Trade-Off Ratio Calculations in Water Resource Planning

Special Report 429

January 1975

Agricultural Experiment Station
Oregon State University, Corvallis

ABSTRACT

The social and economic objectives of society in the United States are many and varied. Water and related land resource development contribute to the achievement of these objectives. In the case of incommensurable objectives, several approaches to water resource planning have been recommended. "Trade-offs" are to be calculated among money and non-money valued goods. A description of the conceptual basis necessary for trade-off calculations, and an application, are presented. Net benefit trade-offs are shown to be valid only under certain limiting conditions. Product-product and factor-product trade-offs are defined and calculated in an actual river basin. The pitfalls of using several other recommended approaches are highlighted where appropriate. Results suggest that economic theory should play a larger role in water resource planning.

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ACKNOWLEDGEMENTS: The research herein reported was partially funded by the Office of Water Resources Research, Department of the Interior, Washington, D.C., and through the Robert Johnson Fellowship, Oregon State University. Many individuals have contributed to this report, including Dr. John A. Edwards, Dr. Albert N. Halter, Dr. Joe B. Stevens, and Dr. Kenneth C. Gibbs.

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TRADE-OFF RATIO CALCULATIONS IN WATER RESOURCE PLANNING

Gary D. Lynne and Emery N. Castle

INTRODUCTION

The social and economic objectives of society in the United States are many and varied. A great deal of concern has been expressed by individuals and groups, especially in recent years, over the direction the nation should take to achieve various social objectives.[1/] This concern has had an effect on water resource planning procedures in the public sector.

Water and related land resource development contribute to the achievement of several objectives. The most recent planning document [16] which reflects this mood outlines the broad conceptual base and some general techniques for applying multiple objective planning procedures to water resource planning.[2/] The various features of a project are to be displayed in such a manner that a decision-making body can decide if the project would contribute the correct combination of products as dictated by social preferences. If non-money valued products and factors are encountered, trade-offs are to be calculated such as ". . . to gain an insight with respect to the relative value of such effects by understanding their impact upon monetary values. . ." [16, p. 24831]. Stated in another manner, the relative value of non-money valued goods is to be determined by comparison with money-valued goods. If money-valued goods must be sacrificed to gain a non-money valued good, a relative valuation of the non-money valued good becomes explicit.

The purpose of this report is to provide a description of the conceptual base necessary to calculate trade-offs and to show how this proposed approach can

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1/ For a discussion of social objectives and the possible relationships among them that should be considered in trade-off calculations, see [2, pp. 729-730 and pp. 734-735].

2/ For the background and much of the discussion culminating in the planning document approved in 1973, see [15, 17, 18, 19, 20, 21, 22, 23, 24].

be used in an actual planning situation. Several approaches have been recommended by others [1, 4, 5, 7, 8, 9, 10, 11, 12]. Most of these have been based on more intuitive notions of the trade-off concept. The most frequently mentioned approach is one advocated by Major [8, 9]. In that approach, a measure of relative value is determined by providing a schedule of net dollar benefits vs. various levels of the non-money valued good to a decision body for choice. Assuming the decision body can accurately reflect society's preference function, choice of a product combination gives an estimate of the relative value of the non-money valued good. This, at least, is the justification for using net benefit curves. Using this procedure, results of the research presented in this report indicate errors in resource allocation and product mix determinations are easily made. The use of net benefit curves in trade-off determinations is valid only under special conditions that are not isolated, by several authors espousing the use of this approach.

CONCEPTUAL BASIS FOR TRADE-OFF CALCULATIONS

One of the basic problems faced by a water resource planner is valuation. With prices for all factors and goods in the water product production process known, the most efficient mix can be achieved by maximizing the net dollar benefit function. When one or more of the prices is not known, the most efficient mix cannot be determined by the resource planner.[3/] Some decision body must be consulted regarding relative values. As a result, the resource planner's role is reduced to identifying the feasible alternatives for development (including no development). The approach to this process of identifying alternatives can be viewed as a problem not unlike that faced by a firm providing several products, except that some of the products and/or factors do not have known, market-determined prices. As a result, a useful approach for the resource planner can be outlined using the (economic) theoretical constructs of the multiple product firm.

The approach to identifying alternatives and isolating "trade-offs", however, must be conditioned by the price (or prices) that is (are) missing. The

3/ Unless the resource planner includes someone's preference function (possibly his own) in the analysis.

approach is necessarily different if the non-money valued good is a factor, as compared to the approach taken if the good is a product of water resource development. As a result, there are at least two trade-off ratios of concern to the water resource planner.

The product-product trade-off ratio should be calculated among incommensurables when the non-money valued good is, indeed, a product. This form of the trade-off ratio has as its theoretical base the iso-cost surface (or curve) in product space. The trade-off ratio, in this case, is the slope of the iso-cost surface. In terms of water resource development involving alternative dam-reservoir configurations, the iso-cost surface could represent alternative mixes of water for recreation (W_R), water for irrigation (W_I), and water for hydroelectric power generation (W_p) from some given cost-investment level. A product-product trade-off ratio would be defined for every pair of these water products (Figure 1). Various (physical) quantities of products W_R, W_I, and W_p are represented on the three axes of the figure. Points A, B, and C define the corners of the iso-cost surface. All alternative combinations of W_R, W_I, and W_p in Figure 1 can be obtained from a given (minimum) cost level. Point D, for example, represents one such combination. The product-product trade-offs among the three products are given from the slopes of the surface at Point D. If Point D is selected by some decision body, Quantities O_a, O_b, and O_c of W_R, W_p, and W_I, respectively, would be produced (Figure 1).

The product-product trade-off ratio can also be defined symbolically. The ratio between W_R and W_I, for example, is given by:

$$\frac{\Delta W_R}{\Delta W_I} = \frac{\text{change in level of water product } W_R}{\text{change in level of water product } W_I} .$$

In the limit, the product-product trade-off ratio is represented by the derivative (dW_R/dW_I). It must be understood that costs are held constant in the calculation of this ratio, and that W_p is at some known level. The economic optimum, then, is:

$$\frac{\Delta W_R}{\Delta W_I} \doteq - \frac{P_{WI}}{P_{WR}} ,$$

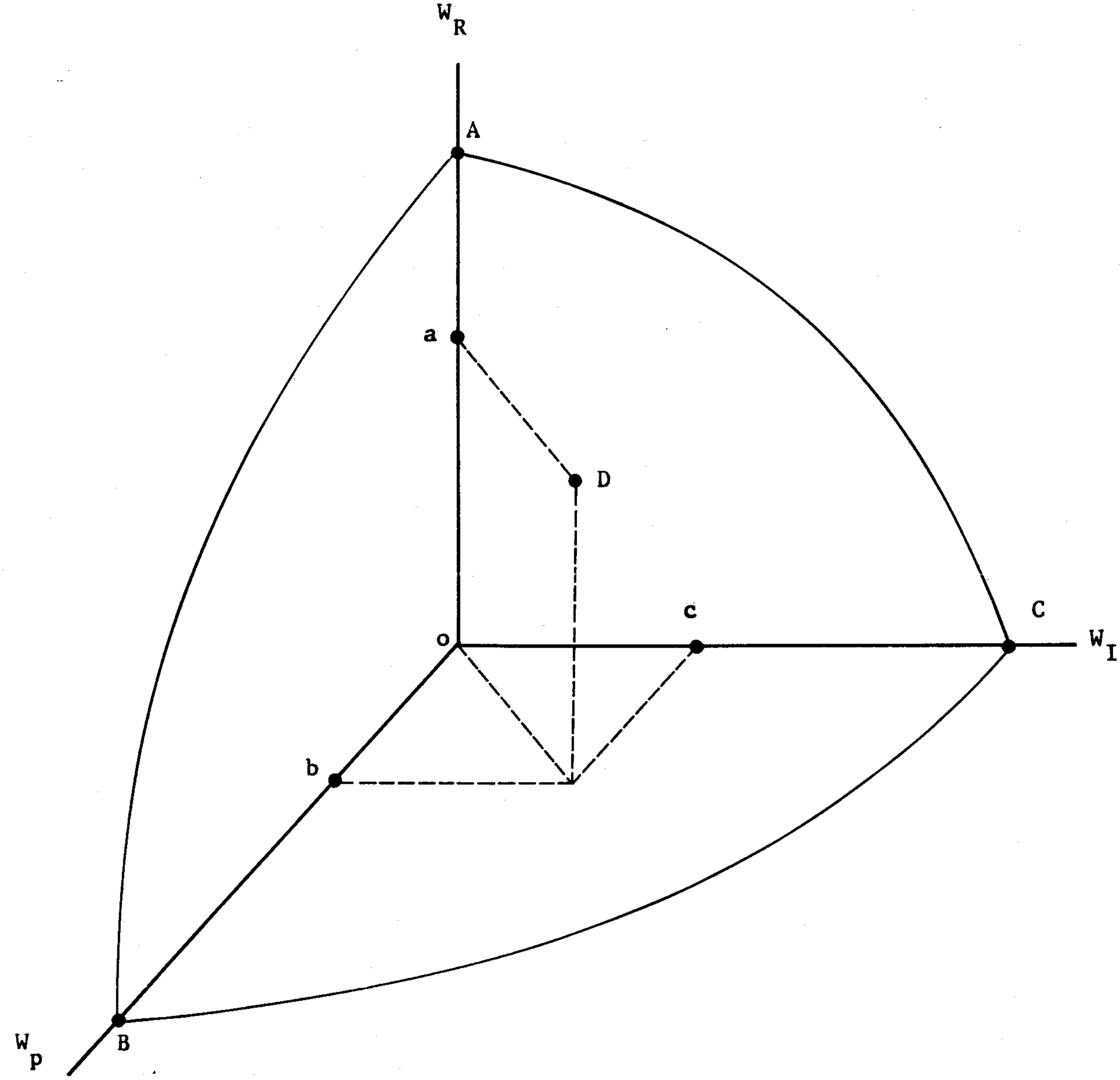

Figure 1. Hypothetical iso-cost surface for three water products: water for power (W_p), water for recreation (W_R), and water for irrigation (W_I).

which implies that:

$$P_{WR} \doteq -(\frac{\Delta W_R}{\Delta W_I})(P_{WI});$$

i.e., the approximate price of W_R is given by multiplying P_{WI} times the change in W_R for a given change in W_I along an iso-cost surface. Also, it is assumed that P_{WI} is known and the decision body has selected the proper trade-off ratio.

The definition of a trade-off differs in two important respects from the approach recommended in the federal planning document [16] and by Major [8, 9]. First of all, costs are held constant between the alternative product combinations. This is very important. If costs are allowed to vary, trade-offs will be biased. A trade-off calculated over varying cost levels is equivalent to looking at trade-offs among different iso-cost surfaces. The implication of calculating trade-offs in that manner is that relative values of non-money valued goods are already known (or have been assigned by the planner) before trade-offs are calculated. The other difference between this approach and other recommendations relates to the notion of calculating net benefit functions. Net dollar benefits can be used to establish relative values if, and only if, costs are constant and all money-valued products are kept in optimum combinations. Also, trade-offs cannot be calculated between different levels of production (see [3] on this point).

