigation and drainage proposals typically are in this category, as are proposals for industrial water development or for reorganizing agricultural land use primarily to increase net farm income.

Type B proposals: Net contributions are qualitative net benefits because, even with computable or quantifiable costs, benefits are nonpecuniary or not completely expressible in monetary terms. Quantitative benefits may be described in nonmonetary terms, such as potential visitor-days of recreation made available in a recreation or water-supply proposal. For proposals of this type, net benefits are presumed to exist if the scope and costs of the proposals are reasonably in line with indicators of projected demands for the services to be made available and, further, if there is no cheaper feasible method of providing the services. Proposals for municipal water supply and waste treatment could be placed in this category. So could proposals aimed at general environmental improvement.

Compound or type AB proposals: For proposals having both computable monetary and nonpecuniary benefits, net benefits remain qualitative. The test for overall feasibility is similar to that for type B. Benefits are presumed to exist if either of these two primary conditions holds: (a) computable monetary benefits are sufficient to cover combined monetary costs; or (b) while computable monetary benefits are insufficient to cover costs, the scope and costs of the proposals are reasonably in line with projected demands for the goods and services made available. Before determining whether conditions (a) or (b) are met, however, costs unequivocally assignable to each class of benefits should be assigned, so that one can determine whether condition (a) may be met for one or more features or purposes of the proposal. It is expected that there are no feasible cheaper means of obtaining all benefits, monetary or otherwise.

An example of a type AB proposal would be a reservoir jointly serving a recreation purpose (boating) and an esthetic purpose (viewing natural beauty). Boating services may be salable to a select class of users, but for various reasons, access to scenic benefits are nonsalable and diffused among many users. The two elements that make this a mixed proposal are the intangible scenic benefits and the joint obtainment of boating and scenic benefits. The latter suggests that attempted allocations of costs to each class of benefits would be arbitrary.

ALTERNATIVE FEASIBILITY TESTS

Feasibility tests are unavoidably technical. The benefit-cost ratio is most widely used for resource development evaluations. Its use and interpretation are described in the appendix.

Other feasibility tests may also be applied, but the results of all depend on such variables as the length of time into the future contemplated and the discount and interest rates used. Carlson (*2*), James and Lee (*14*), and Lutz and Lutz (*20*) describe the basic economics used in developing and applying various feasibility criteria.

Another economic tool, the internal rate of return, is useful as a subcriterion for allocating funds among feasible proposals or for determining the marginal efficiency of capital used for development activities.

APPLYING THE FEASIBILITY CRITERION

This section shows how the feasibility criterion would be applied in practice. However, the fairly complicated formulas that could be used and that could be necessary in evaluating specific resource development proposals are considered unnecessary here. Basic conceptual problems and feasibility computations for a hypothetical irrigation project are outlined first. Feasibility and minimized cost can then be determined simultaneously.

CONCEPTUAL PROBLEMS

An irrigation project is a complex engineering and agricultural undertaking, with social and economic complexities too. For, as people organize for the project, as resources are put into it, and as its products emerge to enter marketing, processing, and distribution channels, economic effects may occur for both consumption and production in local, regional, national, and perhaps even international economies.

Various efforts have been made to classify the different economic effects of irrigation. In his review of research on irrigation in the High Plains of Texas, for example, Osborn (*25*) discusses and estimates irrigation benefits under four categories: (1) Primary benefits to farm operators; (2) secondary benefits to processors of agricultural products; (3) benefits to businesses that supply resources to the farmer—called "tertiary for farm inputs"; and (4) benefits to wholesale and retail sectors—called "tertiary for consumption." An earlier research study by Kimball and Castle, for the North Unit Deschutes Irrigation Project in Oregon (*16*), considered secondary benefits to include what Osborn describes as tertiary under his categories 3 and 4. Other public policy or "extra-market" benefits may include settlement opportunities provided by a project, reduction of unemployment, general enhancement of project areas as places to live, and stabilization of local economies made erratic by drought and other natural hazards.

Components of irrigation and other resource development benefits and costs are not easily measured. If it were simple to determine them, one would expect uniformity in the estimating procedures employed by various analysts and development agencies. This uniformity does not exist, but substantial progress has been made in recent years as concepts of evaluation have been examined more thoroughly. At least a dozen of the references listed on pages 23 and 24 (indicated by *) deal with evaluation concepts and techniques.

TESTING FOR FEASIBILITY

The basic criterion for feasibility is that capitalized net benefits be positive. While applicable most safely to proposals where all costs and benefits can be expressed in monetary terms, the notion of capitalized net benefits and its related computational formulas is useful for conceptually weighing all quantitative and qualitative elements of benefits or costs. The minimum requirement that quantifiable benefits be evaluated means, for an irrigation proposal, that capitalized total benefits are the present value of the increased agricultural or other economic product stemming from irrigation. This includes all secondary and tertiary additions of output in various sectors of the economic system corresponding to the area affected. All increases of gross economic product are counted on a value-added basis. That is, the gross product increase for a particular farm or other business unit is limited to the *excess* of increased sales over increased purchases of goods and services from other business units. This not only ensures against duplicate counting of benefits, but also encourages a full reckoning of benefits among interdependent economic units or sectors. The increased gross product for each economic unit, while figured with regard to its own characteristic enterprises, comes down to the algebraic sum of changes in its payments for the production factors it employs directly. The payments are disbursed as either wages, rent, interest, or profits.

The algebraic sum of such changes in payments for all economic units affected by a proposed project gives total benefits B—to be compared with initial and discounted future required cost C. C includes both the primary investment in project facilities and any anticipated subsequent investment induced by the availability of the facilities. The equation for net benefits N is simply N = B − C, with B/C the aggregate benefit-cost ratio or income/investment multiplier.

Capitalized benefits, costs, and net benefits can be reduced to annual averages, and the above equation for N is transformed by amortizing each term, using the same evaluation period and interest rate used to capitalize benefits. The value of the ratio B/C would be the same. The ratio is an average measure of the rate of return on capital investment and, under some conditions, is useful for planning when investment funds are limited to quantities below that permitting equalization of marginal benefits and costs. See the appendix for a more complete theoretical discussion of average and marginal benefit-cost ratios.

FEASIBILITY AND MINIMUM COSTS

In requiring the existence of net benefits for economic feasibility, it was assumed that costs of achieving the estimated level of total benefits were a minimum. If costs C are minimized for a given amount of total benefits B, then net benefits N as the difference between these amounts will be a maximum, as will be the ratio B/C. Probabilities for a project's surviving the test of feasibility are considerably enhanced if this guideline is observed in conceiving and formulating development proposals.

But what level of total benefits should be the goal, and how can the costs of achieving these benefits be minimized? In some cases, minimum desired population increases are set as benefit targets, or the investment capital available for development is specified—at least approximately. Seldom are both known, however. Even where they are, possibilities may exist for exceeding the specified benefit targets, the targets may be set too high, or the capital funding outlook may change.

Economic theory and engineering economy provide a framework for determining optimum investment levels and resulting benefits within the same planning framework. Main elements of the framework are total benefits (usually increasing at a decreasing rate) expressed as a function of the capacity of a system or design. Total costs are likewise expressed in terms of capacity, but usually increase both relatively and absolutely. The optimum design capacity is that at which total costs are increasing incrementally (marginally) at the same rate at which benefits are decreasing incrementally. If this balance of opposing rates is achieved, then net benefits are a maximum, costs are a minimum with respect to the optimum amount of total benefits, and total benefits are a maximum with respect to the optimum cost and capacity. A numerical example best illustrates these points. It also shows a solution to the problem of selecting among alternative means to accomplish a single purpose.

The single purpose is irrigation, and the required water can be obtained at two dam sites, x and y. Total design capacity is Q and design capacities at each site are designated by the particular numerical values given x and y. For particular valuation studies, capacity may need to be converted to water yield equivalents, but for simplicity, this analysis considers capacity and yield to have a 1:1 relation and to be analytically synonymous.

