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ALTERNATIVE ECONOMIC EVALUATION PROCEDURES AND WATER DEVELOPMENT PROJECTS: THE MULTIPLE OBJECTIVE PROBLEM

Gary D. Lynne, Graduate Assistant
Emery N. Castle, Professor of Agricultural Economics
Christopher Gibbs, Graduate Assistant

Department of Agricultural Economics
Oregon State University
Corvallis, Oregon

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ABSTRACT

Alternative Economic Evaluation Procedures and Water Development Projects: The Multiple Objective Problem

The relationship among varying social objectives is of paramount importance with regard to evaluation and cost allocation processes in water resource use, development, and management projects. This study examines the philosophical and ethical base underlying proposed procedures for dealing with the multiple objective problem. The specific objectives of the study were (1) to account for the evolution of the multiple objective function, (2) to identify the relationships among objectives in water resource development, and (3) to identify the effect of relationships among objectives on the ultimate value of the trade-off ratio as well as the calculation process.

Several legislative documents relating to public intervention in water resource development were reviewed in an attempt at accounting for the evolution of the multiple objective function, and at identifying the relationships among objectives. It was concluded that the multiple objective function was prevalent even in early legislation. Only the elements of the function have changed over time. The relationships among objectives, however, have not been made explicit. A tentative framework is presented which provides insight into the effects of various types of relationships on the ultimate value of the trade-off ratio and the trade-off calculation process. Decision rules and techniques involving trade-offs will have to be quite sophisticated, given interdependent relationships among objectives.

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ALTERNATIVE ECONOMIC EVALUATION PROCEDURES AND WATER DEVELOPMENT PROJECTS: THE MULTIPLE OBJECTIVE PROBLEM*

INTRODUCTION

The relationship among varying social objectives is of paramount importance with regard to evaluation and cost allocation processes in water resource use, development, and management projects. This report details the work accomplished to date in the examination of the philosophical and ethical base underlying proposed procedures for dealing with the multiple objective problem.

The concept of a multiple objective function has evolved over time because of explicit recognition of objectives other than economic development. Multiple objectives have always been a part of the planning and justification process in public intervention; historically, however, multiple objectives were implicit and kept behind the veil of the economic development objective. In recent years, as evidenced by proposals of the Special Task Force on Evaluation Practices of the Water Resources Council [48], attempts have been made to make multiple objective considerations explicit.

Recognition of a multiple objective function is based on a deeper realization that there are "money" and "non-money" valued benefits (and costs). Not all objectives can be reduced to monetary terms (or to non-monetary terms) to allow comparison of objectives on the same basis. This problem of non-commensurable benefits (and costs) is commonly referred to as the "multiple objective problem" [26]. The solution to this "problem" has generally been discussed in terms of calculating "trade-offs".

The contention of most writers on the topic is that the "multiple objective

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problem" will be solved as soon as analysts are able to evaluate all benefits (and costs) on the same basis; i.e., find a common denominator for measurement. If this cannot be accomplished (and it probably cannot), analysts still could feel comfortable with establishing trade-offs between money-valued benefits and non-money valued benefits, as long as the non-money valued benefits are measureable in some sense.

A major point seems to have been missed in attempts to deal with the "multiple objective problem" via trade-off calculations. Certainly, methods must be developed to either find the common denominator or to compare objectives that are admittedly non-commensurable, in order that rational, consistent decisions can be made regarding water resource use, development, and management projects. It seems, however, little progress can be made toward improvements in the decision process until explicit recognition is made of the type of relationships prevailing among alternative objectives. Trade-off calculations among objectives may be misleading if objectives are not independent in their achievement. The proponents of trade-off calculations have not been explicit in recognition of possible differences in the type of relationships among objectives.

Several legislative documents relating to public intervention in water resource development were reviewed in an attempt at accounting for the evolution of the multiple objective function, and at identifying the relationships among objectives.[1/] A theoretical base, useful in identifying and classifying particular types of relations among objectives, was also developed.

The Acts selected for review include most of the major water and related land legislation passed since the middle 1800's. Several Acts not specifically related to water and related land development were selected from a list by Gidez [28, pp. 1-2]. According to Gidez, these Acts (all of which were instituted in the 1960's) are indicative of "shifting priorities" (with regard to objectives in water resources development). Also, "what we have done in the past has not been sufficient, and here is how we will do it" [28, p. 1].

1/ A major assumption guiding the review was that stated objectives were, in fact, real social objectives; this assumption may not be the case, but was a necessary assumption in this study.

The Acts reviewed included three sequences of legislation, namely:

1. the Homestead and Desert Land Acts,
2. the Irrigation and Reclamation Acts,
3. the Flood Control Acts.

Other selected Acts relate to water quality, recreation, environmental quality, regional development, and project analysis and planning.

EVOLUTION OF THE MULTIPLE OBJECTIVE FUNCTION

Initial examination of various legislative Acts made it apparent that there were at least two distinct classes of objectives, namely:

1. the class of broad, socially desirable objectives, such as national prosperity, national security, etc.,
2. the class of more concrete objectives such as irrigation, flood control, improvements in navigation, water quality enhancement, recreation facilities, etc.

The attempt at identifying the evolution of the multiple objective function involved discovering the broad based social and more concrete objectives as specified in each Act.

Homestead and Desert Land Acts

The Homestead Act was the first in a series of Land Acts to eventually affect water resource development. This Act grew out of the desire to give free land grants in order to.

1. acquire, settle, secure, and retain new territory,
2. promote national prosperity (the belief was current [28, p. 351] that "private earnings invested in land improvement was as advantageous to the public good as though they should be paid directly into the treasury"),
3. promote human welfare by giving land to the poor.

The objectives were partially achieved when the Act was passed in 1862.

The development of the Homestead Act of 1862 was a lengthy process, hampered by the issue becoming intimately entwined with the anti-slavery movement. Passage of the Act did give settlers up to 160 acres of land, free of charge except for a fee for filing a claim. The title was transferred after 5 years of settlement. In the early years of the Act, the settlers were genuine homesteaders wanting farms. During the last 20 years of the nineteenth century, through the perverted use of the commutation clause in the Act, large private land holdings resulted. The Homestead Act functioned simply as a lever, pricing public land onto the open market at a low fixed price. The promotion of this activity was one of the principal weaknesses of the Act.