Another type of trade-off encountered in water resources planning is the factor-product trade-off ratio. In situations where the non-money good is an input into the production of water resource products, this ratio should be used. A wilderness area, for example, is really an input into the production of water for irrigation and water for recreation (assuming the dam-reservoir would inundate the wilderness area). The wilderness is, for this hypothetical case, on a different level of production than the water-related products. Use of the product-product trade-off ratio approach would lead to errors in allocation. The value of the wilderness area is now determined by the demand pressures placed on the area from wildlife enthusiasts, campers, and ecologists (product demand) as well as the demand derived from the production of water outputs (factor demand). It must be understood that many components of a proposed water development really serve as factors or inputs into the production of water-related products. Wild and scenic rivers, wilderness areas, and ecologically unique areas, for example, usually serve as inputs. Also, in most cases, these components do not have known prices. The water resource planner, then, is faced with calculating factor-product trade-off ratios for these entities. In essence, the resource planner must discover the derived demand curve for several factors of production.

Symbolically, the factor-product trade-off ratio between W_I and a wilderness area (W_A) may be defined by:

$$\frac{\Delta W_I}{\Delta W_A} = \frac{\text{change in water product } W_I}{\text{change in water resource factor } W_A} .$$

In the limit, this ratio is represented by the derivative (dW_I/dW_A). The economic optimum,

$$\frac{\Delta W_I}{\Delta W_A} \doteq \frac{P_{WA}}{P_{WI}} ,$$

which implies that:

$$P_{WA} \doteq (P_{WI}) \left(\frac{\Delta W_I}{\Delta W_A}\right),$$

i.e., the approximate price of W_A is given from multiplying the known P_{WI} by the factor-product trade-off ratio. Again, of course, it must be assumed the decision body has selected the correct trade-off ratio (which reflects society's preferences) from the alternative $\Delta W_I/\Delta W_A$ ratios provided by the resource planner.

It may be useful, at this juncture, to reason somewhat intuitively about factor-product trade-off ratios. Although it is true that wilderness has product value in itself, it also may become an input into some water-related service if a reservoir is constructed, utilizing the wilderness area. The resulting trade-off ratio indicates the sacrifice in the factor, expressed in some quantitative way, that is associated with an increase in output of the water-related service resulting from the construction of the reservoir. The objective, of course, is the same as for the product-product case; it should serve as an aid to subjective decision-making.

The factor-product trade-off ratio also differs in at least two significant ways from the approach recommended in the federal document [16] and by Major [8, 9]. Net dollar benefits from the money-valued goods can be used to indicate the relative valuation of the factors only if all the money-valued goods are kept in optimum (economic) combinations. Also, it must be the case that the derived demand curve for the factor is negatively sloped. Based on the empirical results presented in the next section, this latter requirement may not be met in many cases encountered in water resources planning.4/

CALCULATION OF TRADE-OFF RATIOS IN THE KNIFE RIVER BASIN

The actual data used to illustrate the application of the approach recommended here were derived from an earlier study by the senior author and others [13, 14]. Several plans for developing the Knife River Basin in western North Dakota were provided in that study. An optimum plan for development was selected, based on a criteria of maximum net dollar benefits; i.e., all factors and products of concern had (or were assigned) prices. A slightly different approach is taken here, under the assumption of some missing prices.5/ Using the approach to planning advocated here, the North Dakota State Water Commission would be viewed as a "firm" in the sense that factors could be combined in varying proportions by the agency to produce (or at least plan for production) alternative product mixes. The Commission would be considered as having a production function, or at least of having the capability of defining the production relations, in the relevant planning unit. Rough estimates of various prices would not be needed, as trade-off ratios would be calculated and submitted to a decision body for choice. In essence, then, the planning agency would provide the alternatives, and <u>not</u> the optimum plan based on agency estimates of market values.

A very important step in the planning process, involving the calculation of trade-offs, is delineation of the independent planning units. This is very

4/ For a more technical and thorough description and discussion of the conceptual base for trade-off calculations, see [6].

5/ By definition, there were no "missing" prices in the earlier study. In reality, it was recognized that some of the prices were nothing more than estimates of market value based on "best guesses".

important, because any plan for development that is recommended within a non-independent planning unit may be sub-optimal when the viewpoint is from some larger planning unit (the independent unit). As a result, if a non-independent unit is selected, the resource allocation and product mix decisions must be viewed with caution. This is true of such decisions made regarding development in the Knife River Basin. This basin is not independent of other river basins in the state. As a result, an iso-cost surface representative of the product conditions (and the trade-off ratios) in the basin is just one of the non-independent surfaces needed by the decision body. The same argument can be made for subsections of the basin. The alternative forms of possible development in the basin were large in number because there were 18 alternative dam locations, and because the multiple purposes of irrigation, power production, recreation, and municipal use were possible at nearly every site (Figure 2). To simplify the discussion, only the Bronco damsite is considered as one of the non-independent planning units in the basin.

Products, Factors, and Prices at the Bronco Site

Several water-related products could be produced at the Bronco dam-reservoir site. The area, primarily agricultural, is contiguous with large areas of coal-bearing lands. Water can be used to produce a wide variety of agricultural crops as well as to produce electricity from coal (as cooling water and for steam generation). Control of flood waters also would yield some benefits. The potential for recreation development exists because of the close proximity of the basin to an urban area. Recreation would be mainly water-based - water skiing, boating, and aesthetic viewing. All these products were considered in the earlier study [14]. Water for recreation (W_R) and water for irrigation (W_I) were chosen for purposes of illustration in this report.

The prices of these two water products were not available from actual demand information. A value of W_I was estimated by finding the residual return to an acre-foot of irrigation water. The residual value was estimated at approximately $30 per acre-foot.[6/] This estimated value was then used as a proxy for price;

6/ This represents an estimate of the maximum amount the farmer-irrigator could pay and still make a "normal" return to management and labor and meet all other production expenses. See [6, pp. 355-359] for the exact procedures followed in the calculation process.

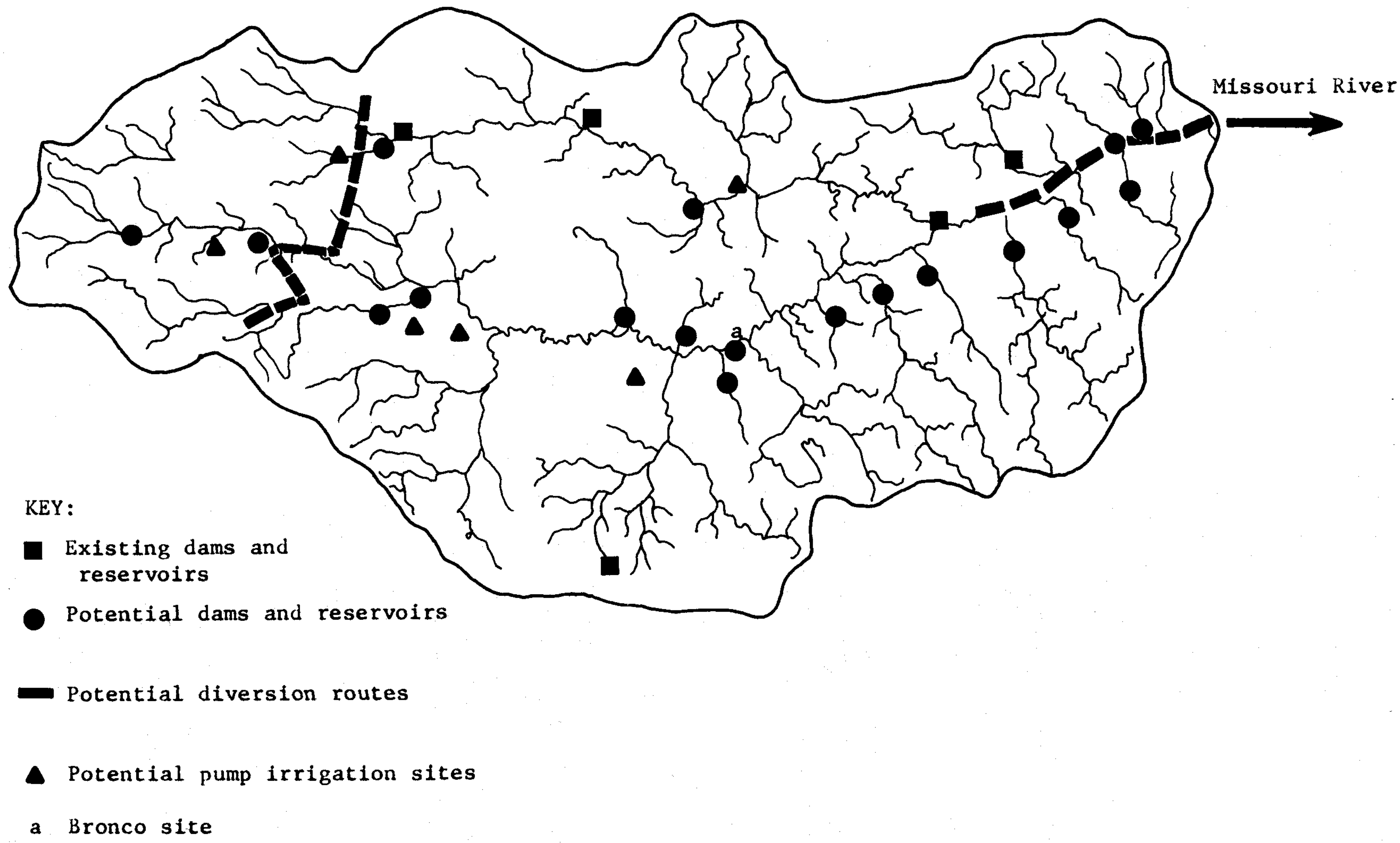

Figure 2. Present and proposed water resource development in the Knife River Basin, North Dakota.

i.e., the price of W_I was set at $P_{WI} = \$30$. The price of W_R was unavailable. As a result, the product-product trade-offs between W_I and W_R need to be discovered to establish relative values.[7/]

Two sets of economic factors of production exist at the Bronco site, although they exist at different levels in the production processes of the basin. The first set are those factors of production necessary in the planning, construction, operation, and maintenance of the necessary structures. These factors were assumed to be combined in a least-cost manner. The dollar value of all these factors is referred to as "cost" in this study. The other set of factors in the analysis were the wilderness areas, scenic views, and wild rivers of the basin. The elements are usually inputs into the production of water products. The specific water resource input considered at the Bronco site was defined as "acres above the proposed damsite". There was no known price for an acre of wilderness area. As a result, the factor-product trade-off concept was used to describe the production trade-offs for that situation.

The natural water flow at the Bronco site must also be considered a factor in the production of W_I and W_R. The capital, operation, and maintenance costs are applied at the Bronco site to transform the natural resource - water - into water products. The amount of water flow at the Bronco site must be known. This flow was estimated in the earlier study [13, pp. 27-58 and 14, pp. 80-82]. The total available (annual) flows were estimated at about 30,000 acre-feet. The largest proportion of the flow becomes available in late spring to early summer. No attempt was made in this study to deal with the dynamics of water availability. The iso-cost surfaces presented here reflect the range of alternatives (and the range in trade-offs) that could be provided, given availability of water. The product-product trade-off case is examined first.

Product-Product Trade-offs

The investment requirements, operation costs, repair costs, and maintenance costs for alternative sizes of structures at the Bronco site are summarized in

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7/ The value of W_R was established with the alternative cost approach in the earlier study [14, p. 104].