The following relations between design capacities (x or y) and total costs in present-value terms of each structure (C_x or C_y) are then postulated here. Capacities are in thousands of acre-feet; costs are in millions of dollars.

$$C_x = 3x + x^2 \text{ and } C_y = -2y + 1.5y^2. \qquad (1.1, 1.2)$$

The incremental costs of storage in each reservoir are the first partial derivatives of the cost-capacity relations:

$$C'_x = 3 + 2x \text{ and } C'_y = -2 + 3y. \qquad (2.1, 2.2)$$

C'_x and C'_y can be set equal to each other to show how capacity in one reservoir can be linked to capacity in the other to achieve total capacity at the least cost. This will give

$$y(x) = (5 + 2x)/3. \qquad (3)$$

Equation 3 shows optimum capacity in reservoir y as a function of capacity in reservoir x. To know the latter, one needs to know the benefits or value of the water stored in both reservoirs. The gross value of the water is assumed to be independent of where it is stored, and its average and marginal values per unit decline with the quantity used. That is, water would go first to the highest-valued crops or would be reserved for critical periods within the irrigation season, and so on down the line. Let us suppose that the average per unit benefit P_q of the stored water Q followed the equation

$$P_q = 11 - 0.5\,Q. \qquad (4)$$

The total value of the water, B, would be the product of P_q and Q, or

$B = 11\,Q - 0.5\,Q^2$, with B in millions of dollars, present value. (5)

The total cost of the water is, of course, the capitalized cost of storage in reservoir x plus the capitalized cost of storage in reservoir y. One already knows from equation 3 the guiding relation between storing in reservoir y in terms of storing in reservoir x. It is also known that Q as total storage must be equal to x + y. So x is expressed in terms of Q as

$$x = (3\,Q/5) - 1. \qquad (6)$$

An expression for total cost C of the two-reservoir system in terms of total capacity Q can now be derived from equations 1, 3, and 6:

$$C = 0.6\,Q^2 + Q - 2.50. \text{ (for } C \geq 0, Q \geq 2.22) \qquad (7)$$

The last steps are to determine optimum total capacity combined in the two reservoirs, divide this between the two reservoirs so as to minimize storage costs, and then compute the benefits, costs, and net benefits for the complete system and for each reservoir individually. The simplest way to apply the condition that incremental total costs of storage be balanced with incremental total benefits is to set down the net benefit formula, differentiate it, force incremental net benefits to zero, and solve for the corresponding value of Q. The appropriate relations in this case are:

$N = B - C = 2.50 + 10\,Q - 1.10\,Q^2$, for net benefits, (8)

$N' = 10 - 2.20\,Q$, for marginal net benefits, and so (9)

Q = an optimum of about 4,540 acre-feet of storage for N' to be zero.

The optimum allocation of this total storage to reservoir x is determined from equation 6—1,720 acre-feet. The remaining 2,820 acre-feet would be in reservoir y, computed from the known value for x and equation 3. Costs of each structure are estimated by substituting these optimum x and y values into equation 1. Likewise, benefits of storage in each structure are proportional to the capacity in each and the benefit function equation 5.

The solution to this problem is summarized in table 1. With an optimum total combined capacity for the two reservoirs of 4,540 acre-feet, total optimum benefits in present value are \$39.64 million, minimum and optimum costs in present values are \$14.37 million, and combined present-value net benefits are a maximum—of \$25.27 million. Note especially that the total and individual benefit-cost ratios differ. This is not surprising, because dam x is more expensive. It entered the system because incremental storage costs in reservoir y were reaching levels exceeding initial incremental costs of storing at least some of the water in reservoir x. The important ratio to equalize is that relating marginal benefits to costs in each reservoir, which can be taken down to unity if costs can be invested without limit. Incremental costs and benefits at the point of solution in this problem are \$6.44 million, obtained by differentiating either equation 5 or equation 7 and then solving for B' and C', inserting for Q the optimum amount (4,540 acre-feet) of total storage. The value of \$6.44 million for incremental benefits and costs thus obtained should equal those computed separately for each reservoir by directly substituting the optimum x or y capacities (1,720 and 2,820 acre-feet) into equations 2.1 and 2.2.

Use of this approach to formulating development projects depends on the availability of two types of relationships: (a) cost-capacity functions as expressed in equation 1; and (b) a benefit function as expressed in equation 4. Cost-capacity functions can be developed by engineers, computing the costs of various capacities provided by a given type of reservoir site and fitting a mathematical function to the pairs of calculations. Adaptations of representative empirical functions developed elsewhere may be useful for this purpose, too.

Total, average, and incremental benefit functions can, within the limits of available data, be developed by economists. The procedure is to rank crops that could be feasibly grown in decreasing order of the marginal returns to water used for each crop, relating the joint marginal returns from irrigating various crop combinations to specific quantities of available stored water. A general notion of the probable

Table 1.—Combining reservoirs to maximize single-purpose net benefits

Reservoir and item	Capacity	Total benefits	Total costs	Net benefits	Benefit-cost ratios
			Symbols		
x	x	B_x	C_x	N_x	B_x/C_x
y	y	B_y	C_y	N_y	B_y/C_y
x & y	Q	B	C	N	
Marginal relations	∂Q	$B'=\partial B/\partial Q$	$C'=\partial C/\partial Q$	$N'=\partial N/\partial Q$	$\partial B/\partial C$
			Optimum values		
	1,000 acre-feet	Mil. dol.			
x	1.72	15.05	8.14	6.91	1.84
y	2.82	24.59	6.23	18.36	3.94
x & y	4.54	39.64	14.37	25.27	2.75
Marginal relations[1]	$\to 0$	6.44	6.44	0.00	1.00

[1] Optimum marginal values for reservoirs x and y are both also $6.44 million.

physical limit to storage, plus knowledge of the crop economy of the area to be irrigated, will indicate how extensive and how detailed these studies should be for specific crops.

Perhaps the limiting supply of available water would not accommodate any but the most highly valued crop, meaning that returns at the margin from irrigating this one crop were higher than those at the margin for any other crop, over the entire range of limiting storage. The aggregate benefit function would be obtained more easily in this case. Declines in average and thus incremental values per unit would be associated with declining incremental (marginal) productivity of the water if used for the one crop, in possible combination with lower unit prices for the crop as production increased.

THE ARRAY OF FEASIBLE PROJECT PROPOSALS

As indicated previously, this phase of economic evaluations would end with a listing of conservation treatment, irrigation, or other proposals that had survived feasibility evaluations. Such proposals could be offered as components of multipurpose development programs. A hypothetical three-element array of proposals is given in table 2. It includes the two-dam irrigation project just discussed, a flood-control levee, and an urban water supply project using ground water.

A more thorough and applied evaluation of an irrigation project is given by Hogg and Larsen (*10, 11*) in their study of the Molokai water diversion project in Hawaii. [3] Anderson and Maass (*1*) made comparable analytical studies.

The three-element array of project proposals given in table 2 is only a simplified example of real-life resource planning. For example, the U.S. Study Commission for the Southeast River Basins (*6, 33*) outlined 150 project proposals for eight basins that included, either separately or jointly, at least 10 kinds of resource development, such as municipal-industrial water supply, navigation, irrigation, drainage, recreation, and pollution abatement. Many considerations are involved in combining such proposals into recommendable total programs. In the next section, some of these considerations are discussed with regard to the three proposals in table 2.

[3] Hogg and Larsen used a price-parametric programming model for allocating given supplies of land of varying productivities to the production of various commodities, with reference to downward-sloping market demand as well as resource productivity functions. Anderson and Maass tested, through simulation models, alternative strategies for allocating limited irrigation water supplies to obtain economies of joint management, simplicity, least cost, benefit maximization, or other objectives.

Table 2.—Economically feasible development proposals

Feasible proposals	Investment costs C	Capitalized benefits B	Net benefits N	Benefit-cost ratio B/C
	Mil. dol	Mil. dol.	Mil. dol.	
2-dam irrigation system	14.37	39.64	25.27	2.75
Flood-control levee[1]	37.15	52.38	15.23	1.41
Urban supply wells	[1] 15.00	([2])	([2])	– –

[1] In this case, capitalized costs could also include capitalized replacement, operation, and maintenance cost, since feasibility is being evaluated independently of benefits.

[2] Adequate domestic water supply for a specified population. In such systems, it is sometimes proposed to measure capitalized benefits by the cost of the next more costly system providing the same services. If the assumption in this guide that costs be minimized for design levels of services provided is honored, the introduction of an alternative-cost measure for capitalized benefits is redundant and leaves undetermined the true economic value of water supply services to urban consumers.

PRELIMINARY COMBINATIONS OF PROJECTS IN PROGRAMS

Given the planning framework and principles outlined so far, the procedure of program formulation is fairly clear. Examine all feasible development proposals, determine any interrelations between them and their corresponding benefits and costs, and then combine them into a program of projects aimed at maximizing the net benefits of development. In the introductory section, net benefits were defined somewhat differently for proposals involving monetary versus qualitative benefits. The formulation process must recognize these distinctions, for they become compellingly evident when feasible proposals are examined together.

It was also noted previously that an optimum program is the best package of feasible activities that can be recommended, within resource and economic limitations not under the control of planners. An important limitation is the amount of investment capital actually available for implementing programs. While some recommended programs offer very good prospects for contributing to economic development, these may not be the only programs to offer substantial economic and social returns. Therefore, priorities must be attached to various components within a program, so that the best or most urgent components can compete for limited investment funds if the entire program cannot be financed.

The remainder of this section offers more definite guidelines on formulating optimum resource development programs—by outlining the elements of comprehensive planning, suggesting how net benefits can be maximized, considering a dual-purpose proposal as the simplest case of multipurpose planning, and proposing a priority-ranking procedure.