The 160-acre land grant was considered too small to provide a basis for a family farm in semi-arid areas. Hence, the first Desert Land Act of 1877 authorized reclamation of up to 640 acres by "conducting water upon the same" within three years of registration and payment of a fee of twenty-five cents per acre [9, p. 377]. A patent was issued upon "proof of reclamation and payment of one dollar per acre" [9, p. 377]. All lands (excluding timber and mineral lands) which would not produce some agricultural crop unless irrigation water was provided, were considered to be "desert lands". The Act encouraged private irrigation developments and became one of the "significant measures adopted ostensibly to aid settlers in gaining ownership of the land and timber they needed" [27, p. 231]. Specific provisions were, however, "commonly used by larger economic interests for speculative purposes in violation of the restrictions of the law" [27, p. 231]. Owing to its loose construction and the possibility of broad interpretation, the Act was open to abuse. It provided a convenient means of acquiring title to land. Land that was "irrigated", but not necessarily cultivated, could be gained cheaply and in large blocks. Yet the Act was not suited to corporate enterprise or reclaiming large valleys [37].

Irrigation and Reclamation Acts

The Irrigation and Reclamation Act of 1888 [30], which was designed to restrain abuse of the Desert Land Act of 1877 by declaring a moratorium on certain claims, most clearly states the broad objectives which permeate this sequence of legislation. The Act was aimed to "permit by means of irrigation . . . (to) render fertile . . . a large portion of the unoccupied public land . . . (capable of) supporting a large population . . . thereby adding to the nation's wealth and prosperity" [30, p. 618]. The legislators, therefore, appeared to have confidence in a chain of causation, running from irrigation to population growth to growth of national income.

The next step in promoting irrigation in semi-arid areas was the Carey Act [3] of 1894, which encouraged states to take leadership in irrigation development. This Act proposed to aid reclamation, settlement, and cultivation, and gave permission to irrigate and reclaim up to one million acres in each of the public land states. The language of the Act was noticeably more explicit with regard to concrete objectives and restrictions on its use. To qualify for approval, a state must demonstrate a map of the land to be irrigated, the mode

of irrigation to be used, the source of water, and the sufficiency of water to reclaim, irrigate, and raise ordinary crops.

The Carey Act was not a great success. According to McKinley [36, p. 114], "the application of the Carey Act resulted in many failures because of improper engineering surveys, and because of financial inadequacy." Ninety percent of the private irrigation companies were at or near bankruptcy by 1902 [38]. Despite the low success rate, it took the strong advocacy of Theodore Roosevelt to precipitate the movement culminating in the Irrigation and Reclamation Act of 1902. In the State of the Union speech of 1901, Roosevelt proclaimed that "great storage works are necessary to equalize the flow of streams and save the flood waters. Their construction has been conclusively shown to be an undertaking too vast for private effort. Nor can it be best accomplished by the individual states acting alone . . . the Government should construct and maintain these reservoirs as it does other public works . . . the lands reclaimed by them should be reserved by the Government for actual settlers, and the cost of construction should, so far as possible, be repaid by the land reclaimed" [44, pp. 6656-6658].

The Irrigation and Reclamation Act of 1902 was a landmark, for it signaled the first national conservation policy. The Act provided for a wide base of ownership and an opportunity for a large number of people [31]. All money collected from the sale of public lands (except for 5 percent of the receipts set aside for educational purposes) was appropriated as a special fund in the treasury, the reclamation fund. The money was "to be used in the examination and survey for, and the construction and maintenance of, irrigation works for the storage, diversion, and development of waters for the reclamation of arid and semi-arid lands" [31, p. 388]. The Act also permitted public entry to the irrigated land in tracts of 40 to 160 acres (under the provisions of the Homestead Act), "an acreage required for the support of a family upon the lands in question" [31, p. 389]. Charges were to be determined with a view to returning to the reclamation fund the estimated cost of construction, and should be apportioned "equitably" [31, p. 389]. Ownership of irrigation works was originally intended to pass to the owners of the irrigated lands when payments for the majority of the lands had been made. Facilities were to be maintained at owner expense under an organization and rules acceptable to the Secretary of the Interior.

The Act did not discriminate between settlers on formerly public lands and owners of private lands; however, stress was placed on the section limiting irrigation benefits to no more than 160 acres for any one landowner. The acreage limitation was prompted by the failure of previous "free land" bills to prevent speculation in land. There was fear that returns from large irrigation works, erected at public expense, would benefit those few who had accumulated large blocks of irrigable land prior to 1902.

The Irrigation and Reclamation Acts of 1888 and 1902 were the first two Acts of a series of 29. The majority of subsequent Acts were designed to make minor changes in the Act of 1902. For example, the size of holding was permitted to fall below 40 acres, and provision was made for townsites in irrigation development areas. Also, the Secretary of the Interior was permitted to negotiate with both individual landowners and water users' associations. During times of economic hardship, financial restrictions and repayment schedules were relaxed. A total of seven Acts passed Congress in the early 1920's to alleviate financial problems.

The most significant change in legislation, aimed at preventing project failures by more careful planning, was the 14th Act in the series [32]. This Act repeated the demand that plans for irrigation projects must be approved by the Secretary of the Interior, show a sufficient water supply for the raising of ordinary agricultural crops, give detailed engineering data, and demonstrate overall project feasibility.

The 25th Act in the series first made "economic viability" (however this was computed) a condition for project approval [33]. This Act was also the first to state explicitly the multiple objectives of conservation, irrigation, drainage, and flood control. The Act authorized the Secretary of the Interior to "execute an agreement with the Middle Rio Grande Conservancy District providing for conservation, irrigation, drainage, and flood control for the Pueblo Indian lands in the Rio Grande Valley, New Mexico, and for other purposes" [33, p. 312]. The Act proposed cost-sharing between the Indians and the public, based on the acreage benefited, including only "lands feasibly susceptible of economic irrigation and cultivation" [33, p. 312].

The Salt River Reclamation Project Act [45] marked the turning point for hydroelectric power generation as a prime project objective. The power plant on the Salt River, Arizona, was established in 1906 to assist in financing the project. The 1922 Act authorized the Secretary of the Interior to sell surplus power, giving preference to municipal users, provided project efficiency was not impaired.