Table 1. An initial investment of \$3,329,726, and annual operation, maintenance, and repair costs (OMR) of \$16,649, can be applied, for example, to provide 61,000 acre-feet of reservoir capacity and 3,260 surface acres (Table 1). These physical measures of production can, in turn, be used for W_I and W_R production. A more useful measure of the cost requirement, annual cost, is also given in Table 1. The annual (minimum) costs are composed of the annual amortization payment (principal plus interest at 5 1/8 percent) for each of 50 years, plus the annual OMR costs. At the 60-foot dam height, for example, total annual costs were determined to be \$202,575 (Table 1). The other estimates of capacity, surface area, and annual cost, for dams varying from 30 to 110 feet, are interpreted similarly.[8/]

The basic cost-physical relations data of Table 1 provided the necessary data base for the development and use of the iso-cost framework. The important relations, in general form, are given by:

$$V = f(C) \tag{1}$$

$$A = g(V) \tag{2}$$

where

C = total annual (minimum) cost, in dollars,

V = total reservoir capacity (volume) at spillway level, measured in acre-feet, and

A = surface area of reservoir when full to capacity, measured in acres.

The discrete forms of Equations (1) and (2) are given in Table 1 and illustrated in Figures 3 and 4 respectively. These discrete forms can be used directly in the iso-cost framework. It is useful, however, to convert the data points into smooth, continuous functions. The entire range of alternatives can then be considered. This was accomplished by using ordinary least squares regression (OLS)

8/ The 30-foot minimum size was chosen somewhat arbitrarily. The engineers involved in the planning of development in the Knife River Basin were asked to provide the data of Table 1 for 10-foot increments in dam height, up to the maximum possible size at each proposed site in the basin. The 30-foot minimum, selected at nearly every site, limited the number of sites that had to be considered in the basin, and the amount of basic cost data needed at every site chosen for evaluation. To consider all alternatives, even smaller dams may have to be considered in some cases.

Table 1. Total Investment Requirements, Annual Costs, Reservoir Capacity, and Reservoir Surface Area, Bronco Damsite, Knife River Basin, North Dakota

Dam height	Total investment requirement	Annual amortization[a/]	Annual OMR	Total annual costs[b/]	Reservoir capacity[c/]	Reservoir surface area[d/]
(feet)	dollars				(acre-feet)	(acres)
30	1,042,994	58,239	5,215	63,454	7,000	700
40	1,523,326	85,060	7,617	92,677	16,000	1,350
50	2,341,294	130,833	11,706	142,439	33,500	2,250
60	3,329,726	185,926	16,649	202,575	61,000	3,260
70	4,402,063	245,803	22,010	267,813	100,000	4,450
80	5,543,504	309,539	27,718	337,257	151,000	5,860
90	7,228,102	403,604	36,141	439,745	215,000	7,130
100	8,874,718	495,547	44,374	539,921	297,000	9,140
110	10,750,898	600,308	53,754	654,062	400,000	11,650

a/ Based on an interest rate of 5 1/8 percent and a 50-year repayment period.

b/ Sum of annual amortization and annual OMR.

c/ Capacity measured at spillway level.

d/ Surface area of reservoir behind dam when reservoir full to spillway level.

Basic data used in table [14, pp. 87-89].

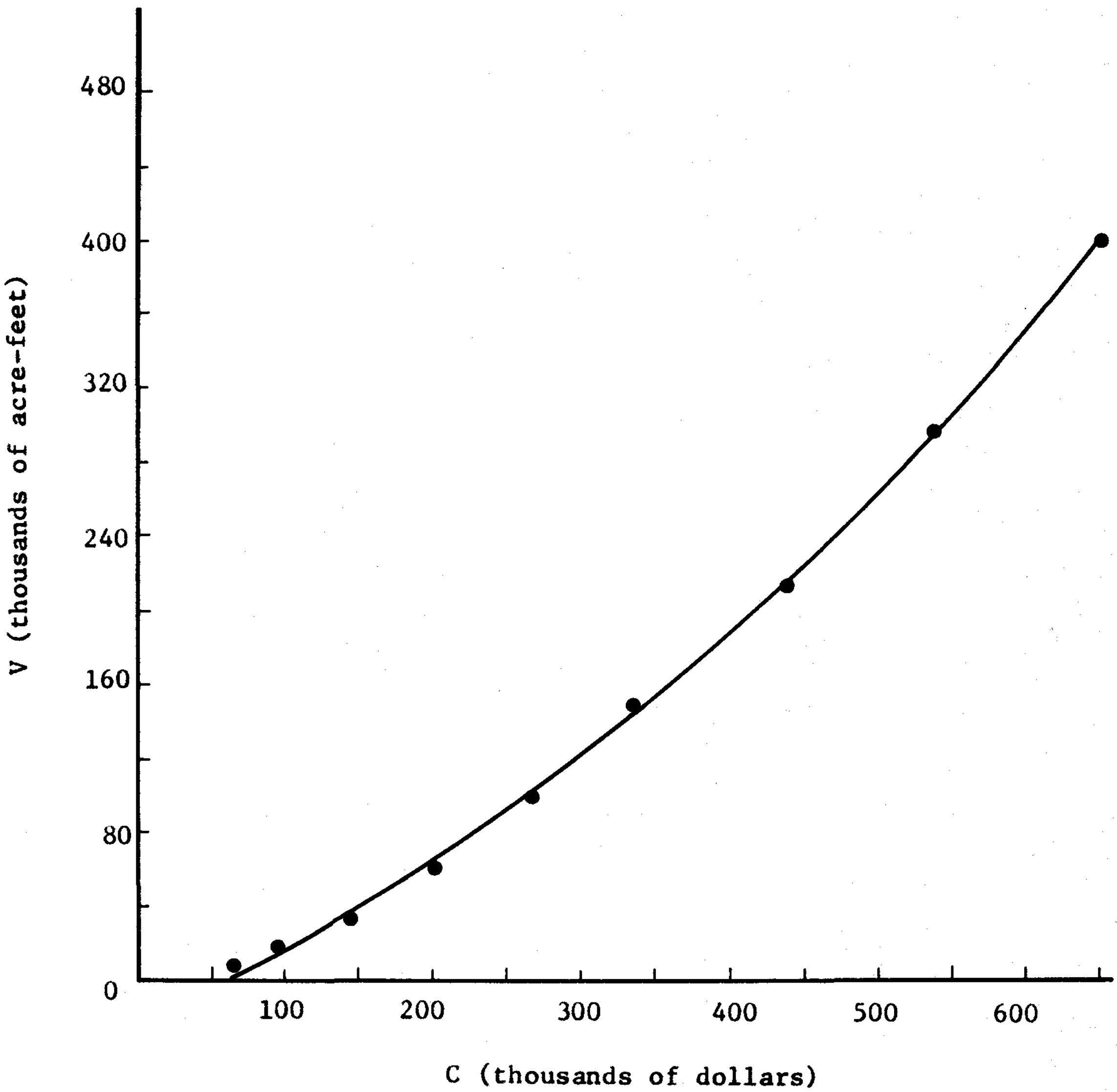

Figure 3. Reservoir capacity (V) as a function of annual cost (C, amortization, and OMR), Bronco site, Knife River Basin, North Dakota.

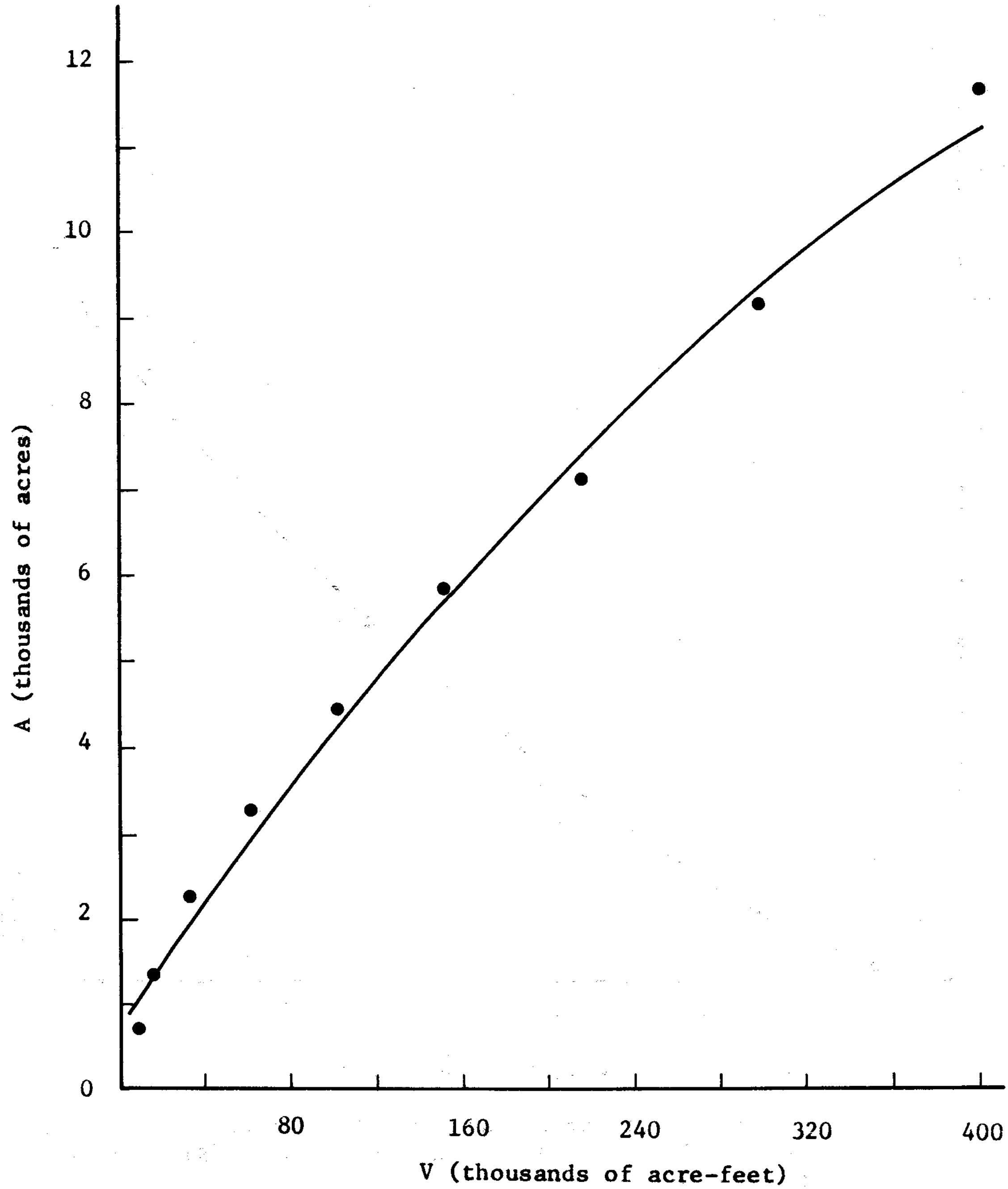

Figure 4. Surface area (A) as a function of water in the reservoir (V), Bronco site, Knife River Basin, North Dakota.

to fit quadratic functions to data of the nature presented in Table 1.[9/] The continuous relations were given by:

$$V = -17893.00 + 0.31070(C) + 0.00000050357(C)^2 \qquad (3)$$
$$\quad (-4.328) \qquad (10.633) \qquad (12.330)$$

$$R^2 = .99939 \qquad \text{d.f.} = 7$$

$$A = 749.33 + 0.03653(V) - 0.000000025712(V)^2$$
$$\quad (6.520) \qquad (20.910) \qquad (-5.295)$$

$$R^2 = .99267 \qquad \text{d.f.} = 24$$

The continuous functions represented in (3) and (4) are also represented in Figures 3 and 4, respectively. Slightly greater accuracy could have been obtained by using two functions in the case of surface area vs. capacity (Figure 4). Two functions could easily be utilized if desired by the planner. The calculated t-statistics are presented in parentheses below each coefficient. All estimated coefficients were significant at acceptable levels for the given degrees of freedom (d.f.).