RULES FOR PROGRAM FORMULATION

In planning multipurpose resource development, programs that show promise of producing maximum net tangible benefits are often the aim. Such a maximum is not an all-important choice indicator, however. Cases where environmental or other kinds of intangible benefits or costs may be considered important enough to permit investment have already been discussed. But formulating a program with both considerations in mind requires a set of rules. References (*15*), (*17*), and (*24*) reflect continuing governmental and academic concern with developing such rules. While yet still unofficial, the U.S. Water Resources Council principles and standards cited in reference (*34*) consolidate various public, academic, and governmental viewpoints concerning multiobjective and multidimensional planning.

Several important evaluation rules or standards are given official U.S. sanction and are reflected in current agency practices (*32*, pp. 7-8). In a following section, they are discussed as applying to the proposals presented in table 2. The rules are:

> *Rule 1—Content of plans.* "Comprehensive plans shall be formulated initially to include all units and purposes which satisfy these criteria in quantitative economic terms: (a) Tangible benefits exceed project economic costs; (b) each separable unit or purpose provides benefits at least equal to its costs; (c) the scope of development is such as to provide the maximum net benefits; and (d) there is no more economical means, evaluated on a comparable basis, of accomplishing the same purpose or purposes which would be precluded from development if the plan were undertaken."
>
> *Rule 2—Optimum scope.* "Net benefits are maximized when the scope of development is extended to the point where the benefits added by the last incremental of scale (i.e., an increment of size of a unit, an individual purpose in a multipurpose plan, or a unit in a comprehensive plan) are equal to the costs of adding that increment of scale.... Reports shall indicate the scale of development that would result from application of the foregoing criteria considering tangible benefits and project economic costs expressed in comparable terms. This will provide a baseline from which the effect of considering intangibles can be judged."

Rule 3—Qualitative considerations. "Reports and plans shall also indicate the extent to which departures from that scale of development (in rule 2) are proposed in order to take into account intangibles or other considerations warranting a modification in scale not reflected in the tangible benefits and project economic costs."

APPLICATION OF RULES TO SPECIFIC STUDIES

The rules above, while perfectly useful, are not listed in the source report in the same sequence in which they would seem to best applied in actual practice, which is unfortunate. For example, rule 3 suggests that the optimum "economic" scale of a program be set before intangible (including environmental) considerations are introduced. But if intangibles are expected to significantly influence decisions, they are best stated at the outset as side conditions that need to be met in formulating a recommended total program. One of the examples in table 2 of a feasible development proposal—for urban wells—involves intangibles of the form referred to in rule 3.

Rule 2 refers to an optimum economic scope of development as a baseline from which the effect of considering intangibles can be judged. But the scope of development depends on the capital available. If alternative programs are being planned to be in accord with different amounts of capital, planners are faced with the problem of a shifting baseline.

I recommend the use of these rules in specific situations, except that I also recommend that the hard costs of the intangible proposals be considered benchmarks. Planners can ascribe minimum benefits to these proposals in accordance with the tangible benefits willingly forgone in entailing the corresponding costs. As is shown below, benefits forgone are a function of the capital being allocated. Accordingly, the minimum economic values ascribed to environmental or other intangible considerations will be lower as the range of opportunities for accumulating tangible benefits is wider. In other words, the values will be higher if the intangible is chosen when funds are limited. How these considerations would operate in formulating optimum multipurpose programs for the three proposals of table 2 is shown next. The basic data for the analysis are in the first section of table 3.

PRELIMINARY MULTIPURPOSE PROGRAMS

Assume that estimates of the amount of capital available for three increasingly costly programs have been obtained: Program X = $15 million, program Y = $29.37 million, and program Z = $66.52 million. These amounts are underscored in table 3. Note that $15 million could finance either the urban wells or the two irrigation reservoirs. For obtaining tangible benefits, the obvious choice is irrigation, but the urban residents would not have adequate water. Health and humanitarian considerations urge that the first $15 million should go toward installing the urban water supply wells and related distribution facilities.

Note that the benefits attributed to program X are $39.64 million, viewed as the returns on essentially the same amount of money invested in the two-dam irrigation system. The project community, in selecting the urban wells, gives them a gross social value comparable to at least the tangible returns from irrigation, which was the best alternative *not* chosen. Theoretical net benefits are valued at $24.64 million at least, and the benefit-cost ratio is at least 2.64—roughly the same as if the investment funds had gone toward irrigation development. Program X would be recommended if $15 million in capital were available and it could be justified on the grounds described. Summary data are in the final column of table 3.

The analytical picture changes if the available capital is about double the amount permitting only the urban wells. For example, the $29.37 million in total capital shown for program Y in table 3 would finance both the urban wells and the irrigation project. The minimum value of the wells would not remain at $39.64 million, because the benefits of irrigation were not being sacrificed. But proportional flood-control benefits in the amount of $21.15 million would still be sacrificed and, in this case, would be an implicit subjective measure of the minimum value of the urban wells. Program Y would be recommendable for $29.37 million of investment capital and justified as having an overall benefit-cost ratio of at least 2.06. Total benefits would be at least $60.79 million and net benefits at least the equivalent of $31.42 million. The amount divides into $25.27 million in objectively measured irrigation net benefits and $6.15 million in subjectively valued net benefits of the urban wells.

The picture changes again if enough capital —$66.52 million—could be made available to finance all three proposals. Program Z exhausts remaining alternatives for investments in the project area yielding tangible benefits.

Table 3.—Preliminary optimum multipurpose development programs
(All data in million dollars)

Items and programs	Urban supply wells	2-dam irrigation system	Flood-control levee	Program totals
		Basic data, from table 2		
Investment costs	15.00	14.37	37.15	– –
Capitalized benefits	([1])	39.64	52.38	– –
Net benefits	– –	25.27	15.23	– –
B/C ratio	– –	2.75	1.41	– –
		Program X, urban supply wells only		
Investment costs	15.00	– –	– –	15.00
Capitalized benefits	[2] 39.64+	– –	– –	39.64+
Net benefits	24.64+	– –	– –	24.64+
B/C ratio	2.64+	– –	– –	2.64+
		Program Y, urban wells plus irrigation system		
Investment	15.00	14.37	– –	29.37
Capitalized benefits	[3] 21.15+	39.64	– –	60.79+
Net benefits	6.15+	25.27	– –	31.42+
B/C ratio	1.41+	2.75	– –	2.06+
		Program Z, urban wells plus irrigation and flood control		
Investment costs	15.00	14.37	37.15	66.52
Capitalized benefits	[4] 15.00+	39.64	52.38	107.02+
Net benefits	0.00+	25.27	15.23	40.50+
B/C ratio	1.00+	2.75	1.41	1.60+

[1] Adequate domestic water for a specified population. This is also an element added to all subsequent monetary estimates of capitalized benefits of the water supply.

[2] Assumed to be at least the capitalized benefits of the foregone irrigation system. All plus signs indicate that the amounts tabulated are minimums and do not include additional subjective values.

[3] Assumed to be at least the capitalized benefits of the forgone flood control levee if built to a scale involving $15 million in cost, presuming a B/C ratio of at least 1.41 still held.

[4] Assumed to be at least the value of the investment if all alternative profitable investments are already being undertaken.

But what is the implicit minimum subjective value of the urban supply wells in this event? In approving the wells as one component of the program, the project community and lenders would be giving them a value at least equal to their cost. If a less costly alternative for meeting water requirements in fact existed, but had been overlooked or was ignored, this valuation procedure would tend to overstate the real value of the wells.

With capital adequate to finance all identified feasible project measures, program Z would be recommended. It includes the three projects or purposes of urban water supply, irrigation, and flood control. Summary data in the final column of table 3 indicate that, for a total input or capitalized cost of $66.52 million, at least $15 million of benefits of meeting urban water needs would result, along with $39.64 million of irrigation benefits and $52.38 million of flood control benefits. Total benefits would be at least the equivalent of $107.02 million. Net benefits would be at least the equivalent of $40.50 million in total socioeconomic terms.

A special question on this procedure for formulating preliminary multipurpose programs concerns the rationale for the *minimum* values imputed to the urban wells declining from $39.64 million under program X to $15 million under program Z. A brief and admittedly partial answer is that the value placed by any project community on an item consumed or a service used is reflected implicitly by the value of other goods and services desired but not available, or perhaps desired but not preferred. A relatively poor society presumably has many unmet desires for goods and services. In giving first choice to a service fulfilling intangible economic desires (the urban wells), the society places on that service a relatively high value measured by the visible tangible returns willingly forgone. A comparatively wealthy society presumably is already undertaking many productive investments. Its decision to provide a service fulfilling intangible economic desires draws resources away from relatively low-yielding alternative investments. The service thus tends to be valued at the minimum in line with the returns on such investments. This may help explain the difficulties of getting an affluent society to agree on an appropriate level of investment to devote to qualitative improvements in its physical environment, on the competing investments that should be sacrificed, and on who should undertake and manage activities for the improvement of everyone's environment.