The activities of the Bureau of Reclamation changed most dramatically with the Boulder Canyon Project Act of 1928 [2]. Attention moved from irrigation to true multi-purpose planning. The Act authorized the construction of works in order to control floods, improve navigation, regulate flow of the river, permit storage and delivery of water for land reclamation, and generate electrical power. In addition, the following ranking of project objectives was to be used in time of conflict:

1. river regulation, the improvement of navigation, and flood control,
2. irrigation and domestic water uses, and the satisfaction of existing claims and perfected water rights,
3. generation of electrical power.

The Reclamation Project Act of 1939 was designed "to provide a feasible and comprehensive plan for the variable payment of construction charges on U.S. reclamation projects" [43, p. 1187]. The Act was intended to make special allowance for fluctuations in the economy and solve repayment problems arising from them. In order to lay down the rationale underlying the repayment plan, the Act went into considerable detail outlining the various objectives contained in any one project. To be authorized, a new project, or an addition to an existing project, must have:

1. engineering feasibility,
2. repayable and returnable allocations equal to the total estimated cost for the following items:
   a. irrigation,
   b. electrical power,
   c. municipal water supply,
   d. flood control,
   e. navigation,
   f. other purposes.

Irrigation was considered to be the paramount objective, for no other uses of water were permitted under the Act if they interfered with the efficiency of the project for irrigation purposes.

Flood Control Acts

The Flood Control Act of 1917 [13] was the first of a sequence of 27 pieces of legislation, the most recent being the Flood Control Act of 1968 [25]. The 1917 Act was designed to resolve specific flood control problems on the Mississippi River and on the Sacramento River, California. Also, general guidelines were provided for future flood control projects. The stated aim of the legislation was to permit the "controlling of floods, removing the debris (from rivers), and continuing the improvement" [13, p. 949]. All project examinations were to include reports on:

1. the probable effect of flood control measures on any navigable water or waterway,
2. the possible economical development and utilization of water power,
3. "other such uses as may be properly related to, or coordinated with, the project."

Flood control, navigation, and water power development were specifically included in the Act as legitimate multi-purpose objectives.

The "drainage of lands" was included in the Flood Control Act of 1920, the second act in this series [14]. Following this, the Act of 1921 [15] authorized a "plan for the protection of river basins from . . . flood waters . . . consistent with all other interests" [15, p. 1354]. The geographical unit of interest was extended to the river basin, which permitted more comprehensive planning.

Emphasis in the Act of 1928 [16] was placed on the "soundness" of the principle that there shall be local contributions for flood control protection. This was based on both the special interests of the local population in its own protection, and the prevention of requests for large sums for works of no material national interest. No local contribution was required, however, "in view of the national concern in control of floods in the interests of national prosperity, the flow of interstate commerce, and the movement of the mails, and in view of the gigantic scale of the project(s) . . ." [16, p. 535].

The next major Act in this sequence was the Flood Control Act of 1936, which contained the most comprehensive declaration of policy for public works for flood control to that time [17]. "It is hereby recognized that destructive floods . . . causing loss of life and property, including the erosion of lands and impairing . . . navigation . . . and other channels of commerce . . . constitute a menace to national welfare; that it is the sense of Congress that flood control on navigable waters . . . is a proper activity of the Federal Government in cooperation with States . . . (and) Federal Government should improve or participate in the improvement of navigable waters . . . for flood control purposes, if the benefits to whomsoever they may accrue are in excess of the estimated costs, and if the lives and social security of people are otherwise adversely affected" [17, p. 1570].

The 1936 Act introduced the benefit-cost concept, and made a strong case for public intervention for flood control. Justification for public intervention appeared to be synonymous with justification for public investment. The motives for intervention were broadened in 1937 to include water-flow retardation [18], and in 1939 to include tidal effects as a source of flooding [19].

The Act of 1941 [20] not only repeated the multi-purpose outlook, but also broadened it to include pollution abatement. The Act authorized works to allow for "full utilization of the site for all purposes of conservation, such as flood control, navigation, reclamation, the development of hydroelectric power, and the abatement of pollution" [20, pp. 638-639]. The authorization of certain works was made in the interests of national security and the stabilization of employment.

The first mention of construction, maintenance, and operation of public park and recreation facilities in reservoir areas appeared in the Act of 1944 [21]. The lands were to be open to the public without charge, for "boating, swimming, bathing, fishing, and other recreational purposes" [21, p. 890].

The 1958 Act authorized the extension of flood control projects to include beach erosion and the eradication of certain aquatic plants from navigable waters. This latter aim was stated to be "in the combined interest of navigation,

flood control, drainage, agriculture, fish and wildlife conservation, public health, and related purposes, including research" [22, p. 300].

The Flood Control Act of 1962 [23] contains a section applying to a particular geographical location, Alaska. Section 204 authorizes a project in order to develop "hydroelectric power and to encourage and promote the economic development of, and to foster the establishment of, essential industries in the State of Alaska" [23, p. 1193]. A further broadening of the scope of Flood Control Acts was the promotion of regional objectives.

Further recognition of peculiar regional requirements is contained in the Act of 1965 [24], where Congress recognizes the water supply problems of the northeastern United States and large metropolitan areas. This Act also recognizes public responsibility not only for water storage, but also for conveyance and purification.

A slight change was made in Federal flood control policy with passage of the National Flood Insurance Act of 1968 [39]. In addition to providing insurance, effort was to be directed toward flood plain management, with restricted development of land in potential flood damage areas. Previous Acts had dealt only with controlling flood waters to protect, rather than restrict, development in flood plains.

Prior to 1968, the only Acts of significance, relative to estuary waters, were related to flood control. The Estuarine Act of 1968 changed that policy. The purpose of the Estuarine Act was to facilitate determination of the proper balance between conservation and development in the estuaries of the nation. The proper balance was to be determined such as "to further growth and development of the nation" [11, p. 626]. The phrase "growth and development", as used in the Act, was to encompass wildlife and recreation, ecological, and esthetic values, in addition to "the value of such areas (estuaries and estuary zones) for more intensive development for economic use" [11, p. 626].

Regional Development Acts

Regional development considerations became especially apparent in Federal

policy of the middle 1960's. Regional development objectives were made explicit with two Acts passed during that period.