The iso-cost surface can now be derived. The problem can be defined in the following manner. Information is available on:

1. the annual cost versus capacity relation,
2. the capacity vs. surface area relation,
3. the water products for which there is a demand,
4. the price of one of those products, and
5. the availability of water in the basin at the site of concern.

The resource planner must organize this information in such a way as to make it possible for the decision-making body to select the optimum size of the structure and the optimum product mix. The necessary information can be represented in the iso-cost surface.

9/ The constant term was used to account for the fact that no data were provided for a dam less than 30 feet in size. Also, Equation (3) was derived from the OLS fit to data in Table 1, while Equation (4) was derived from the OLS fit to the data of Table 1 plus 17 other observations on the relation between A and V.

The iso-cost curve for W_I and W_R at the Bronco site was derived from the physical relations in (3) and (4), and several assumptions, to give:

$$W_R = 749.33 + 0.03653\ (V-W_I) - 0.000000025712\ (V-W_I)^2 \qquad (5)$$

The most significant assumption, reflected by $(V-W_I)$ in (5), is that any water allocated for irrigation use could not be used for recreation. This assumption may have to be modified in every particular situation. It is a most reasonable assumption in the Knife River Basin, however, for any water used for irrigation cannot be used for recreation (as surface area) since recreation and irrigation demands occur during the same season. Water was allocated to irrigation (by drawing the reservoir down) or to recreation (by not drawing the reservoir down). This assumption does not, however, affect the validity of the iso-cost framework. The iso-cost surface is essentially an *ex post* description of product mixes anyway; i.e., the operating rule chosen affects the product combination. A different assumption regarding the relation between W_I and W_R will merely give a different iso-cost surface. It was also assumed that 10 percent of the capacity, for all capacity levels, would constitute "dead" storage, and 30 percent of total capacity must be left for low stream flow years. As a result, only 60 percent of the total capacity was assumed available for irrigation in any irrigation season.

The various possible product mixes were then generated from (5) by using Equation (3) to find various values of V. The alternative levels of V were then allocated, arbitrarily, between W_I and W_R on an annual basis. The iso-cost relations derived by this process are presented in Figure 5.[10/] These relations represent different (constant and minimum) annual costs, in increments of $75,000, from $200,000 to $650,000. Movement along any one of the curves represents changes in W_I for changes in W_R. Movement from Point A to Point B along the $575,000 iso-cost relation, for example, represents a decrease in W_I of approximately 79,000 acre-feet of water allocated to irrigation, and an increase of 2,200 acres of surface area available for recreation. This is the product-product trade-off ratio. It shows the sacrifice in a market-valued use (irrigation water) for an increase in the output of a non-market valued use (recreation). If, for example, Point B is chosen rather than Point A, 79,000 acre-feet of irrigation water are

10/ Data used to develop this figure are presented in the Appendix.

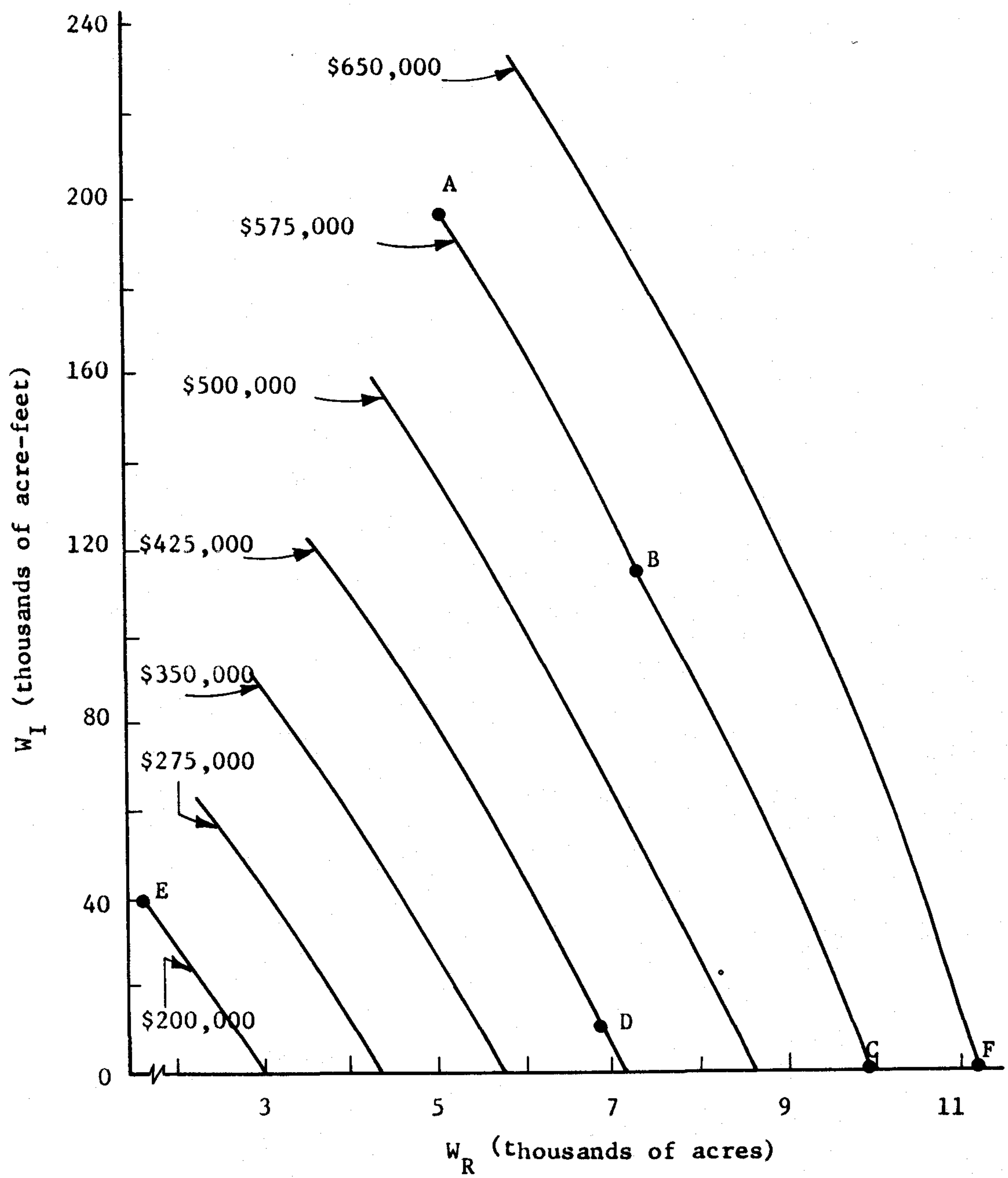

Figure 5. Iso-cost curves (annual cost: amortization and OMR), water for irrigation (W_I) vs. water for recreation (W_R), Bronco damsite, Knife River Basin, North Dakota.

sacrificed for 2,200 acres of surface area for recreational purposes. If the price of irrigation water is $30 per acre-foot, this would amount to a sacrifice of $2,370,000. This would imply that a recreational acre of surface water had an annual return value in excess of approximately $1,077. In symbolic terms:

$$\frac{\Delta W_I}{\Delta W_R} \doteq -\frac{P_{WR}}{P_{WI}} \doteq -\frac{P_{WR}}{\$30}, \text{ or}$$

$$(-\$30)(-\frac{79{,}000}{2{,}200}) \doteq P_{WR}, \text{ or}$$

$$P_{WR} \doteq \$1{,}077.$$

While the main purpose of the analysis is not to calculate the implicit price of recreation, to do so may help those responsible for making a decision. It will assist them in judging whether the social return is likely to be greater than this "price" which will have to be paid by a sacrifice elsewhere in the economy - in this case, in irrigation water.

The production trade-offs for much smaller increments in W_R are provided in the Appendix. The approximate trade-offs are shown for 100-acre increases in surface area, while the exact trade-offs are calculated at a point from the derivative of the $W_I = f(W_R, TC)$ function derived in the analysis.[11/] The point estimates of the trade-offs are, of course, the most accurate. The point estimate at Point B (Appendix Table 6, Figure 4), for example, is given to be:

$$-(P_{WI}) \left(\frac{dW_I}{dW_R}\right) = P_{WR}$$

$$= (-\$30)(-38.88) = \$1{,}166.40.$$

The interval estimate, using the 100-acre increase, is:

$$(-\$30)(-38.79) = \$1{,}163.70.$$

The latter estimate of $1,163.70 per acre of surface area is the average price over the curve up to Point B from a point to the left of B by 100 acres. The two estimates are very close, as the change in the slope of the curve is slight. The difference between point and interval estimates would be greater for relations having more curvature.

11/ The quadratic formula was used in Equation (5) to form the function $W_I + f(W_R, V)$.

The trade-off ratios become greater as W_I is reduced for increases in W_R. Using the point estimates of the trade-offs, the ratio changes from -33.56 at Point A to about -50.50 at Point C (Appendix Table 6, Figure 5). If the decision-making entity selected Point A, the implicit price of W_R is approximately (-\$30)(-33.56) = \$1,006.80, as compared to (-\$30)(-50.50) = \$1,515.00 at Point C. The same type of relations exist along all the iso-cost relations illustrated in Figure 5. For comparison purposes among the curves, the lowest trade-off is represented by -28.41 at Point E on the \$200,000 curve, and the highest trade-off is represented by -61.00 at Point F on the \$650,000 iso-cost curve. In all cases, the trade-offs increase (become more negative) for the movements "down" the curve of concern.

The relations in Figure 5 are the type of information needed by the decision-making group for one damsite and two products, when the prices of one of the products are missing.[12/] Other types of recommendations have been made elsewhere. Some of the various types of misleading trade-off ratios can now be isolated.