If the question is examined from the opposite direction—that is, in terms of the activities a society would be willing to discontinue to retain or obtain an intangible service—a measure of maximum imputed value might be obtained. With specific studies of these matters, analysts might converge on the true value of an intangible service to a society at a particular time, given the society's preference structure and range of alternative want-satisfying social and economic activities.

The treatment of program formulation in this section admittedly has been sketchy, but it illustrates some elementary principles involved in shaping programs from feasible project components. Some more advanced applications include Dorfman's review (*4*) of simulation and analytic approaches to water resource planning in the Harvard Water Program, the related simulation studies of Hufschmidt and Fiering (*13*) on the Lehigh basin in Pennsylvania, and the simulation study by Halter and Miller (*9*) of the Calapooia tributary of the Willamette River in Oregon, in which irrigation, drainage, and flood-control objectives were evaluated jointly. Further, Miller and Holloway (*24*) and also Castle (*3*) have demonstrated some particular ways for simultaneously evaluating these kinds of income-producing objectives against objectives for regional development, environmental improvement, and other considerations with which the Water Resources Council is concerned in implementing multiobjective resource planning.

ADDITIONAL PLANNING CONSIDERATIONS

To this point, programs X, Y, and Z have been formulated in line with assumptions concerning permissible expenditures. The basic optimizing rule was that independent feasible single-purpose proposals be ranked in the order in which they added to net benefits, giving first consideration, as in program X, to the intangible benefits of the urban wells. Program Y was dual-purpose, including both the urban wells and irrigation. Program Z was multipurpose, adding a flood-control levee as a third purpose. The three purposes were regarded as mutually exclusive choices, however, and possibilities for obtaining additional net benefits by designing functionally dependent systems (one element depending on another to complete its role) for urban water supply, irrigation, flood control, or other purposes were not searched out. This section will show how to examine such possibilities.

INTEGRATING PURPOSES AND FACILITIES

Functional dependence was involved earlier in reduced form in designing an irrigation system using dam x and dam y. Similar situations could arise for preliminary programs X, Y, and Z as they are given further review. For example, aggregate net benefits in program Z are estimated as at least $40.50 million in table 3. These are the combined net returns from building the irrigation reservoirs and the flood-control levee. The combined cost of the two reservoirs and the levee, if they were built independently is estimated at $51.52 million ($14.37 million + $37.15 million). Could the same or perhaps even a smaller investment yield more net benefits from irrigation and flood control if these two purposes could be served by using the same two dams included for irrigation in program Z, rather than both the dams and the levee? In other words, is the levee really necessary, because its benefit-cost ratio of 1.41 (table 3) is considerably under the ratios for the dams? Shouldn't the two reservoirs also be used for flood control?

These are legitimate questions. Answering them requires that knowledge of the functional relation between reservoir capacity and flood-control benefits be considered in the context previously shown for irrigation. In the earlier case, there were two design unknowns—irrigation capacity in dam x (denoted now as I_x) and irrigation capacity in dam y (I_y), both in thousands of acre-feet. Corresponding flood-control capacities in the two dams would be F_x and F_y, also in thousands of acre-feet. Combined capacities would be $I_x + F_x$ for dam x, $I_y + F_y$ for dam y, $I_x + I_y$ for irrigation, and $F_x + F_y$ for flood control. Borrowing from the problem in the earlier section (see equations 1.1 and 1.2), the reservoir total cost functions C_x or C_y (in millions of dollars) can be rewritten as follows:

$$C_x = 3(I_x + F_x) + (I_x + F_x)^2 \text{, and} \qquad (10)$$

$$C_y = -2(I_y + F_y) + 1.5(I_y + F_y)^2 . \qquad (11)$$

Similarly, a total benefit function for irrigation B_i in millions of dollars can be rewritten from equation 5 as

$$B_i = 11(I_x + I_y) - 0.5(I_x + I_y)^2 . \qquad (12)$$

Assume next that flood control benefits B_f in millions of dollars as a function of reservoir capacity can be expressed as

$$B_f = 22(F_x + F_y) - (F_x + F_y)^2 . \qquad (13)$$

By comparing B_i and B_f, it can be determined that at least some of any capacity will be allocated to flood control, as maximum marginal benefits of allocating storage capacity to flood control ($22 million) are twice those allocated to irrigation ($11 million). This determination can be made by taking the first derivative of B_i and B_f and assuming the capacities I and F to be zero. By also looking at C_x and C_y, it can be seen that dam y will be favored—at least initially—because its minimum marginal costs are $5 million lower than those for dam x.

The remaining design problem is to maximize net benefits for this two-purpose/two-dam system by, given the cost and benefit functions, optimally allocating capacity in each dam to each purpose, without exceeding the total cost limitation of $51.52 million.

In solving for the unknowns, I_x, I_y, F_x, and F_y, one would first proceed as if the particular cost limit may not prevent carrying each purpose and structure to the point where aggregate net benefits are a maximum. If costs of doing so do not exceed the limit, the solutions are sufficient and the analysis need not be carried further. Should they exceed the limit, the analysis would have to be structured a little differently, but it need not be illustrated here.

The total cost function C in the simpler procedure is:

$$C = C_x + C_y \text{, or equations 10 and 11 expanded.} \quad (14)$$

The aggregate benefit function B is similarly:

$$B = B_i + B_f \text{, or equations 12 and 13 expanded.} \quad (15)$$

Aggregate net benefits N are then summarized as:

$$N = B - C = (B_i + B_f) - (C_x + C_y). \quad (16)$$

By expanding and then reconsolidating equations 10 to 13, aggregate net benefits N in terms of the four capacity unknowns or required solutions to the problem come down to:

$$N = 8\,I_x + 13\,I_y - 1.5\,I_x^{\,2} - I_x I_y - 2\,I_y^{\,2} + 19\,F_x + 24\,F_y - 2\,F_x^2 - 2\,F_x F_y - 2.5\,F_y^2 - 2\,I_x F_x - 3\,I_y F_y. \quad (17)$$

Optimum values for the capacity unknowns are determined by partially differentiating equation 17 with respect to each, forcing these partial derivatives to zero, and using equation 3 as the criterion for dividing capacities x and y between I and F. The resulting system of reduced simultaneous equations and solutions is:

	Equation system	Solutions in capacity units
(18.1)	$3\,I_x + I_y + 2\,F_x = 8$	$I_x = 0.73$
(18.2)	$I_x + 4\,I_y + 3\,F_y = 13$	$I_y = 0.49$
(18.3)	$2\,I_x + 4\,F_x + 2\,F_y = 19$	$F_x = 2.66$
(18.4)	$3\,I_y + 2\,F_x + 5\,F_y = 24$	$F_y = 3.44$
(3)	$3(I_y + F_y) - 2(I_x + F_x) = 5$	

IMPLICATIONS FOR REVISING PLANS

The above overall answer to the design problem is summarized in table 4. It is about as one would expect, given the benefit-cost equations characterizing each purpose and reservoir. The cost data in table 4 are computed by direct substitution of optimum values for I_x, I_y, F_x, and F_y into expanded equation 14. Gross benefit estimates result from similar substitutions into expanded equation 15. Net benefits through the system are the difference between these sets of estimates. Irrigation and flood-control benefits are allocated between reservoirs x and y in proportion to their respective irrigation and flood-control capacities. This is consistent with equations 12 and 13. Similarly, the costs of reservoirs x and y are prorated to irrigation and flood-control purposes proportionally in relation to their demands for water storage. This is consistent with equations 10 and 11. An arithmetic check on net benefits can be made by substituting all optimum capacities directly into equation 17.

Aggregate net benefits in table 4 are a maximum of \$72.72 million, obtained primarily but not exclusively from flood control. Net flood-control benefits in reservoir y are considerably higher than those in reservoir x. Note how total costs and total benefits associated with flood-control storage differ between the two reservoirs. A nominal amount of irrigation storage would be provided, primarily in reservoir x. The total integrated system has a benefit-cost ratio of 2.97, ranging from 1.67 for irrigation storage in reservoir x to 4.03 for flood-control storage in reservoir y. The overall ratios for the two major purposes are 1.98 for irrigation and 3.17 for flood control. By reservoirs, they range from 2.32 for x to 3.88 for y.

The solution is also consistent with the cost limit imposed, because the \$36.96 million cost of this integrated system is well under the \$51.52 million cost for the levee and reservoirs. In summary, in an integrated system of reservoirs which eliminates the levee, total benefits are \$109.68 million, total costs are \$36.96 million, and aggregate net benefits are \$72.72 million. The last-named exceed those for the irrigation reservoirs and the flood-control levee as separate facilities by \$32.22 million, or by about 75 percent, and with a one-third saving in cost.