The purpose of the Appalachian Regional Development Act of 1965 was "to provide public works and economic development programs, and the planning and coordination needed to assist in development of tha Appalachian region" [2, p. 5]. The specific objectives of the Act were to improve the economic and social well-being of people in the Appalachian region. Economic efficiency criteria were to be utilized in project justification within the region. "Public investments made (in the region) shall be concentrated in the areas where there is significant potential for future growth, and where the expected returns on public dollars invested will be the greatest" [1, pp. 5-6].

Several other factors, however, in addition to maximum economic efficiency, were to be considered in project justification. The factors were [1, p. 18]:

1. the relationship of the particular project to overall development of the region,
2. the population to be served; i.e., per capita income and unemployment rates of the population in the particular area of the region to be served,
3. the financial resources of the state or other organization planning to undertake the project,
4. the importance of the project or class of projects in relation to other projects or classes of projects which may be in competition for the same funds (italics added),
5. the prospects that the proposed project will improve, on a continuing basis, the following: (a) opportunities for employment, (b) average level of income, or (c) economic and social development of the area served by the project (italics added).

The factors mentioned in Items 4 and 5 allowed evaluation of a project on the basis of criteria other than economic efficiency. Economic development, however, remained the primary objective of the Act, and economic efficiency criteria were emphasized. The implication was that improved social well-being was accomplished through economic development, within some constraints.

Emphasis was also given to regional development in the Public Works and Economic Development Act of 1965. The policy, as a basis for the Act, was stated

as "the Congress declares that the maintenance of the national economy at a high level is vital to the best interests of the United States. . ." [42, p. 552]. The "maintenance of the economy at a high level" was associated with regional economic development in the Act. It was specified that "the Federal government, in cooperation with the states, should help areas and regions of substantial and persistent unemployment and under-employment to take effective steps in planning and financing their public works and economic development" [42, p. 552].

Funds provided for public works and economic development were to be used to provide new employment opportunities. Jobs were not to be transferred from one area of the United States to another; thus, a concern was expressed for distributional aspects among regions. In addition, concern was expressed for the distribution of benefits within the region. Expenditures in the region were to create "new employment opportunities." Primary emphasis was directed toward affecting the long-term unemployed and members of low-income families.

The distribution of population (among regions and within regions) and social development were also of concern. Regional development should occur when the rate of outmigration of labor (or capital) was "substantial". The level of housing, health, and education facilities in the region must not be "substantially below" the national level; development should proceed if the "substantially below" requirement was met. Regional Development Commissions, established by the Act, were to insure consideration of ". . . the economic and social development of the area served by the project" [5, p. 566].

Recreation, Water Quality, and Environmental Quality Acts

The purpose of the Federal Water Project Recreation Act of 1965 was "to provide uniform policies with respect to recreation and fish and wildlife benefits and costs of federal multiple purpose water resource projects, and for other purposes" [12, p. 213]. Emphasis was placed on guaranteeing full consideration of the potential for outdoor recreation and fish and wildlife enhancement during the evaluation of proposed water resource projects.

Benefits from recreation and/or fish and wildlife enhancement may be

considered in project justification only if the local intent was to bear one-half the separable costs and all operation, maintenance, and repair costs. This requirement must be met in all projects evaluated after 1965. There were, however, two exceptions. Benefits from recreation and/or fish and wildlife enhancement not receiving local financial support can be used in project justification if (1) facilities result from satisfying other purposes, or (2) minimum facilities are necessary to public health and safety. In both cases, value is to be determined on the basis of visitor days. Any area not developed for recreation and/or fish and wildlife enhancement, in conjunction with other development allowed with a project, may be improved in later years. In general, the Act allows and encourages maximum recreation and fish and wildlife enhancement.

The Water Quality Act of 1965 provided for changes in the Federal Water Pollution Control Act. The changes allowed the establishment of the Federal Water Pollution Control Administration, provided funds for research and development, provided additional funds for sewage treatment facilities, and required the establishment of water quality criteria [47, p. 903]. The objectives of the original Act were also modified. The following statement was added: "The purpose of this Act is to enhance the quality and value of our water resources and to establish a national policy for the prevention, control, and abatement of water pollution" [47].

The Clean Water Restoration Act of 1966 provided for further changes in the Federal Water Pollution Control Act, and for changes in the Oil Pollution Act, 1924. The major change in the Federal Water Pollution Control Act was emphasis placed upon the effects of pollution in estuaries and estuarine areas. The effects of pollution on all "beneficial purposes" were to be ascertained in comprehensive studies. Specific attention was to be paid to the effect of "demographic trends . . . exploitation . . . development . . . and navigation" on pollution in estuaries [8, p. 1247]. The most significant change in the Oil Pollution Act, 1924, was a shift in emphasis. The main purpose of the original Act was "to protect navigation . . . by preventing the discharge of oil . . ." [41, p. 604]; the emphasis in the amended Act was shifted to the effects of pollution on the environment [8, p. 1253].

Another Act related to the quality of water was the Wild and Scenic Rivers Act of 1968. The purpose of this Act was to preserve "certain selected rivers . . . for the benefit and enjoyment of present and future generations" [54, p. 906]. The Act was directed toward environmental quality maintenance; "the established national policy of dams and other construction at appropriate sections of the rivers of the United States needs to be complemented" (italics added). Selected rivers are to be preserved "to protect the water quality" (of such rivers) and "to fulfill other vital national conservation purposes" [54, p. 906].

The potential uses of rivers and related land areas proposed for preservation must be compared to the "worth" of such areas in the wild and scenic rivers system. The only criteria specified in the Act required that the Secretary of the Interior "shall evaluate and give due weight" to recommendations from all affected Federal agencies [54, p. 910].

The National Environmental Policy Act of 1969 was oriented toward environmental quality aspects. The purposes of the Act were [38, p. 852]:

1. to declare a national policy which will encourage productive and enjoyable harmony between man and his environment,
2. to promote efforts which will prevent or eliminate damage to the environment and biosphere, and stimulate the health and welfare of man,
3. to enrich the understanding of the ecological systems and natural resources important to the nation,
4. to establish a Council on Environmental Quality.