The calculation of trade-offs using net benefit (NB) changes between iso-cost curves can lead to very misleading estimates. Assume, for example, the decision-making entity is presented with only Points A and D in Figure 5. Point A can be achieved with an annual cost of \$575,000, while Point D can be obtained with \$150,000 <u>less</u> annual cost, or only \$425,000. The trade-off would, intuitively, appear to be (data from Appendix Tables 4 and 6):

Point	W_I	W_R	NB
A	196,351	5,090	\$5,315,542
D	10,919	6,873	-97,430
	-185,432	+1,783	-\$5,412,972

which gives the trade-off at:

$$\frac{\Delta W_I}{\Delta W_R} = - \frac{18,432}{1,783} = -104.00$$

12/ In addition, of course, the planning agency must provide information regarding water availability at the damsite. It may be impossible to reach any point on some of the curves because of available flows.

or,

$$\frac{\Delta(NB)}{\Delta W_R} = -\frac{\$5,412,972}{1,783} = -\$3,036.00.$$

A total of 104 acre-feet of water, evaluated at \$30 (gross) or \$3,120 per acre, would be "sacrificed" to obtain one more acre of surface area (on the average, from Point A to D). Stated in net benefit terms, \$3,036 would be given up to obtain one more acre of surface area (on the average) for recreation (as the reduction in cost is \$84 per acre-foot). This is not the correct estimate of the value of W_R. Using the correct approach, the value of W_R at each of the points is given by:

Point	dW_I/dW_R	$(-P_{WI})(dW_I/dW_R) = P_{WR}$
A	-33.56	\$1,006.80
D	-37.68	\$1,130.40

The distortion is nearly three-fold, using the "net-benefits-between-curves" approach. Prices or value must be estimated at points on particular curves. It is impossible to choose between Points A and D without knowledge of the iso-cost curves for the \$425,000 and \$575,000 levels. Neither physical nor net dollar benefit measures of trade-offs between curves can be used without some knowledge of the shape of the curves through those points.

This finding is extremely crucial in application of the new water resource planning procedures [16]. It has been recommended that at least one plan emphasizing national economic development and one with emphasis on environmental quality are to be developed. Also, ". . . other alternative plans reflecting significant trade-offs between the national economic development and environmental quality objectives may be formulated so as not to overlook a best overall plan" [16, p. 24830]. Relative values of non-money valued goods can be estimated by calculating what is given up or traded off among plans [16, p. 24830]. The problem with this approach is now apparent. In most instances, the cost of each of these plans, then, will lead to misleading estimates of relative values. The approach recommended in the new planning document would work only if all goods have known prices. In that case, of course, trade-offs are not needed to estimate relative values.

Factor-Product Trade-offs

The lack of a known price for a factor used in the production of such water products as W_I and W_R necessitates the determination of factor-product trade-offs. Assume, for illustrative purposes, the proposed dam and reservoir at the Bronco site would inundate a wilderness area.[13/] To simplify the case further, consider the production of only W_I. The wilderness area (W_A), in combination with investment capital and operating costs, is now an input into the production of W_I. The basic relations in (3) and (4) can also be used to solve this problem.

The surface area of the reservoir was used as a measure of the number of acres of wilderness area used to produce water products. This reflects the assumption that a wilderness area is lost to all other uses once it has been covered with water (even for a short period of time). The production relation is, as a result, given (from application of the quadratic formula to Equation (4)) by:

$$W_S = \frac{0.03653 - [(0.03653)^2 - (4)(0.000000025712)(W_A - 749.33)]^{1/2}}{(2)(0.000000025712)} \qquad (6)$$

where

W_S = water in storage (measured in acre-feet),

W_A = wilderness area inundated (measured in acres).

Given a particular cost level, the level of W_A was then changed arbitrarily to give various levels of W_S. The W_S was then allocated to the production of W_I. The resulting relations from (6) are represented in Figure 6 for annual cost levels of \$200,000 - \$650,000 (in \$75,000 increments).

The product-input combinations along the \$200,000 curve are presented in Table 2. The "application" of 1,673 acres of wilderness area (W_A), for example, gave the zero level of W_I (Point A, Figure 6 and Table 2). An increase in the

13/ This was not considered a problem in the previous study [13, 14]. There were groups in the state at the time, however, that did not want to inundate the river valley. Rather, those groups wanted to maintain present use, which was primarily as range land for livestock and "river-side" recreation. Only in this sense is the present example descriptive of the real situation at the Bronco site.

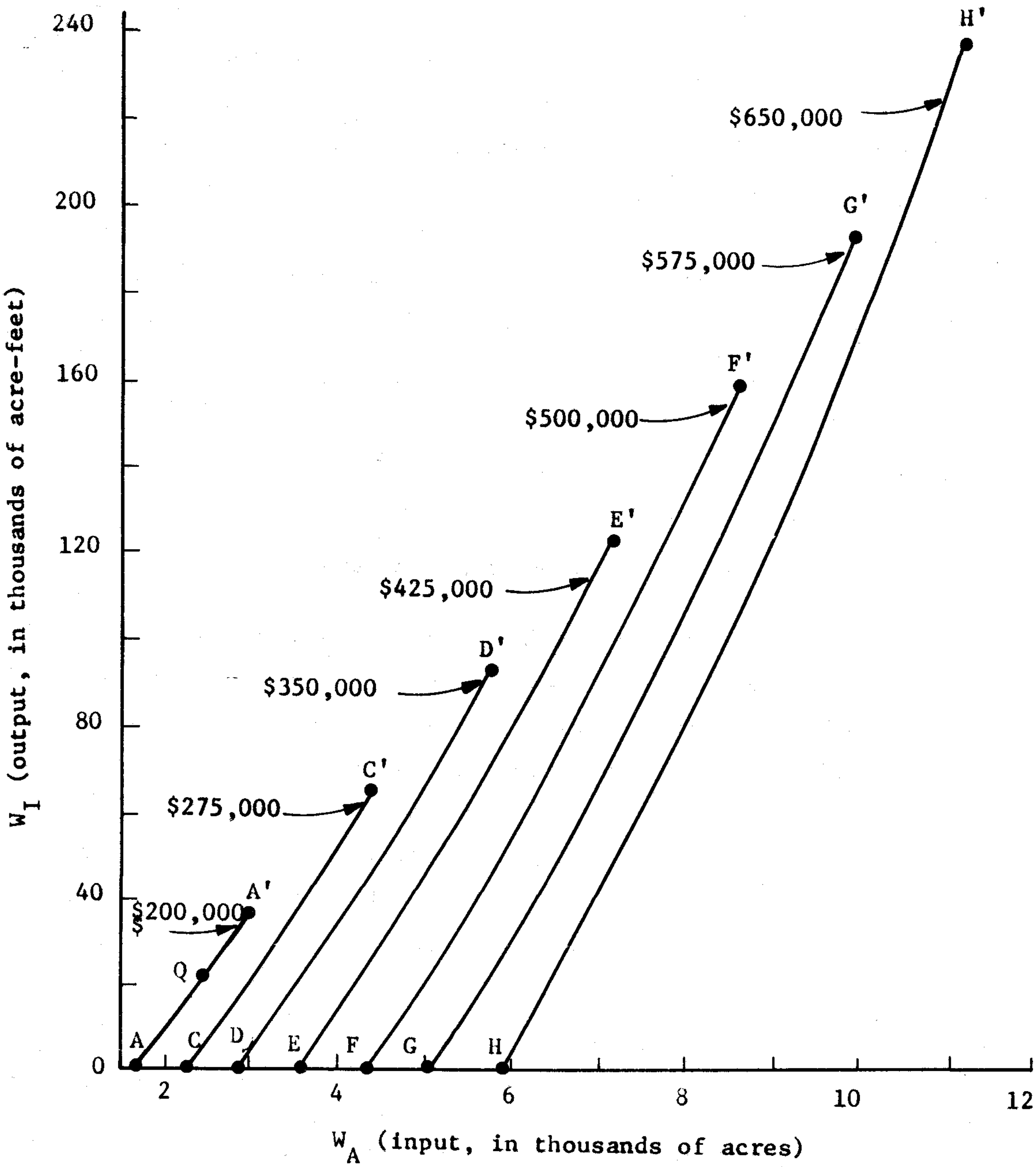

Figure 6. Production function relations, water for irrigation (W_I) as a function of acres of wilderness area inundated (W_A), Bronco site, Knife River Basin, North Dakota.

Table 2. Water for Irrigation as Produced from Various Levels of Wilderness Area Inundated, $200,000 Cost Level, at Bronco Damsite, Knife River Basin, North Dakota

Water for irrigation (W_I)	Wilderness area inundated (W_A)	Remaining wilderness area (W_{AN})	Net benefits (NB)	dW_I/dW_A a/	$d(NB)/dW_A$ b/
(acre-feet)	---------- (acres)	----------	(dollars)		
0	1,673	1,321	-200,000	28.41	
2,846	1,773	1,221	-114,620	28.52	853.96
5,705	1,873	1,121	- 28,850	28.64	857.54
8,576	1,973	1,021	57,280	28.77	861.17
11,458	2,073	921	143,740	28.89	864.84
14,354	2,173	821	230,620	29.01	868.56
17,261	2,273	721	317,830	29.14	872.33
20,182	2,373	621	405,460	29.27	876.15
23,115	2,473	521	493,450	29.40	880.02
26,062	2,573	421	581,860	29.53	883.84
29,021	2,673	321	670,630	29.66	887.91
31,994	2,773	221	759,820	29.80	891.94
34,981	2,873	121	849,430	29.94	896.02
37,982	2,973	21	939,460	30.07	900.16
38,614	2,994	0	958,420	30.10	903.00

a/ Rate of change in W_I for a change in W_A; i.e., the factor-product trade-off ratio.

b/ Rate of change in net benefits (NB) for a change in W_A.

use of W_A to 2,273 acres resulted in about 17,261 acre-feet of water available for W_I at Point Q. If W_A was increased to approximately 3,000 acres, W_I would be about 38,614 acre-feet, as represented at Point A' in Figure 6.

Increases in the annual cost resulted in shifts to the right in the production function relation. This occurs due to the assumption made regarding usable reservoir capacity. As was noted earlier, it was assumed that the reservoir would always be at 40 percent of capacity. As a result, larger structures (as a result of increases in annual cost) result in larger areas of W_A inundated. For the \$200,000 expenditure, for example, 1,673 acres of W_A were covered with water when the reservoir was at 40 percent of capacity. This level of use for W_A is represented at Point A in Figure 6. At Point H, 5,900 acres of W_A are covered when the reservoir level is at 40 percent of capacity. Point H is on the production function for the \$650,000 expenditure level.

The factor-product trade-off ratio was found to increase for increases in W_A at any given expenditure level. Moving from Point A toward Point A' on the \$200,000 production function, for example, results in the changes:[14/]

Point	W_A	ΔW_A	W_I	ΔW_I	$\Delta W_I/\Delta W_A$
A	1,673		0		
Q	2,273	600	17,261	17,261	28.77
A'	2,873	600	34,981	17,720	29.53

The first increase in W_A of 600 acres resulted in an increase in W_I of 17,261 acre-feet for a factor-product trade-off ratio of 28.77. The second increase in W_A of 600 acres gave a trade-off ratio of 29.53. The same type of relations prevail throughout the entire family of curves in Figure 6, with the factor-product trade-off ratio varying from 28.41 at Point A to 63.30 at Point H'.

The point estimates of the factor-product trade-off ratios, for all cost levels, are illustrated in Figure 7. Curve AM is a continuous curve, generated over the entire range of expenditures from \$200,000 to \$650,000. Only segments

14/ Point A' is actually W_A = 2,995. The 2,873 level was chosen to keep ΔW_A constant for illustrative purposes.