Table 4.—Combining alternative reservoirs to maximize dual-purpose net benefits

Reservoir and purpose	Units of storage capacity	Total benefits	Total costs	Net benefits	Benefit-cost ratio
	1,000 acre-feet	Mil. dol.			
x:					
Irrigation	0.73	7.61	4.55	3.06	1.67
Flood control	2.66	42.68	17.11	25.57	2.49
Subtotal	3.39	50.29	21.66	28.63	2.32
y:					
Irrigation	0.49	5.07	1.84	3.23	2.75
Flood control	3.44	54.32	13.46	40.86	4.03
Subtotal	3.93	59.39	15.31	44.09	3.88
x & y:					
Irrigation	1.22	12.68	6.39	6.29	1.98
Flood control	6.10	97.00	30.57	66.43	3.17
Total	7.32	109.68	36.96	72.72	2.97

MODIFIED MULTIPURPOSE PROGRAMS

ANOTHER LOOK AT THE OPTIONS

In modifying the revised multipurpose development programs, and using the three levels of costs allocated in preliminary programs X, Y, and Z, at least five feasible options exist. Their basic benefit-cost data are given in the first block of table 5. Option I (the wells for urban water supply costing $15 million) and option II (the two-dam irrigation water storage system costing $14.37 million) are carried over from table 3. The flood-protection levee of table 3 is dropped in favor of option III. Option III is a flood-control system, also costing $14.37 million, and using the same reservoirs as the irrigation system for which it is a possible substitute. Option IV represents an expansion of option III for an additional outlay of $15 million —the same outlay required to install the wells for urban water supply. The benefits and costs of option IV are incremental. They are readily approximated from equations 7, 10, 11, and 13. (Similar calculations using equations 7, 10, 11, 12, and 13 show that incurring about the same costs ($14.37 million) for an optimum limited irrigation *and* flood control system theoretically would produce about the same net benefits but would imply a negative quantity of irrigation storage.) Finally, option V represents the optimum integrated two-dam system for irrigation and flood control derived in the foregoing section and detailed in table 4.

As in the preliminary program planning, option I is assumed to have first priority, despite its inherent benefits not being quantifiable in terms of money. Its minimum total benefits are regarded as the maximum inherent benefits willingly forgone by not selecting other options costing about the same.

Taking the same hypothetical expenditure levels for preliminary program X ($15 million), program Y ($29.37 million), program Z ($66.52 million), revised programs based on the options of table 5 are summarized below.

Program XX.—With expenditure limited to $15 million, resource development would be limited to option I, the urban wells. The minimum value of the wells would be regarded as at least $79.14 million—the returns forgone by not building the two-dam flood-control system (option III) as the most "profitable" option financed by an equivalent cost. The feasible but less profitable irrigation system, costing the same and using the same two dams (option II),

Table 5.—Revised optimum multipurpose development programs
(All data in million dollars)

Items and programs	Urban supply wells— option I	2-dam irrigation system— option II	2-dam flood-control system— option III	Partial flood-control expansion option IV	Integrated irrigation and flood control— option V	Program totals
Basic data on remaining or new feasible options						
Costs	15.00	14.37	14.37	15.00	36.96	– –
Benefits	([1])	39.64	79.14	20.25	109.68	– –
Net benefits	– –	25.27	64.77	5.25	72.72	– –
B/C ratio	– –	2.75	5.50	1.35	2.97	– –
Program XX, urban supply wells only, option III forgone						
Costs	15.00	– –	– –	– –	– –	15.00
Benefits	[2]79.14+	– –	– –	– –	– –	[2]79.14+
Net benefits	64.77+	– –	– –	– –	—	64.77+
B/C ratio	5.27	– –	– –	– –	– –	5.27+
Program YY, wells and 2-dam flood control, option IV forgone						
Costs	15.00	– –	14.37	– –	– –	29.37
Benefits	20.25+	– –	79.14	– –	– –	99.39+
Net benefits	5.25+	– –	64.77	– –	– –	70.02+
B/C ratio	1.35+	– –	5.50	– –	– –	3.38+
Program ZZ, wells and irrigation/flood-control system						
Costs	15.00	(6.39)	(30.57)	– –	36.96	[3]51.96
Benefits	15.00+	(12.68)	(97.00)	– –	109.68	124.68+
Net benefits	0.00+	(6.29)	(66.43)	– –	72.72	72.72+
B/C ratio	1.00+	(1.98)	(3.17)	– –	2.97	2.39+

[1] Adequate domestic water supply for a specified population.

[2] Plus signs are explained in footnote 2 of table 3.

[3] Gross availability actually $66.52 million as in program Z, table 3.

( ) indicates optimum distributions to irrigation and flood control within the integrated system. Distributions between the two dams are shown in table 4.

while a viable alternative, can be ruled out of consideration. Subjective net benefits ascribed to program XX would be regarded as at least the equivalent of objective net benefits of $64.77 million, while the subjective benefit-cost ratio would be at least 5.27. Note that program XX in table 5 would have the same visible features as program X in table 3, but it is characterized quite differently in economic terms.

Program YY.—With possible expenditure raised to $29.37 million, resource development could include both the wells for urban water supply (option I) and the basic two-dam flood-control system (option III). The minimum value of the wells would be regarded as at least $20.25 million, the returns forgone by not putting the money used for the wells into building larger flood-control reserviors (option IV). The selection of option III completely rules out the substitute option II. Subjective net benefits of program YY are $70.02 million, and the corresponding benefit-cost ratio is at least 3.38. Program YY (table 5) and program Y (table 3) are similar only with respect to cost.

Program ZZ.—If an expenditure of $66.52 million were possible, resource development would include the wells for urban water supply costing $15 million (option I), and an integrated irrigation and flood-control reservoir system costing $36.96 million (option V), for a total cost of $51.96 million. The $14.56-million surplus could be available for financing activities not described in table 5, because a program involving options I and V forecloses options II, III, and IV.

To again summarize, the minimum benefits of the urban wells in program ZZ are regarded as equivalent to at least their $15 million cost. Total program benefits are considered subjectively equivalent to at least $124.68 million, while net benefits are similarly at least $72.72 million and the benefit-cost ratio is 2.39. In short, ZZ would be a program for planners to actually recommend if a $51.96-million expenditure were possible. It takes full advantage of the development opportunities described in table 5 and more or less culminates the development planning process as discussed in this report. Principal questions remaining concern the manner in which a recommended plan like program ZZ would fit into the general economy of the development area.

PROGRAM ZZ AND AREA ECONOMIC ACCOUNTS

The introductory sections of this guide indicated that the gross economic product of an economic system could be considered the sum of expenditures by consumers for goods and services, expenditures for new capital investment in the form of fixed physical assets or increased inventories of goods, expenditures by government for goods and services, and net receipts for goods and services produced within the system under study but purchased by other systems (net exports). Of equal importance are the relations between increases in real gross product (economic growth), increases or decreases in the rate of unemployment, and the various components of personal income or returns to factors of production.

Table 6 shows in a purely hypothetical way how program ZZ might change some principal items reported in the U.S. system of national income accounts over the period of the program's existence (*31*). Pooled estimates are given for the irrigation and flood-control components of option V in the program; that is, the estimates are net for the two purposes.

The first set of figures in table 6 indicates how planning information—like capitalized costs, total benefits, net benefits, and benefit-cost ratios as used in foregoing sections of this guide—can logically be interpreted within the framework of a system of area or national economic accounts. Total program benefits are the analog of gross area (or gross national) product, while capitalized investment costs are the analog of gross domestic investment. The ratio B/C as our multiplier shows the rise in equilibrium gross product per unit increase in investment. The magnitude of the multiplier and thus of program benefits depends basically on the spending habits of consumers and will increase according to the fraction of personal income that is spent for consumer goods and services. Note that the benefit-cost ratio or income multiplier is a result of the analysis and is not a previously decided measure for estimating benefits.