The general purpose of the Act was to improve human welfare. In the section of the Act on administration, it was specified that "all Federal agencies shall identify and develop methods or procedures . . . which will insure that presently unquantified environmental amenities and values be given appropriate consideration in decision making, along with economic and technical considerations" [38, p. 853]. In addition, the Council authorized by the Act shall "be conscious of and responsive to the scientific, economic, social, esthetic, and cultural needs and interests of the nation." Further, "the Congress declares that it is the continuing policy . . . to use all practicable means . . . to improve the general welfare . . . to create and maintain conditions under which

man can exist in productive harmony with the environment, and fulfill the social, economic, and other requirements . . ." [38, pp. 852-854]. It seems the multiple objective function was to be part of the "continuing policy" of the Congress.

The Environmental Quality Improvement Act of 1970 is very similar in nature to the National Environmental Policy Act of 1969. The purpose of the 1970 Act was to assure implementation of laws enacted prior to 1970, relative to the enhancement of environmental quality. Further, a professional and administrative staff was authorized for the Council on Environmental Quality created by the 1969 Act [3, p. 114].

The statement of Congressional policy relative to the enactment of the Act was, ". . . there is a national policy for the environment which provides for the enhancement of environmental quality" [3, p. 114]. The "findings" of Congress, as a basis for the Act, were [38, p. 114]:

1. that man has caused changes in the environment,
2. that many of these changes may affect the relationship between man and his environment,
3. that population increases and urban concentration contribute directly to pollution and degradation of the environment.

Planning and Project Analysis Acts

The Water Resources Planning Act of 1965 provided support for planning the optimum development of the nation's water and related land resources. Financial assistance was provided to establish river basin planning commissions. Planning was to be conducted with state participation. The policy, as a probable basis for the Act, was noted as "to encourage conservation, development, and utilization of water and related land resources of the United States on a comprehensive and coordinated basis . . ." [53, p. 244]. The creation of the river basin commissions gave substance to a felt need for comprehensive and coordinated water planning.

Guidelines for project analysis were provided in the "Green Book" [29]. The setting for economic analysis of project effects is viewed as ". . . one in

which, over the long run, an expanding economy will require increasing amounts of goods and services to satisfy increased needs resulting from population shifts and growth and higher levels of living" [29]. Guidance was provided regarding the application of principles of approval to the following project purposes: irrigation, drainage, flood and erosion control for the development of agricultural land, flood control, navigation, electrical power generation, recreation, fish and wildlife, and water pollution control. Attention was focused on the concrete components of multi-purpose projects. The broader objectives of development were largely ignored, and the guidelines disregarded local and regional objectives that may have been different from long-run national goals.

Senate Document 97 [46] contains a Section II, "Objectives of Planning", where a list is provided of "those things which appear to be important end products of natural resource management . . . (However) it is doubtful that this portion of the report will provide much guidance to planners as they come to grips with difficult applied problems" [7, p. 695]. The objectives are listed under three headings: development, preservation, and well-being of people. This was a change over the "Green Book", for a verbal explanation and justification of the latter two headings was permitted. No guidance, however, was provided for the resolution of conflicts among objectives within the multiple objective function.

The amendment of the planning objectives in Senate Document 97 was recommended in the "Blue Book" [48]. The effects of water and related land development are to be displayed in a system of four accounts, one relating to each of the following classifications: national income objectives, regional development objectives, environmental objectives, and well-being objectives. No indication was made that one account should receive relatively more or less emphasis than any other; it was requested, however, that explicit recognition be made of all project objectives in project planning and implementation. The multiple objective function was to be made explicit.

The recommendations represented in the "Blue Book" were subjected to critical review by several universities, state and federal water officials, and the

public, after the release of the Task Force report in 1969 [50, p. 2]. A total of 19 tests of the proposed evaluation procedures were conducted prior to July of 1970 [49]. Recommendations from these tests and inputs from many other sources were considered in the development of the current documents regarding principles and standards [51, 52]. The major theme of the Task Force report seems to revolve around the statement, "Planning in the future must give explicit recognition to important values which have, largely, gone unrecognized in the past" [50, p. 10].

The principles and standards for planning water and related land resource use and development projects reflect the Task Force conclusion that such planning "can best be carried out in the context of four broad objectives" [50, p. 4]. The objectives were stated somewhat differently than in the 1969 report, due to some refinements from the many hearings, tests, and reviews. The four objectives of water development projects were defined to be [50, p. 5]:

1. to enhance national economic development,
2. to enhance the quality of the environment,
3. to enhance social well-being,
4. to enhance regional development.

Plans may be explicitly developed to emphasize any one of the objectives, rather than to place emphasis entirely on national economic development [50, p. 6].

The Task Force recommended that trade-off calculations be used to guide decisions, rather than the one measure used previously, namely the benefit-cost ratio [50, p. 7]. Alternative plans are to be developed, each having different levels of achievement of the stated objectives, such as to facilitate the calculation of trade-offs. The multiple objective function is recognized fully as a viable concept.

Recent action on the proposed guidelines for planning water and related land resources has included publishing a detailed "Summary Analysis of Public Response to the Proposed Principles and Standards for Planning Water and Related Land Resources" [40, p. 1]. The bulk of the response relates to particular aspects of the report; the concept of a multiple objective function seems acceptable to most reviewers.

A summary of the Acts reviewed, and the objectives explicitly mentioned in each Act, is presented in Table 1. Again, it is important to note that these were stated objectives, and do not necessarily reflect social objectives or objectives actually accomplished.[2/]

Recognition of quantifiable and non-quantifiable (in money terms) objectives is apparent as early as 1862. The Homestead Act of 1862 had, as explicit objectives (in addition to promoting national prosperity) the acquisition, settlement, securing, and retention of territory, most of which are non-quantifiable (in money terms) objectives. One of the guiding objectives of that Act was to give land to the poor "to promote human welfare," another non-quantifiable entity. More recent legislation still has concern expressed for the "health and welfare" of mankind, as well as for the promotion of national prosperity (Table 1). The multiple objective concept has merely been made explicit in recent years.

Concern was expressed for irrigation, reclamation, navigation, water quality, and power objectives, as well as flood control, in the Flood Control Act of 1941. In addition, the broader social objectives of national income, national security, and conservation were all of concern in this Act (Table 1). Even some of the earlier Flood Control Acts were concerned with more than one objective (Table 1).