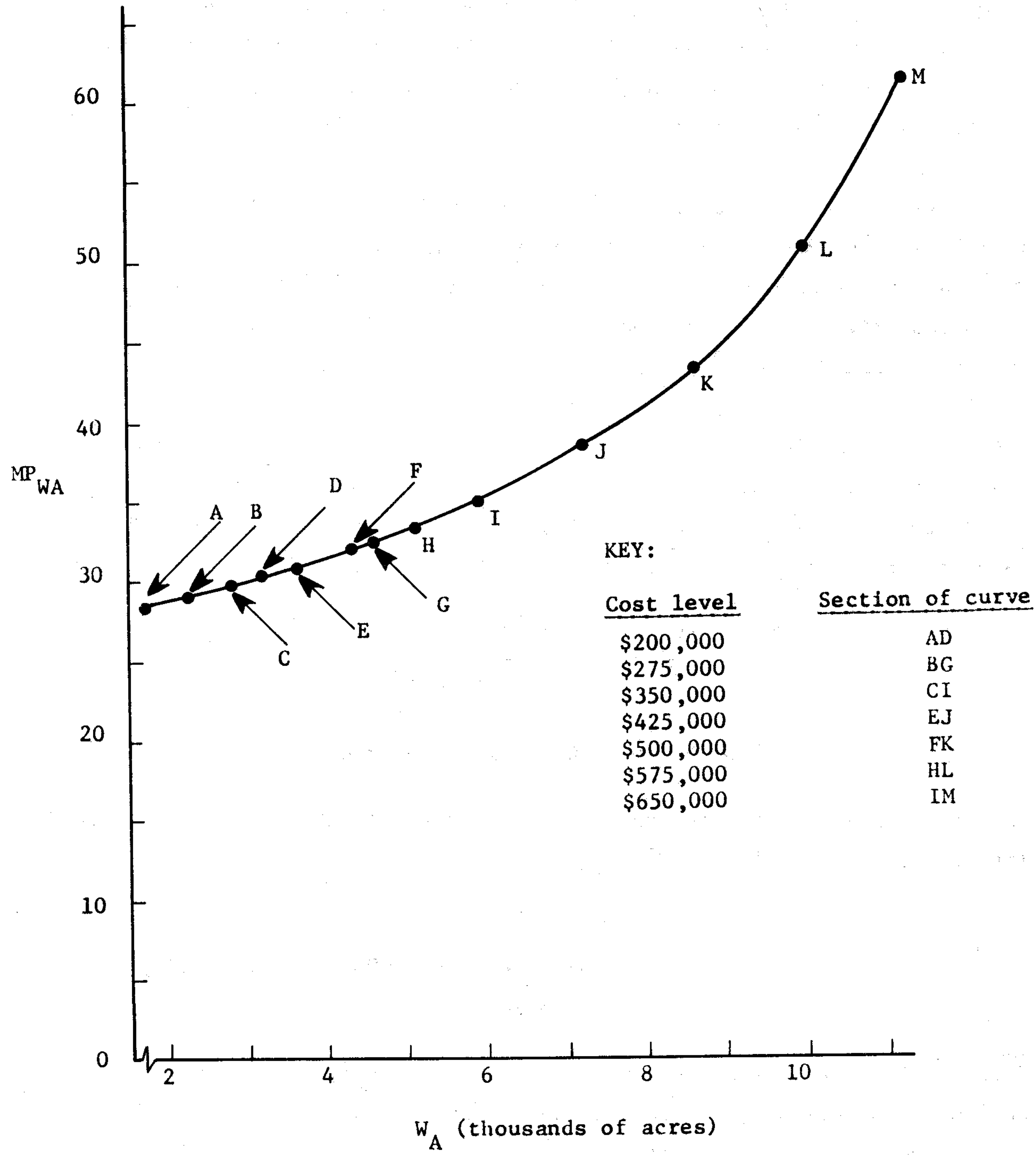

Figure 7. Marginal productivity (MP_{WA}) of wilderness area (W_A) as used in production of water for irrigation, Bronco damsite, Knife River Basin, North Dakota.

of the curve, however, represent particular expenditure levels. The trade-off ratios for the \$200,000 expenditure level (from Table 2), for example, are represented on Segment AD. Similarly, the trade-off ratios for the \$650,000 expenditure level are represented by the IM segment. The various segments were also found to be overlapping, which indicates the areas on the respective production functions having equal slopes. The relation AM in Figure 7 also reflects the increasing returns situation.

Given increasing factor-product trade-off ratios, a different interpretation must be made of a decision to produce at a particular point. The price of W_A, P_{WA}, is not revealed directly from the choice of a point on the total product schedules (Figure 6) or of a particular trade-off ratio (Figure 7). This point can be clarified with reference to Curve CEB in Figure 8. Curve CEB represents the factor-product trade-off ratios for the \$200,000 cost level, and is identical with Section AD of Curve AM in Figure 7, except for scale of the illustration. Assume the decision body selects Point A' on the \$200,000 production function. The trade-off at that point is 30.10, as represented at Point B in Figure 8. Using the concept of a factor-product trade-off ratio, it would appear that:

$$\frac{dW_I}{dW_A} = 30.10 = \frac{P_{WA}}{P_{WI}} = \frac{P_{WA}}{\$30}$$

or

$$P_{WA} = (\$30)(30.10) = \$903.00.$$

The price of W_A is not, however, \$903 per acre. If the price of W_A were \$903, the net benefits would be:

$$\begin{aligned} NB &= P_{WI}W_I - P_{WA}W_A - C \\ &= (\$30)(38{,}614) - (\$903)(2{,}994) - \$200{,}000 \\ &= -\$1{,}945{,}162. \end{aligned}$$

There would be a loss of nearly \$2,000,000. In fact, using this price of W_A implies the decision body had the goal of maximizing losses. All the prices, taken directly from choice of a particular trade-off ratio on CEB in Figure 8, are the maximum loss prices of W_A. The incorrect price results because the factor-product trade-off curve has a positive slope.

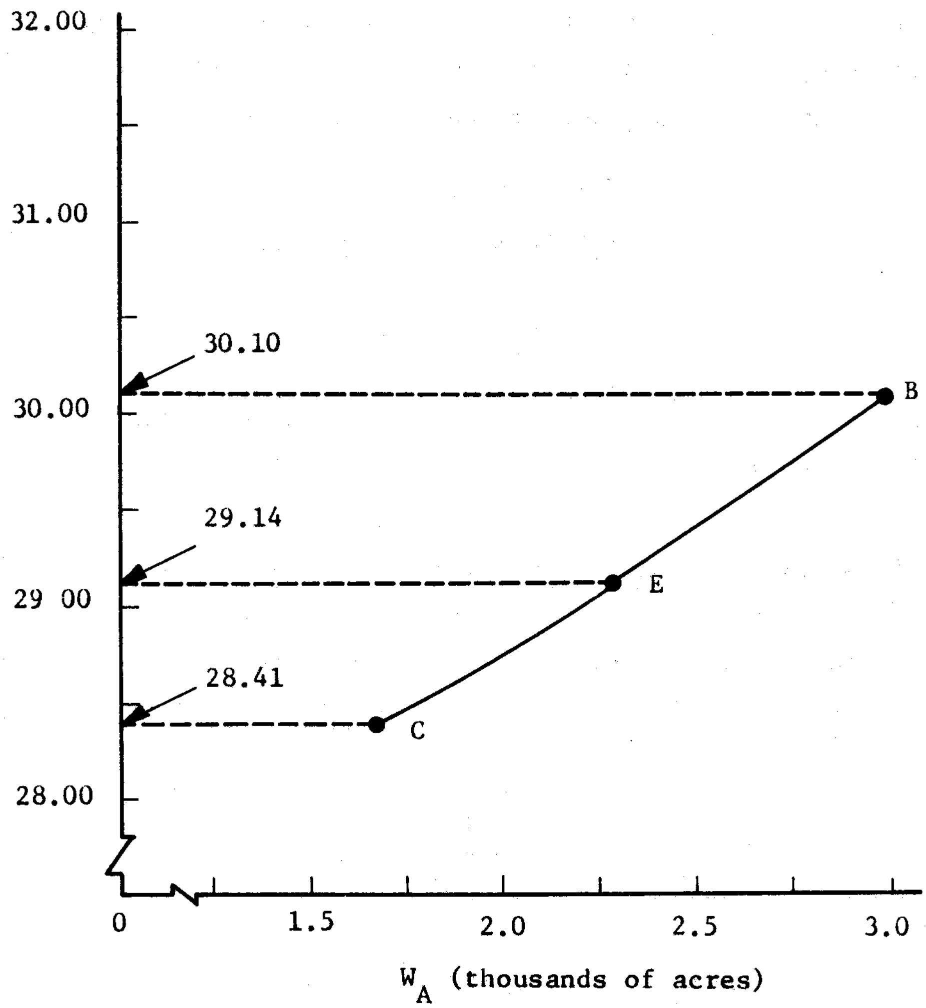

Figure 8. Factor-product trade-off ratios (MP_{WA}), wilderness area (W_A) as a factor in the production of water for irrigation, \$200,000 cost level, Bronco site, Knife River Basin, North Dakota.

Further information regarding the choice process used by the decision body must be available before the implicit price can be made explicit. Assume, for example, the decision body requires that net dollar benefits are non-negative. Given this additional information, choice of Point A' over any other point on AA' in Figure 6 implies that marginal dollar benefits of using W_A to reach A' exceed the marginal dollar costs by a sufficient magnitude to make net dollar benefits at least zero. An approximation of price can be found, then, by finding the price of W_A that makes net benefits equal to zero at Point A' (Point B in Figure 8). This price is given by (data from Table 2):

$$NB = P_{WI}W_I - P_{WA}W_A - C = 0$$
$$= (\$30)(38{,}614) - (P_{WA})(2{,}994) - \$200{,}000$$

or

$$P_{WA} = \frac{\$958{,}420}{2{,}994} = \$320.11.$$

This price of W_A exactly exhausts all the net dollar benefits from W_I production up to W_R = 2,994 acres.

The implicit price of W_A is even lower than \$320.11 per acre when some point between A and A' is selected. Assume, for example, the decision body chooses Point Q in Figure 6. The factor-product trade-off ratio at Point Q is 29.14, as represented at Point E in Figure 8. Using the (incorrect) direct approach, P_{WA} is given by:

$$\frac{dW_I}{dW_A} = 29.14 = \frac{P_{WA}}{P_{WI}} = \frac{P_{WA}}{\$30}$$

which implies that:

$$P_{WA} + (\$30)(29.14) = \$874.20.$$

If the trade-off schedule were downward sloping, this would be the implicit price. Assuming, again, the decision body requires net benefits to be at least zero, the implicit price of W_A is given by:

$$NB = P_{WI}W_I - P_{WA}W_A - C$$
$$= (\$30)(17{,}261) - P_{WA}\ (2{,}273) - \$200{,}000 = 0,$$

or

$$P_{WA} = \$139.83.$$

A total of 2,273 acres of wilderness area were, in essence, "purchased" at \$139.83 per acre to provide 17,261 acre-feet of water. The implicit price is considerably below the level of \$874 per acre estimated with the direct approach.