Because the urban wells are incorporated in program ZZ on a subjective priority basis and are considered to have a service value at least equal to their hard costs, the plus signs are

Table 6.—Changes in principal area accounts associated with program ZZ

(All data in million constant dollars)

Principal planning and economic account items	Option I—urban wells	Option V—irrigation and flood control	Totals for program ZZ
Relations of basic planning data in table 5 to area economic accounts			
Capitalized costs, C = domestic investment, I	15.00	36.96	51.96
Total benefits, B = gross area product, GAP	[1] 15.00+	109.68	[1] 124.68+
Net benefits, N = net area product, NAP	0.00+	72.72	72.72+
Benefit-cost ratio, B/C - income multiplier	1.00+	2.97	2.39+
Types of personal income changes and derivation of gross area product			
Wages and salaries	8.00	6.54	14.54
Corporate dividends	1.25	−1.25	0.00
Rental income	0.00	2.07	2.07
Interest income, @ 5 percent of I above	0.75	1.85	2.60
Proprietary profits, farm and nonfarm	0.00	49.36	49.36
Business transfer payments to persons or households	0.00	4.15	4.15
Total personal income before personal taxes	10.00	62.72	72.72
Total area income[2]	10.00	58.57	68.57
Net area product, NAP above[3]	0.00	72.72	72.72
Add: Capital depreciation, I above	15.00	36.96	51.96
Gross area product, GAP above	15.00	109.68	124.68
Change in area rate of unemployment	(reduced to 4.6% from 5.3%)		
Components of increase in gross area product (expenditure basis)			
Personal consumption expenditures	0.00	48.54	48.54
Gross domestic investment expenditures	15.00	36.96	51.96
Government purchases of goods and services	0.00	12.08	12.08
Net export balance for area	0.00	12.10	12.10

[1] Plus signs are explained in footnote 2 of table 3.

[2] Would be less than personal income by such items as the amount of transfer payments by the government to persons, net interest paid by government and consumers, and business transfer payments. Would exceed personal income by the amount of corporate profits. Adjustments are calculated algebraically with due regard to increases or decreases for any item entering the calculations.

[3] Is less than area income by amount of such items as business subsidies from government. Is greater than area income by amount of surplus of government-operated enterprises, sales and other indirect business taxes, and business transfer payments. These adjustments are also calculated algebraically.

Table 7.—Changes in subsidiary economic accounts associated with program ZZ

(All data in million constant dollars)

Subsidiary economic accounts and items	Option I—urban wells	Option V—irrigation and flood control	Totals for program ZZ
Accounting of personal income disposition			
Total personal income, before personal taxes	10.00	62.72	72.72
Personal income and other personal tax payments	10.00	8.78	18.78
Disposable personal income, Y_d	0.00	53.94	53.94
Personal consumption expenditures, @ 0.9 Y_d	0.00	48.54	48.54
Personal saving, @ 0.1 Y_d	0.00	5.40	5.40
Government accounts			
Total government receipts	10.00	8.78	18.78
Personal income and other personal taxes	10.00	8.78	18.78
Corporate income taxes	0.00	0.00	0.00
Sales and other indirect business taxes	0.00	0.00	0.00
Total government expenditures	10.00	2.08	12.08
Business subsidies	10.00	−10.00	0.00
Transfer payments to persons	0.00	0.00	0.00
Social insurance benefits	0.00	0.00	0.00
Government purchases of goods and services	0.00	12.08	12.08
Government surplus or deficit	0.00	6.70	6.70
Gross saving and investment identity for area			
Gross saving and gross investment	15.00	49.06	64.06
Total personal and business saving	15.00	42.36	57.36
Personal saving	0.00	5.40	5.40
Business saving	15.00	36.96	51.96
Undistributed profits and other adjustments	0.00	0.00	0.00
Capital depreciation allowances	15.00	36.96	51.96
Government surplus or deficit	0.00	6.70	6.70
Area domestic investment	15.00	36.96	51.96
Fixed investment	15.00	36.96	51.96
Inventory change	0.00	0.00	0.00
Area investment outside area (net exports)	0.00	12.10	12.10

retained in table 6 on the pertinent total benefits, net benefits, and benefit-cost ratios. This poses no problem of consistency with national economic accounts as presently constructed, because such accounts do not yet include pecuniary values for the services flowing from roads, hospitals, schools, and many other public investments.

Suppose the urban wells were installed by the business sector, which in turn would be subsidized by government for all operating costs and for a competitive rate of interest return on the capital investment. Government would recover the subsidy from consumers via personal taxes. Under this arrangement, table 6 indicates that the water supply wells would yield personal income of $10 million over their period of usability and so would contribute $10 million to area income but, because of their being subsidized, would not add to net area product. They would add to gross area product, however, by the investment of $15 million required to install them. Note also that the wells would not cause a net increase in consumer expenditures, because the added $10 million in personal income distributed to employees of the operator or received as dividends or interest would merely offset a corresponding increase in personal taxes. So, on balance, total disposable personal income, and thus personal consumption, would show no net change.

The irrigation and flood-control components of program ZZ could be undertaken in a context typical of the present U.S. economy, involving some elements of subsidy perhaps, but in the main, influencing all four components of gross area product.

In a general economic accounting or global sense, program ZZ could be summed up from table 6 as increasing consumer expenditures by $48.54 million, investment expenditures by $51.96 million, government purchases of goods and services by $12.08 million, and net exports by $12.10 million, for an aggregate increase of $124.68 million in gross area product. The aggregate increase also can be broken down into a capital depreciation allowance of $51.96 million (to offset ultimate exhaustion of the investment) and a residual net area product increase of $72.72 million. Along with this net increase would occur a net change in area income of $68.57 million and a net change in personal income of $72.72 million. The increase of $4.15 million in business transfer payments to households is why the increase in area income is less than the increase in personal income. Included in table 6 is a hypothetical employment effect of program ZZ, computed to be a decrease in the rate of area unemployment from 5.3 percent without the program to 4.6 percent with the program. However, there is no reason why a resource development program that advantageously increases gross area product might not also cause an undesirable increase in the unemployment rate. Thus employment policy can effectively and justifiably impose criteria for economic and social justification of resource development apart from its gross area product and income effects.

Some final hypothetical statistics on program ZZ are given in table 7, which shows changes in subsidiary economic accounts induced by the program over its period of existence. Items include disposition of personal income, a skeletal government balance sheet of receipts and expenditures, and a balancing-out of gross saving and investment for the area's economic system. Again, the objective in presenting such illustrative data is to show how the formulation of an optimum multipurpose resource development program can affect the different components of area income and expenditures in positive, negative, or neutral ways, even while maximizing prospective increases in real gross product and thereby contributing to economic growth.

A CONCLUDING ASSESSMENT

The expository nature of this guide and the hypothetical development alternatives evaluated do not require overall analytical conclusions. However, a few closing comments on content and limitations are in order.

A distinctive characteristic of the procedures is that economic efficiency is not regarded as an exclusive or necessarily superior guide for making planning decisions. Its importance is still recognized, however, especially for making consistent comparisons of both market and extra-market benefits or costs of development alternatives.

As a first limitation, the guide admittedly gives minor treatment to some important theoretical aspects of resource planning, especially those involving the interdependency of various kinds of qualitative benefits, locational dissociations of costs and benefits, and interpersonal or interfirm welfare dissociations. While this omission is not regarded as critical to the objective of describing the planning process itself, the utility of welfare economics principles for resolving problems of benefit-cost dissociation in resource development should not be overlooked. Krutilla (*18*), Maass (*21*), and Timmons (*29*) have treated these problems in somewhat dissimilar but instructive ways.

Another limitation is in the few types of development activities or purposes for which numerical examples of benefits and costs were given. While the stress was on principles for properly comparing alternatives, one should keep in mind that different purposes can pose practical differences that need to be well understood before particular principles are applied.

The guide does not fully relate theory and practice in linking alternative resource development proposals to the behavior of economies where development programs would operate. Perhaps the most critical procedural step in optimizing resource development in an area-accounts or macroeconomics framework is to properly relate variations in the possible physical scale of each development alternative to changes in the subsidiary elements of macroaccounts. These include personal income, tax liabilities, savings, and other elements that affect such major components of gross economic product as consumption, investment, government purchases, and export-import activity. Tables 6 and 7 do this hypothetically and partially for program ZZ. In practice, similar information should be incorporated into benefit functions related to system capacity, as in equations 12 and 13. Other measures of physical scope can be used too, like acres of land improved for recreational purposes.

The need to improve our natural environment is a principal reason for including the urban wells as a development option evaluated in an 'opportunity cost' or indirect manner. Municipal water supply service and water quality improvement not only involve a similar kind of reasoning on intangible factors, but also are closely related in a physical and technological sense. Moreover, ground water development versus surface water development and treatment is, in many parts of the world, still the essential choice to make in obtaining adequate water of acceptable quality. Although the study recognized and discussed environmental protection issues in a cursory manner, a more thorough treatment was beyond its intended scope. Long's research in Pennsylvania is an example of a substantial theoretical and applied effort to analyze resource enhancement in an environmental perspective encompassing both entrepreneurial and social interests (*19*).

While the guide takes a somewhat simplistic approach to balancing the qualitative and quantitative features of development alternatives and is technically incomplete, it does illustrate some of the important concepts and techniques that guide planning work.

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APPENDIX: INTERPRETING AND USING THE BENEFIT-COST RATIO

This appendix shows in diagrammatic form the meaning of the benefit-cost ratio traditionally used as a feasibility indicator in resource development. Its proper interpretation and use are discussed with reference to five kinds of cases or planning situations that are likely to be encountered.