The Public Works and Economic Development Act of 1965 was concerned with various aspects of national income, growth, and population. Concerns for national income and population were also expressed, however, in the Irrigation and Reclamation Act of 1888 (Table 1). Even though different issues may have been at stake, the broad social objectives relating to national income and population were of concern in 1888 and again, over 75 years later, in 1965 (Table 1).

The "evolution" of a multiple objective function, then, is not really an "evolution" at all. The concept of a multiple objective function surfaces in much of the early legislation pertaining to water resource use, development, and management. Only the elements (variables, arguments) of the multiple objective function have changed over time.

[2/] See Footnote 1, page 2.

Table 1. Objectives of Selected Legislative Acts, 1862 - 1970*

Year	Act	Evaluation process, (planning, jurisdiction)	Fish and wildlife	Domestic water use	Flood control, drainage, management	Irrigation	Land requisition, distribution	Navigation	Water quality	Power	Recreation	Environmental quality	National income, prosperity, employment, growth	National security	Population growth, distribution	Preservation, conservation	Regional concerns	Social welfare, national welfare, well-being
1862	Homestead						X						X					X
1877	Desert Land					X	X											
1888	Irrigation and Reclamation					X	X						X		X			
1894	Carey Act					X	X											
1902	Irrigation and Reclamation					X	X									X		
1916	Irrigation and Reclamation	X				X	X											
1917	Flood Control				X			X		X								
1920	Flood Control				X													
1921	Flood Control	X			X													
1922	Salt River Reclamation			X		X	X			X								
1928	Boulder Canyon Reclamation			X	X	X	X	X		X								
1928	Flood Control							X					X					
1928	Irrigation and Reclamation	X			X	X	X						X			X		
1936	Flood Control	X			X			X										X
1937	Flood Control				X													
1939	Flood Control				X													
1939	Reclamation Project	X		X	X	X	X	X		X								
1941	Flood Control				X	X	X	X	X	X			X	X		X		
1944	Flood Control				X	X		X			X							
1958	Green Book	X	X		X	X	X	X	X	X	X		X		X			
1958	Flood Control		X	X	X			X										
1962	Senate Document 97	X											X			X		X
1962	Flood Control				X					X							X	
1965	Flood Control			X	X				X								X	
1965	Appalachian Regional Development	X															X	X
1965	Federal Water Project Recreation	X	X								X							
1965	Water Resources Planning	X									X							
1965	Public Works and Economic Development												X		X		X	X
1965	Water Quality								X									
1966	Clean Water Restoration								X			X						
1968	Flood Control				X			X										
1968	Wild and Scenic Rivers											X				X		
1968	National Flood Insurance				X													
1968	Estuarine		X										X			X		
1969	Blue Book	X										X	X				X	X
1969	National Environmental Policy											X						X
1970	Environmental Quality											X			X			

* The existence of an "X" in the Objective-Act matrix indicates only that the objective was stated or mentioned in the Act. The stated objectives are not necessarily social objectives or objectives that were accomplished by the Act in question.

RELATIONSHIP AMONG OBJECTIVES - A SURVEY

The legislative recognition of the relationship among various stated objectives has changed over time. In the earlier Acts the emphasis was on economic development, with other objectives supposedly emanating from the realization of a high level of development. The Irrigation and Reclamation Act of 1888, for example, emphasized irrigation development to increase population which, in turn, was to increase national income. Human welfare would supposedly be increased. A more recent Act, the Environmental Quality Act of 1970, specifies that "population increases . . . contribute to pollution and degradation of the environment," which, in turn, supposedly reduces human welfare. The relationship between increases in population and changes in human welfare seems to have reversed: the implication is that increases in national income, accomplished through population growth, led to improvements in welfare at one time, and now lead to decrements in human welfare.

Legislative intent in another recent Act points toward improvements in "social well-being" through economic development with maximum economic efficiency, but with other constraints. The Appalachian Regional Development Act of 1965 was passed to accomplish economic and social development; no chain of causation is specified. However, constraints included income distribution questions and the importance of the project, relative to other projects, in improving social well-being. Housing, health, and education objectives, all related to "social development", were to be attained via economic development in another Act passed the same year.

It is very difficult, at best, to discern the intended relationship among objectives in the legislative Acts. It appears that legislators have left considerable vagueness in the Acts, to permit action agencies to interpret the laws and implement programs based on that interpretation. The relationships among objectives have not been made explicit.

The framework presented in the next section provides some insights into the different types of relationships that may exist among objectives. Also, the factors that may cause the different types of relationships become more apparent within this framework.

RELATIONSHIP AMONG OBJECTIVES - A THEORETICAL FRAMEWORK

The concept of a multiple objective function, while not new, has become more important in recent years, as evidenced by much of the legislation in the past decade and recent concerns expressed in the Task Force reports on Evaluation Procedures for Water Resource Development [48, 49, 50, 51, 52]. The objectives of water resource and related land development are several, and no simple objective is to always dominate the procedure of analysis or implementation of programs and projects. Because of this recognition, the relationship among varying objectives becomes of great concern. Very little is known about the relationships among objectives; as a result, little is known about how public investment in water resources development should be tempered, given a multiple objective function.

The framework proposed in this section, while only tentative, provides some insight into effects of various types of relations among objectives on the decision to invest in water resources development. The decision to invest in a particular water resources project will be affected by the trade-off ratios calculated for that project; the trade-off ratios are, in turn, affected by the type of relations among the objectives. There are two different sets of relations of concern here. The relations among the objectives in the social preference function may be quite different from the relations among the objectives in the production function. Both sets of relations, in turn, affect the trade-off ratio. Reference to the following model will help clarify this point.

The social preference function may be represented by the equation:[3/]

$$W = f(c_1, c_2, \cdots, c_n) \tag{1.10}$$

where

W = welfare level attained by society,

$c_1, c_2, \cdots, c_n$ = components of welfare "consumed".

This function will be maximized by the decision maker's choices, subject to the constraint

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3/ The general form of this function and the terminology follows [5, pp. 7-11, A-1 - A-3].

$$X = g(c_1, c_2, \cdots, c_n) \tag{1.20}$$

where

X = resources available to society,

$c_1, c_2, \cdots, c_n$ = components of welfare produced.