The importance of the factor-product trade-off concept becomes apparent only after trying to apply the techniques advocated by some authors (see, e.g., [9]) for evaluating elements such as wilderness areas, ecologically unique areas, and other inputs. The most favored technique is to represent net dollar benefits as some function of the non-money valued element. Such a "net effect" curve is represented in Figure 9 for the present case. Movement from C' toward B' in Figure 9 represents <u>increases</u> in the amount of W_A used in W_I production. Points B', E', and C' correspond to Points B, E, and C respectively, in Figure 8. The horizontal axis, then, represents "non-use" of W_A in W_I production. The "non-use" levels of wilderness area (W_{AN}) and the net benefit levels are also shown in Table 2. The trade-off, it is argued by some [9], results as "non-use" is increased from 0 toward Point C' in Figure 9. The slope of B'C' is said to be the trade-off and, as a result, gives an indication of the value of W_A (as soon as the decision-maker chooses a point on C'B'). Assume the decision body (as in the previous example) selects Point E' where W_{AN} = 721. An estimate of the slope at Point E' is given by:

W_{AN}	NB	$\Delta(NB)/\Delta W_{AN}$
621	\$405,460	
		\$874.20
821	\$203,620	

The implicit price of W_A, it is argued, is given by \$874.20 per acre. This value was shown to be incorrect in the previous example. Assuming the decision body wants to insure that net benefits are at least zero, the value of W_A was shown to be, at most, \$139.83 per acre. The reason for this distortion, of course, is the positive slope of the trade-off function.

The net benefit trade-off, then, must also be used with extreme caution in the case of missing factor prices. A factor-product trade-off ratio must be calculated, but it can be used directly only when the ratios are declining as more of the factor (in this case, the wilderness area) is used in producing water products. Net dollar benefit changes can then be used for movements along the factor-product trade-off curve.

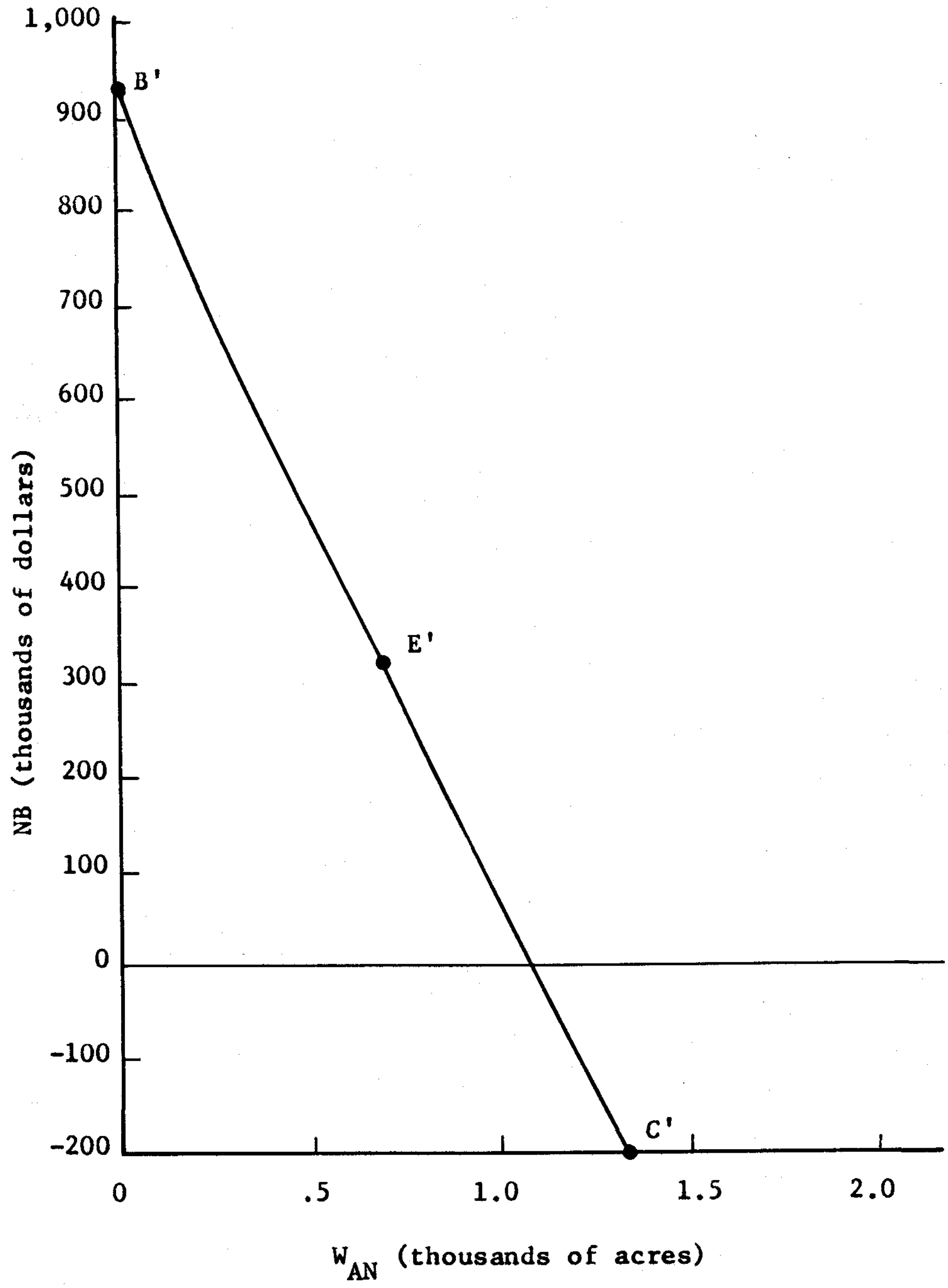

Figure 9. Net benefits (NB) from "non-use" of wilderness area (W_{AN}) in production of water for irrigation, price of water for irrigation at \$30 per acre-foot, \$200,000 expenditure level, Bronco site, Knife River Basin, North Dakota.

This problem of increasing factor-product trade-offs, it is expected, will occur often in water resources planning. The level of use for most other water resource factors such as wilderness areas, ecologically unique areas, and historical sites - in other words, nearly all the components of the environmental quality objective - will usually be correlated with the surface area of a reservoir. In addition, all surface area-capacity relations for dam-reservoir configurations will be of the general nature of the relationship exhibited in Figure 4. As a result, the factor-product trade-off relations will have positive slopes.

CONCLUSIONS

The purpose of this report was to provide a description of the conceptual base necessary to calculate trade-offs and to show how this proposed approach can be used in an actual planning situation. It can be concluded that:

1. There are at least two types of trade-off ratios that should be considered when incommensurables are encountered in water resources planning. A product-product trade-off ratio should be calculated when the non-money valued good is a product, and a factor-product trade-off ratio should be calculated when a water resource factor does not have a known price.

2. Many of the components of the environmental quality objectives are, indeed, inputs in the water product production process. As a result, the concept of a factor-product trade-off ratio must be clearly understood by the resource planner to calculate the proper set of trade-off ratios.

3. Net dollar benefit trade-off ratios will give misleading results unless costs are held constant in comparisons among plans (in the case of a missing product price) and when the factor-product trade-offs are increasing (in the case of a missing factor price). No matter what price is missing, the products and factors must be kept in optimum (economic) combinations. Most prior research work and recommendations regarding trade-off calculations have failed to recognize these important findings.

A cautionary note: Prices and relative values cannot be calculated from the trade-off ratios obtained from any of the methods discussed here. Relative values and prices become known only after a choice has been made by a decision body that can, indeed, reflect society's preferences for the products and/or factors in question.

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APPENDIX

Table A-1. W_S, W_I, and W_R, for Annual Cost of $200,000 and Total Capacity of 64,000 Acre-Feet, Bronco Site

W_S	W_I	W_R	$\Delta W_I/\Delta W_R$	dW_I/dW_R
------ (acre-feet)	------	(surface acres)		
25,756	38,634	1,673		-28.41
28,602	35,787	1,773	-28.46	-28.52
31,461	32,929	1,873	-28.59	-28.64
34,332	30,058	1,973	-28.70	-28.77
37,214	27,176	2,073	-28.83	-28.89
40,110	24,280	2,173	-28.95	-29.01
43,017	21,373	2,273	-29.08	-29.14
45,938	18,452	2,373	-29.20	-29.27
48,871	15,519	2,473	-29.33	-29.40
51,818	12,572	2,573	-29.46	-29.53
54,777	9,612	2,673	-29.60	-29.66
57,750	6,639	2,773	-29.73	-29.80
60,737	3,653	2,873	-29.87	-29.94
63,738	652	2,973	-30.00	-30.07

Table A-2. W_S, W_I, and W_R, for Annual Cost of $275,000 and Total Capacity of 105,632 Acre-Feet, Bronco Site

W_S	W_I	W_R	$\Delta W_I/\Delta W_R$	dW_I/dW_R
------ (acre-feet)	------	(surface acres)		
42,253	63,379	2,247		-29.11
45,170	60,462	2,347	-29.17	-29.24
48,100	57,532	2,447	-29.30	-29.36
51,043	54,589	2,547	-29.43	-29.50
53,999	51,633	2,647	-29.56	-29.63
56,969	48.663	2,747	-29.70	-29.76
59,952	45,680	2,847	-29.83	-29.90
63,949	42,683	2,947	-29.97	-30.04
65,960	39,672	3,047	-30.11	-30.18
68,984	36,648	3,147	-30.25	-30.32
72,024	33,608	3,247	-30.39	-30.46
75,078	30,554	3,347	-30.54	-30.61
78,146	27,468	3,447	-30.68	-30.76
81,230	24,402	3,547	-30.84	-30.91
84,328	21,304	3,647	-30.99	-31.06
87,443	18,189	3,747	-31.14	-31.22
90,572	15,060	3,847	-31.30	-31.38
93,718	11,914	3,947	-31.46	-31.54
96,880	8,752	4,047	-31.62	-31.70
100,058	5,574	4,147	-31.78	-31.86
103,253	2,379	4,247	-31.95	-32.03

Table A-3. W_S, W_I, and W_R, for Annual Cost of $350,000 and Total Capacity of 152,539 Acre-Feet, Bronco Site

W_S	W_I	W_R	$\Delta W_I/\Delta W_R$	dW_I/dW_R
------ (acre-feet) ------		(surface acres)		
61,016	91,524	2,882		-29.95
64,018	88,522	2,982	-30.02	-30.09
67,033	85,506	3,082	-30.16	-30.23
70,063	82,476	3,182	-30.30	-30.37
73,108	79,432	3,282	-30.44	-30.52
76,167	76,372	3,382	-30.59	-30.66
79,241	73,298	3,482	-30.74	-30.81
82,330	70,210	3,582	-30.89	-30.96
85,434	67,105	3,682	-31.04	-31.12
88,554	63,986	3,782	-31.17	-31.28
91,689	60,850	3,882	-31.35	-31.43
94,840	57,699	3,982	-31.51	-31.59
98,008	54,531	4,082	-31.68	-31.76
101,192	51,347	4,182	-31.84	-31.92
104,393	48,146	4,282	-32.01	-32.09
107,611	44,929	4,382	-32.18	-32.26
110,846	41,694	4,482	-32.35	-32.44
114,098	38,441	4,582	-32.53	-32.62
117,369	35,170	4,682	-32.70	-32.80
120,658	31,882	4,782	-32.89	-32.98
123,965	28,575	4,882	-33.07	-33.16
127,290	25,249	4,982	-33.26	-33.35
130,635	21,904	5,082	-33.45	-33.54
134,000	18,540	5,182	-33.64	-33.74
137,384	15,156	5,282	-33.84	-33.94
140,788	11,751	5,382	-34.04	-34.14
144,213	8,327	5,482	-34.25	-34.35
147,658	4,881	5,582	-34.45	-34.56
151,125	1,414	5,682	-34.67	-34.77