GENERAL CONCEPTS

The benefit-cost ratio commonly used in resource planning can be defined as total capitalized benefits divided by total capitalized cost. Capitalized costs and benefits can be expressed either as discounted (present-value) or recurring (annual) amounts. Program, project, and activity costs include expenditures for the use of productive factors employed in realizing benefits. Such expenditures can be considered as values forgone by not incurring them for other economic activities. Land, labor, capital, and management are principal classes of productive factors usually involved. In general, all construction, operation, and maintenance expenses can be associated with one or another of these classes of factors. Outlays may take the form of purchase prices or rent for land, wages for labor, and capital or interest on capital.

Monetary benefits represent market or imputed values of goods or services rendered, employing the productive factors mentioned above. Benefits are computed by multiplying physical quantities of goods or services, such as kilowatt-hours of electric power or acre-feet of storage capacity in reservoirs, by their estimated unit values. The unit value of power is usually taken as its selling price or marketable value per kilowatt-hour. The unit value of storage capacity, however, depends on the particular purposes for which the capacity is utilized; that is, whether it is used for, say, recreation, flood control, or irrigation.

The benefit-cost ratio can be calculated at any level of aggregation. It can refer to programs or projects in total, project activities, individual beneficiaries or participants, or project subareas. The main requirement in this regard is that costs and benefits be accurately associated. Net benefits are total capitalized or annualized benefits less total capitalized or annualized costs. Consequently, the ratio of net benefits over total costs (or dollars of "profit" for each dollar invested) is computed by subtracting 1.00 from the corresponding gross ratio of benefits over costs, and a value greater than zero is taken to justify the expenditure. However, the gross ratio is almost always the one presented and discussed in evaluation reports, and a value for it of unity is commonly regarded as the threshold value of justification. A recognition that development activities, projects, or programs can each have a varying scale is essential in interpreting the subsequent discussion.

RESTRICTIONS ON INTERPRETATION

By definition, the benefit-cost ratio is an average relation. Average relations are properly used in allocating scarce resources (including money) if they are synonymous with marginal relations. Therefore, the benefit-cost ratio as usually computed in resource evaluations is an appropriate criterion for deciding how to allocate resources to a project, provided it satisfies the following condition, called condition X: **The ratio does not change with the amount of money represented by the total costs assigned to a particular program, project, or activity.**

Condition X satisfied. In figure 1, there is a straight-line relation between total costs and total benefits. Slopes of the three benefit lines, A, B, and C, do not change with costs, so they denote ratios of marginal changes in benefits to marginal changes in cost as well as ratios of total benefits divided by total costs.

Condition X not satisfied. In figure 2, there is no straight line relation between total costs and total benefits (see line I) Line II, as the marginal benefit-cost ratio and the plotted slope of line I, changes as costs change and so is not the same as average benefit or the conventionally figured benefit-cost ratio. The latter is shown as line III. Marginal and average relations (lines II and III) coincide at one point in figure 2—where costs total q dollars. At this point, the benefit-cost ratio is a maximum, but net benefits are definitely not maximum. The case shown in figure 2 can be expected much more frequently than the case in figure 1.

USEFULNESS OF THE RATIO

Figures 1 and 2 show how the benefit-cost ratio can be used as an efficiency standard if condition X is met or is not met. A good rule to follow is to determine what the same cost will do in different programs, projects, or activities, without assuming, however, that such comparisons will remain valid if costs are either increased or decreased. The essential point is that proper use of the benefit-cost ratio in incurring costs or appraising projects, while still based on the relation between costs and benefits, allows for any changes in the relation as costs are changed. Some different uses are explained next. They depend on whether the gross benefit-cost relationship is linear or not.

LINEAR FUNCTIONS

Three possible cases are described, based on constant magnitudes of the function slope.

Case A: If the benefit-cost ratio is less than unity, money will be lost whatever benefits are received, and losses will increase proportionately with costs. Refer to line A in figure 1, where $\tan\theta < 1$. A broad decision rule here would be that, unless more-than-compensating net intangible values can be realized, no expenditure is justified.

Case B: If the benefit-cost ratio is equal to unity, net benefits will be zero regardless of the total benefits received. Refer to line B in figure 1, where $\tan\theta = 1$. The decision rule here is that the expenditure is a matter of indifference unless the existence of associated net intangible values or net intangible losses is established, and the decision is modified accordingly.

Case C: If the benefit-cost ratio exceeds unity, net benefits will increase proportionately with cost. Refer to line C in figure 1, where $\tan\theta > 1$. The broad decision rule in this case is that expenditure is limited only by more lucrative alternatives and the cost that could be incurred. However, associated intangible benefits and costs should be considered here too, as the existence of associated net intangible losses considered significant by decisionmakers could qualify judgments as to the desirability of the activity.

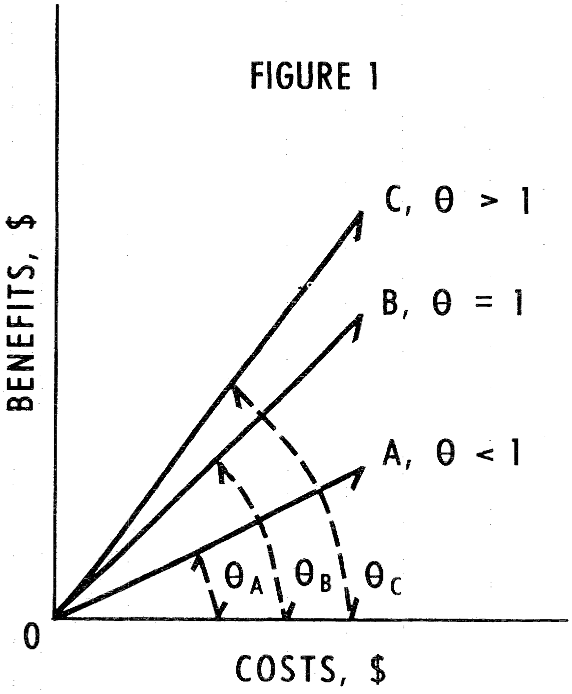
NONLINEAR FUNCTIONS

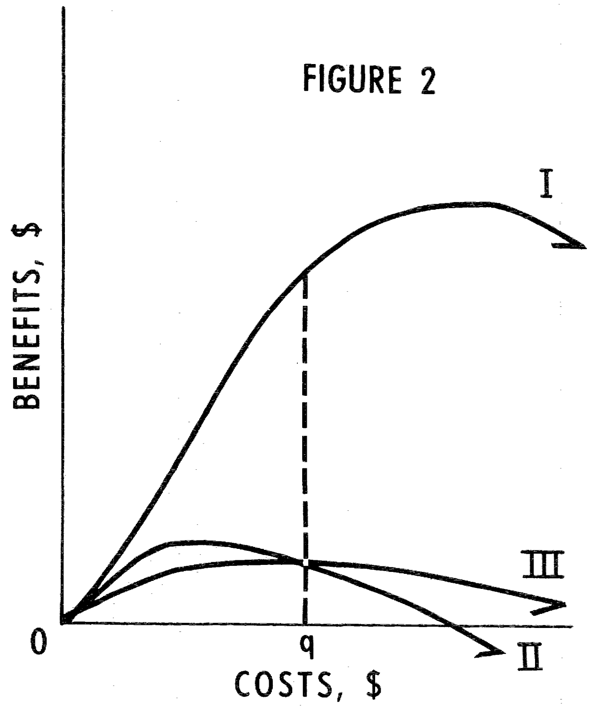
Determining justified cost if the benefit-cost function is not linear, or if the benefit-cost ratio is not constant, depends on whether the scale of only one alternative (case D) or the scales of more than one alternative (case E) are being considered. Associated intangible values or losses may be involved in either event and could modify the decisions implied.