One can then envision a function to be maximized, of the form:

$$Z = f(c_1, c_2, \cdots, c_n) + \lambda[x^o - g(c_1, c_2, \cdots, c_n)] \tag{1.30}$$

where x^o represents a particular resource base of society. The function Z will be maximized when the marginal rate of (component) substitution (MRS) in consumption, $-\left(\frac{\partial f}{\partial c_i} / \frac{\partial f}{\partial c_j}\right)$, is equal to the marginal rate of (component) transformation (MRT) in production, $-\left(\frac{\partial g}{\partial c_i} / \frac{\partial g}{\partial c_j}\right)$, for every possible combination of c_i and c_j where $i \neq j$, $i,j = 1,2,\cdots, n$.

The decision making entity in water resource development is faced with the problem of finding the solution to the maximization of Equation (1.30); i.e., the decision making entity is faced with the problem of finding Point A in Figure 1, where the trade-off in consumption is equal to the trade-off in production. This problem is identical to maximizing welfare (Equation (1.10)) subject to the constraint that all resources available are used (Equation (1.20)), and finding the levels of c_i. In essence, the decision making entity must equate the trade-off ratios; the trade-off ratio in consumption is the MRS and the trade-off ratio in production is the MRT. Both of these trade-off ratios are, in turn, affected by the relations among the objectives.

Past literature on the calculation of trade-offs provides some insights into means of solving the multiple objective problem.[4/] Most of that literature deals with quantifying Equation (1.10), with the ultimate goal of finding Point A in Figure 1.

[4/] The "multiple objective problem" exists due to the inability of analysts in the past to find a common denominator for measurement of all benefits (and costs). The multiple objective problem is basically a valuation problem (see Freeman [26, p. 566]).

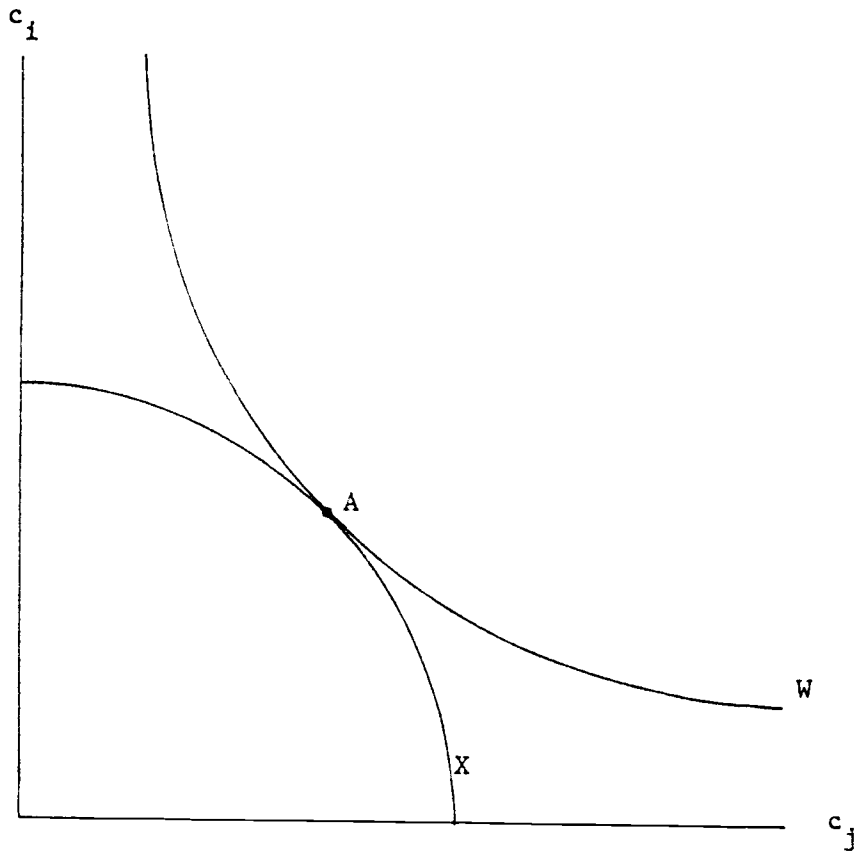

Figure 1. Societal preference function and Component-Component relationship, components c_i and c_j.

Marglin proposes two techniques, basically, for handling a multiple objective function [35]. Objectives may be explicitly weighted or various objectives may be constrained at certain levels [35, pp. 23-39]. The constraint approach, where n-1 of the objectives are constrained and the remaining objective maximized, results in implicit weights. Both procedures ultimately lead to the same weights and, consequently, the same trade-offs. Freeman lists three different approaches, all which lead ultimately to the determination of trade-offs [26]. Freeman suggests one approach and attributes the other two to McKean and Marglin.

An array of money-valued benefits and measurable (but non-money valued) benefits should be presented to the decision-making entity, in the McKean approach [26, p. 570]. The trade-off between money-valued and non-money valued benefits can be ascertained from observing the choices made, as compared to other combinations the decision maker could have chosen. This approach is tantamount to providing the decision maker with Equation (1.20), observing the choice made, and specifying that choice to be Point A in Figure 1.

Freeman suggests that weights be assigned to the measurable, but non-money valued benefits, before choices are made. In this way, value is allowed to determine choice, rather than choice determine value [26, p. 566]. According to Freeman, both the McKean approach and the constrained maxima approach suggested by Marglin result in choice determining value [26, p. 566, pp. 570-572]. Freeman's suggestion of assigning explicit weights to money and non-money valued benefits seems identical with Marglin's proposed explicit weighting of objectives [35, pp. 23-29].

Maass also suggested the calculation of trade-offs. According to Maass, ". . . objective functions of most government programs are complex; yet benefit-cost analysis has been adapted to only a single objective - economic efficiency" [34, p. 312]. Maass was concerned with the calculation of a trade-off ratio between economic efficiency and income redistribution.[5/]

[5/] This necessarily implies that economic efficiency and income redistribution goals are on the same hierarchy level as social goals. Economic efficiency and income distribution may be at different hierarchy levels (see [6, pp. 1662-1663]).