Table A-4. W_S, W_I, and W_R, for Annual Cost of $425,000 and Total Capacity of 205,112 Acre-Feet, Bronco Site

W_S	W_I	W_R	$\Delta W_I/\Delta W_R$	dW_I/dW_R
------ (acre-feet) ------		(surface acres)		
82,045	123,067	3,573		-30.95
85,148	119,964	3,673	-31.03	-31.10
88,266	116,846	3,773	-31.18	-31.26
91,400	113,712	3,872	-31.34	-31.52
94,550	110,562	3,973	-31.50	-31.58
97,716	107,396	4,073	-31.66	-31.74
100,898	104,214	4,173	-31.82	-31.91
104,098	101,014	4,273	-31.99	-32.08
107,314	97,798	4,373	-32.16	-32.25
110,547	94,564	4,473	-32.33	-32.42
113,798	91,314	4,573	-32.51	-32.60
117,067	88,045	4,673	-32.69	-32.78
120,354	84,758	4,773	-32.87	-32.96
123,660	81,452	4,873	-33.05	-33.15
126,984	78,128	4,973	-33.24	-33.34
130,327	74,785	5,073	-33.43	-33.53
133,689	71,423	5,173	-33.62	-33.72
137,071	68,040	5,273	-33.82	-33.92
140,474	64,638	5,373	-34.02	-34.12
143,896	61,215	5,473	-34.23	-34.33
147,340	57,772	5,573	-34.44	-34.54
150,805	54,307	5,673	-34.65	-34.75
154,291	50,821	5,773	-34.86	-34.97
157,800	47,312	5,873	-35.08	-35.19
161,330	43,782	5,973	-35.31	-35.42
164,884	40,228	6,073	-35.54	-35.65
168,461	36,651	6,173	-35.77	-35.89
172,062	33,050	6,273	-36.01	-36.13
175,686	29,425	6,372	-36.25	-36.37
179,336	25,776	6,473	-36.50	-36.62
183,011	22,101	6,573	-36.75	-36.88
186,712	18,400	6,673	-37.01	-37.14
190,439	14,673	6,773	-37.27	-37.40
194,193	10,919	6,873	-37.54	-37.68
197,974	7,138	6,973	-37.81	-37.95
201,784	3,328	7,073	-38.10	-38.24

Table A-5. W_S, W_I, and W_R, for Annual Cost of \$500,000 and Total Capacity of 263,350 Acre-Feet, Bronco Site

W_S	W_I	W_R	$\Delta W_I/\Delta W_R$	dW_I/dW_R
------ (acre-feet)	------	(surface acres)		
105,340	158,010	4,312		-32.14
108,563	154,787	4,412	-32.23	-32.32
111,803	151,547	4,512	-32.40	-32.49
115,061	148,289	4,612	-32.58	-32.67
118,337	145,013	4,712	-32.76	-32.85
121,631	141,714	4,812	-32.94	-33.03
124,943	138,406	4,912	-33.12	-33.22
128,275	135,075	5,012	-33.31	-33.41
131,625	131,724	5,112	-33.50	-33.60
134,995	128,354	5,212	-33.70	-33.80
138,385	124,964	5,312	-33.90	-34.00
141,795	121,554	5,412	-34.10	-34.20
145,226	118,123	5,512	-34.31	-34.41
148,678	114,672	5,612	-34.52	-34.62
152,151	111,198	5,712	-34.73	-34.84
155,646	107,704	5,812	-34.95	-35.06
159,163	104,187	5,912	-35.17	-35.28
162,702	100,647	6,012	-35.40	-35.51
166,265	97,085	6,112	-35.63	-35.74
169,851	93,499	6,212	-35.86	-35.98
173,461	89,889	6,312	-36.10	-36.22
177,095	86,254	6,412	-36.34	-36.47
180,755	82,595	6,512	-36.59	-36.72
184,440	78,910	6,612	-36.85	-36.98
188,150	75,199	6,712	-37.11	-37.24
191,888	71,462	6,812	-37.37	-37.51
195,652	67,697	6,912	-37.64	-37.78
199,445	63,905	7,012	-37.92	-38.06
203,265	60,084	7,112	-38.21	-38.35
207,115	56,234	7,212	-38.50	-38.64
210,904	52,355	7,312	-38.79	-38.94
214,904	48,445	7,412	-39.10	-39.25
218,845	44,505	7,512	-39.41	-39.57
222,818	40,532	7,612	-39.73	-39.89
226,823	36,527	7,712	-40.05	-40.22
230,862	32,488	7,812	-40.34	-40.56
234,935	28,415	7,912	-40.73	-40.90
239,043	24,306	8,012	-41.08	-41.26
243,187	20,162	8,112	-41.44	-41.63
247,369	15,981	8,212	-41.82	-42.00
251,589	11,761	8,312	-42.20	-42.39
255,847	7,502	8,412	-42.59	-42.79
260,146	3,203	8,512	-42.99	-43.20

Table A-6. W_S, W_I, and W_R, for Annual Cost of $575,000, and Total Capacity of 327,252 Acre-Feet, Bronco Site

W_S	W_I	W_R	$\Delta W_I/\Delta W_R$	dW_I/dW_R
------ (acre-feet)	------	(surface acres)		
130,901	196,351	5,090		-33.56
134,267	192,986	5,190	-33.66	-33.76
137,652	189,600	5,290	-33.86	-33.96
141,058	186,194	5,390	-34.06	-34.16
144,484	182,768	5,490	-34.26	-34.37
147,932	179,321	5,590	-34.47	-34.58
151,400	175,852	5,690	-34.68	-34.79
154,890	172,362	5,790	-34.90	-35.01
158,402	168,850	5,890	-35.12	-35.23
161,937	165,315	5,990	-35.35	-35.46
165,494	161,758	6,090	-35.58	-35.69
169,076	158,177	6,190	-35.81	-35.93
172,680	154,572	6,290	-36.05	-35.17
176,309	150,943	6,390	-36.29	-36.41
179,963	147,289	6,490	-36.54	-36.66
183,643	143,610	6,590	-36.79	-36.92
187,348	139,904	6,690	-37.05	-37.18
191,080	136,173	6,790	-37.32	-37.45
194,838	132,414	6,890	-37.59	-37.72
198,624	128,628	6,990	-37.86	-38.00
202,439	124,813	7,090	-38.14	-38.29
206,282	120,970	7,190	-38.43	-38.58
210,155	117,097	7,290	-38.79	-38.88
214,058	113,194	7,390	-39.03	-39.18
217,992	109,260	7,490	-39.34	-39.10
221,958	105,294	7,590	-39.66	-39.82
225,956	101,296	7,690	-39.98	-40.15
229,988	97,265	7,790	-40.31	-40.48
234,053	93,199	7,890	-40.66	-40.83
238,154	89,098	7,990	-41.01	-41.18
242,290	84,962	8,090	-41.36	-41.55
246,464	80,788	8,190	-41.73	-41.92
250,675	76,577	8,290	-42.11	-42.31
254,926	72,327	8,390	-42.50	-42.70
259,216	68,036	8,490	-42.90	-43.11
263,547	63,705	8,590	-43.32	-43.53
267,921	59,331	8,690	-43.74	-43.96
272,339	54,914	8,790	-44.18	-44.40
276,801	50,451	8,890	-44.62	-44.86
281,310	45,942	8,990	-45.09	-45.33

(continued)

Table A-6. (Continued)

W_S	W_I	W_R	$\Delta W_I/\Delta W_R$	dW_I/dW_R
------ (acre-feet) ------		(surface acres)		
285,867	41,385	9,090	-45.57	-45.81
290,474	36,779	9,190	-46.06	-46.32
295,131	32,121	9,290	-46.57	-46.84
299,841	27,411	9,390	-47.10	-47.37
304,606	22,646	9,490	-47.65	-47.93
309,428	17,824	9,590	-48.22	-48.51
314,308	12,944	9,690	-48.80	-49.10
319,250	8,003	9,790	-49.41	-49.72
324,254	2,998	9,890	-50.04	-50.37

Table A-7. W_S, W_I, and W_R, for Annual Cost of $650,000 and Total Capacity of 396,820 Acre-Feet, Bronco Site

W_S	W_I	W_R	$\Delta W_I/\Delta W_R$	dW_I/dW_R
------ (acre-feet)	------	(surface acres)		
158,728	238,092	5,900		-35.25
162,265	234,556	6,000	-35.37	-35.48
165,825	230,996	6,100	-35.60	-35.71
169,408	227,413	6,200	-35.83	-35.95
173,015	223,806	6,300	-36.07	-36.19
176,646	220,174	6,400	-36.31	-36.44
180,302	216,518	6,500	-36.56	-36.69
183,984	212,836	6,600	-36.82	-36.94
187,692	209,129	6,700	-37.08	-37.21
191,426	205,394	6,800	-37.34	-37.48
195,187	201,633	6,900	-37.61	-37.75
198,976	197,844	7,000	-37.89	-38.03
202,793	194,027	7,100	-38.17	-38.31
206,639	190,181	7,200	-38.46	-38.61
210,515	186,306	7,300	-38.76	-38.91
214,421	182,400	7,400	-39.06	-39.21
218,358	178,463	7,500	-39.37	-39.53
222,326	174,494	7,600	-39.69	-39.85
226,328	170,493	7,700	-40.01	-40.18
230,362	166,458	7,800	-40.35	-40.52
234,431	162,389	7,900	-40.69	-40.86
238,535	158,286	8,000	-41.04	-41.22
242,675	154,146	8,100	-41.40	-41.58
246,852	149,969	8,200	-41.77	-41.96
251,066	145,754	8,300	-42.15	-42.34
255,320	141,500	8,400	-42.54	-42.74
259,614	137,206	8,500	-42.94	-43.14
263,950	132,870	8,600	-43.35	-43.56
268,328	128,493	8,700	-43.78	-44.00
272,749	124,071	8,800	-44.22	-44.44
277,216	119,604	8,900	-44.67	-44.90
281,730	115,091	9,000	-45.13	-45.37
286,291	110,529	9,100	-45.61	-45.86
290,902	105,918	9,200	-46.11	-46.36
295,564	101,256	9,300	-46.62	-46.88
300,280	96,541	9,400	-47.15	-47.42
305,050	91,771	9,500	-47.70	-47.98
309,877	86,944	9,600	-48.27	-48.56
314,762	82,058	9,700	-48.86	-49.16
319,710	77,111	9,800	-49.47	-49.78

(continued)

Table A-7. (Continued)

W_S	W_I	W_R	$\Delta W_I/\Delta W_R$	dW_I/dW_R
------ (acre-feet) ------		(surface acres)		
324,720	72,100	9,900	-50.10	-50.43
329,796	67,024	10,000	-50.76	-51.10
334,941	61,879	10,100	-51.45	-51.80
340,158	56,662	10,200	-52.16	-52.53
345,449	51,371	10,300	-52.91	-53.29
350,818	46,002	10,400	-53.69	-54.09
356,268	40,552	10,500	-54.50	-54.92
361,804	35,016	10,600	-55.36	-55.80
367,429	29,392	10,700	-56.25	-56.71
373,148	23,673	10,800	-57.19	-57.67
378,965	17,855	10,900	-58.17	-58.68
384,886	11,934	11,000	-59.21	-59.75
390,918	5,903	11,100	-60.31	-60.88