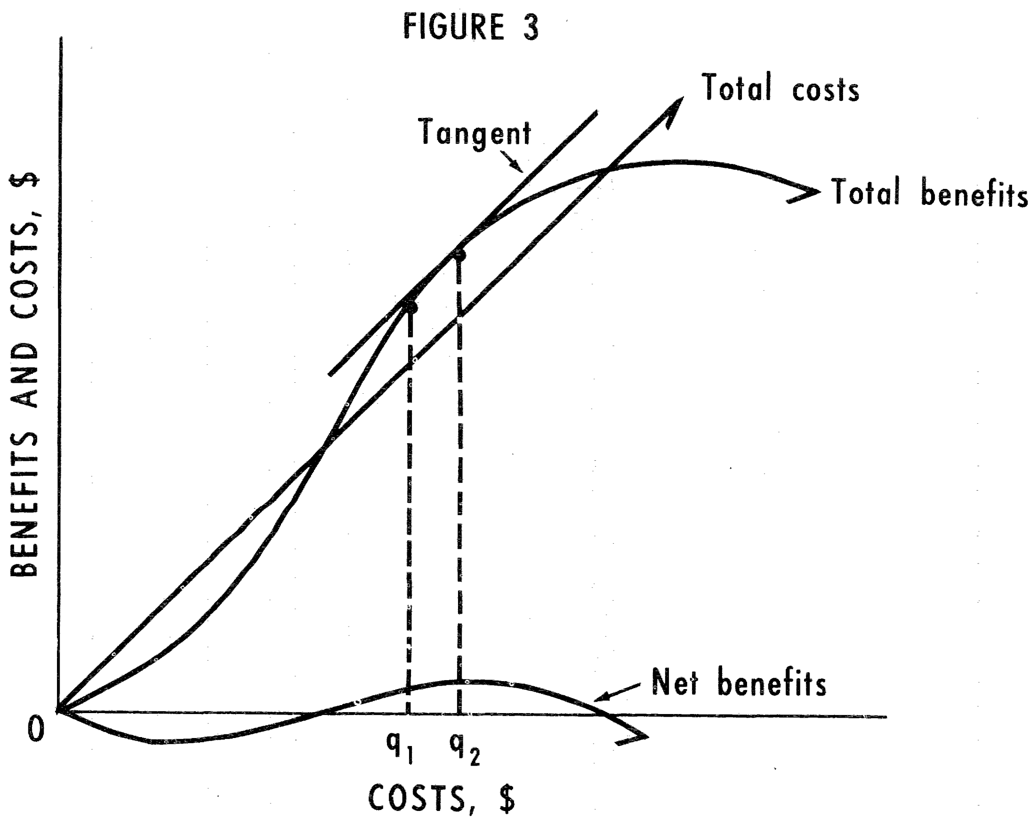
Case D: If the appropriate scale of only one project or activity is under consideration, the economic rule is to incur costs to the point where **added** total cost is equal to **added** total benefit obtained. Expected overall net benefits are maximumized by doing so. In figure 3, the optimum cost to incur is shown as q_2 dollars. The amount q_2 is identified by drawing a tangent to the total benefits function that parallels the total cost function, and by then dropping a perpendicular to the horizontal or cost axis from the tangency point. The total cost function will be at 45 degrees from the horizontal, as in figure 3, if the horizontal and vertical axes are marked off in the same way.

Case E: If the appropriate scales of a series of projects are under consideration, the general rule is that net benefits will be maximized if costs are incurred among the projects so that marginal net benefits are the same in all projects undertaken, and would not be greater if the equivalent cost were to be devoted to any omitted project. The rule fits situations where

SCHEMATIC BENEFIT - COST RELATIONS







MAXIMIZING BENEFITS FROM WATER STORAGE

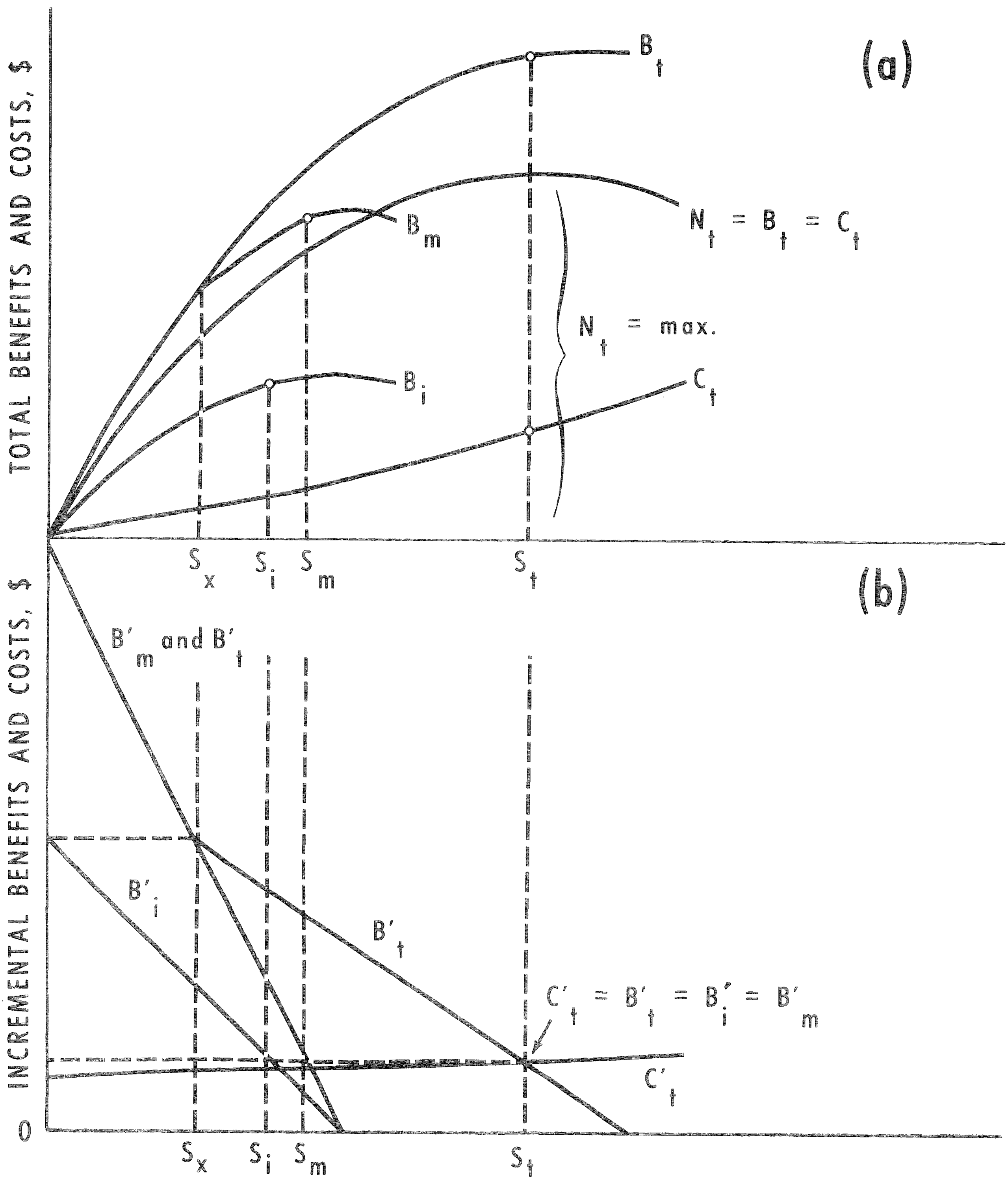


FIGURE 4

resources may be sufficient to undertake each project at scale q_2 in figure 3, thus getting maximum net benefits in each one by pushing its marginal net benefits to zero. But the rule also recognizes that, owing to capital, engineering, or perhaps political or institutional constraints, it may not be possible to incur the cost that would push to zero the rate of increase in net benefits for an entire series of projects.

The general rule for case E can be validated from basic economic theory. The Carlson and Lutz textbooks (*2, 20*) are excellent for this purpose. The procedure is also covered by many other authors, often under the theory of price discrimination. For example, figure 4 illustrates a practical planning problem of discriminately deciding the optimum total and separable capacities of a dual-purpose reservoir designed to serve irrigation (i) and industrial water demands (m). The curves B_i and B_m in figure 4 denote gross benefits obtained by storing water for each purpose in relation to respective separable allocations of any total capacity that might be planned. Incremental benefits for each purpose are the derivatives of their respective gross benefits and are denoted by B'_i and B'_m in the lower section of the diagram. Total incremental benefits B'_t stemming from either or both purposes are synonymous with B'_m at capacities under S_x. Thereafter, B'_t is composited from B'_i and B'_m by horizontal adding. The total benefit curve B_t in the upper section is not the sum of B_i and B_m. It is the compound integral of B'_t. Total cost as related to total capacity is given by C_t and marginal cost is C'_t. Corresponding aggregate net benefits as total benefits less costs are N_t.

Aggregate net benefits N_t in figure 4 would be maximized if S_t units of total storage were planned, with S_i units allocated to irrigation and S_m units to industrial purposes. At these optimal capacities, incremental costs of storage are shown (in the lower section) to be equal to incremental total benefits as well as to incremental benefits for each purpose. Optimal positions on total benefit and cost functions are indicated by the small circles in the upper section of the figure. These denote points at which slopes of tangents to the functions would be equal, according to the condition $C'_t = B'_t = B'_i = B'_m$. If this condition holds, then $N'_t = N'_i = N'_m$, which means that marginal net benefits in the aggregate N'_t are identical to marginal net benefits from irrigation water storage N'_i and also from industrial water storage N'_m. This is consistent with the rule first outlined for case E.