Although all of these approaches have merit in the attempt to empirically determine the social preference function, none of the approaches have been explicit as to the effect of varying types of relationships among the components of the social preference function or the production function. All approaches ultimately lead to the calculation of a trade-off ratio. None of the approaches seem to recognize the significance of the effect of relationships among the components in Equation (1.10) and Equation (1.20) on the trade-off calculation process and ultimate value of the ratio. Several implications of different types of relationships can be drawn.[6/]

Calculation of a Trade-off Ratio

The idea of a "trade-off ratio" is well-founded in economic theory, but under a slightly different name. Limiting the discussion to the production side, Equation (1.20), the trade-off ratio is defined as the amount of a product that must be sacrificed to attain another unit of some other product or, more specifically, the marginal rate of transformation (MRT). The trade-off ratio can be illustrated by observing the possible movements along a production possibilities curve, such as pp in Figure 2.

The pp curve represents a given dollar outlay for resources used in the provision of different combinations of Component One (c_1) and Component Two (c_2) (Figure 2). The amounts at A (c_{2A} and c_{1A}) and B (c_{2B} and c_{1B}) can be produced with the same dollar outlay for resources. Any combination on the curve pp can be produced with the same level of dollar outlay for resources.

The trade-off ratio varies along the curve, and is actually the slope of curve pp. For discrete changes such as from Point A to Point B in Figure 2, the trade-off ratio is $-\left(\frac{c_{2A} - c_{2B}}{c_{1A} - c_{1B}}\right)$, which is the average MRT. An amount $c_{2A} - c_{2B}$ of c_2 must be "sacrificed" to obtain $c_{1B} - c_{1A}$ of c_1; the cost of this change is reflected by the MRT.

6/ The results of non-independence or independence in consumption, i.e., among the components in Equation (1.10), must necessarily be conjectural because of the difficulty of specifying a welfare function. In order to point out some implications of non-independence and independence then, discussion is limited only to the production side for the purposes of this paper.

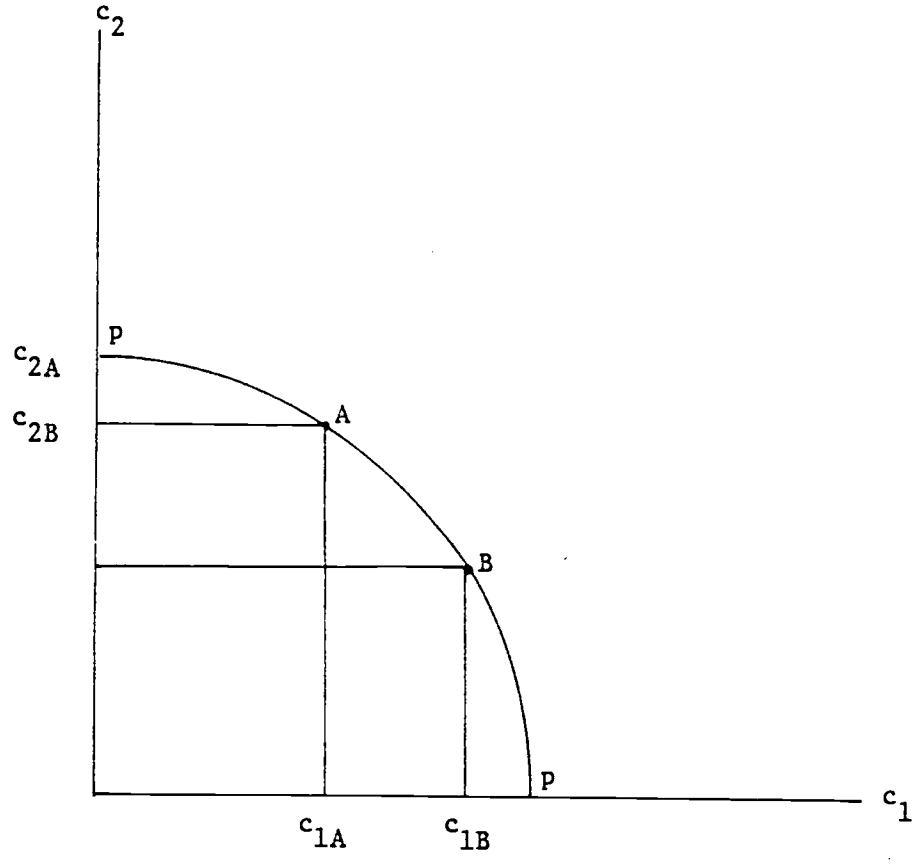

Figure 2. Component-Component relationship, components c_1 and c_2.

The shape of the curve is crucial to the value of the trade-off ratio. Consider, for example, the cases specified in Figure 3. At level 1.50 of c_1, an incremental change in c_1 would result in a -0.24 change in c_2 (the trade-off ratio is 0.24) for the upper curve, a -1.14 change in c_2 for the middle curve, and a -1.24 change for the bottom curve.[7/] In terms of an example, let c_2 represent national income (NI), and c_1 represent some numerical measure of environmental quality (EQ). If the actual relationship between NI and EQ (both are assumed "components" of welfare) was represented by the lower curve in Figure 3, use of either of the other pp curves as the appropriate one would result in an underestimation of the loss in national income from improving EQ from the present level of 1.5 (as depicted in Figure 3). The crucial point is that the trade-off ratio will be affected by the nature of the relationship among the components of welfare in production.

Several different types of relationships among the components of an equation such as Equation (1.20) can be posited, all of which will give slightly different trade-off ratios for any given resource base. There are at least three interesting possibilities from the vantage point of this paper.

The components of welfare are assumed independent in the following case:

Case I

$$c_1 = f(x_1, x_2, x_3, x_4) \qquad (1.40)$$

$$c_2 = h(x_1, x_2, x_3, x_4, x_5)$$

where $x_1, x_2, \cdots, x_5$ are inputs from either the public or private sectors. In this case it is appropriate to treat the two components as competitive, for inputs. "Trade-offs", as the term is usually used in the cost-effectiveness literature, would appear to be appropriate. The policy issues here are quite straightforward, and it appears that much of the literature on public policy assumes this to be descriptive of reality.

[7/] Based on use of the calculus to derive the relationship $\left(\frac{dc_2}{dc_1}\right)_{x \text{ constant}} = \frac{\partial c_2}{\partial c_1}$ from the functions: $x = c_1^2 + c_2^2 - c_1c_2$, $x = c_1^2 + c_2^2$, and $x = c_1^2 + c_2^2 + c_1c_2$ for the upper, middle, and lower curves respectively, in Figure 3.

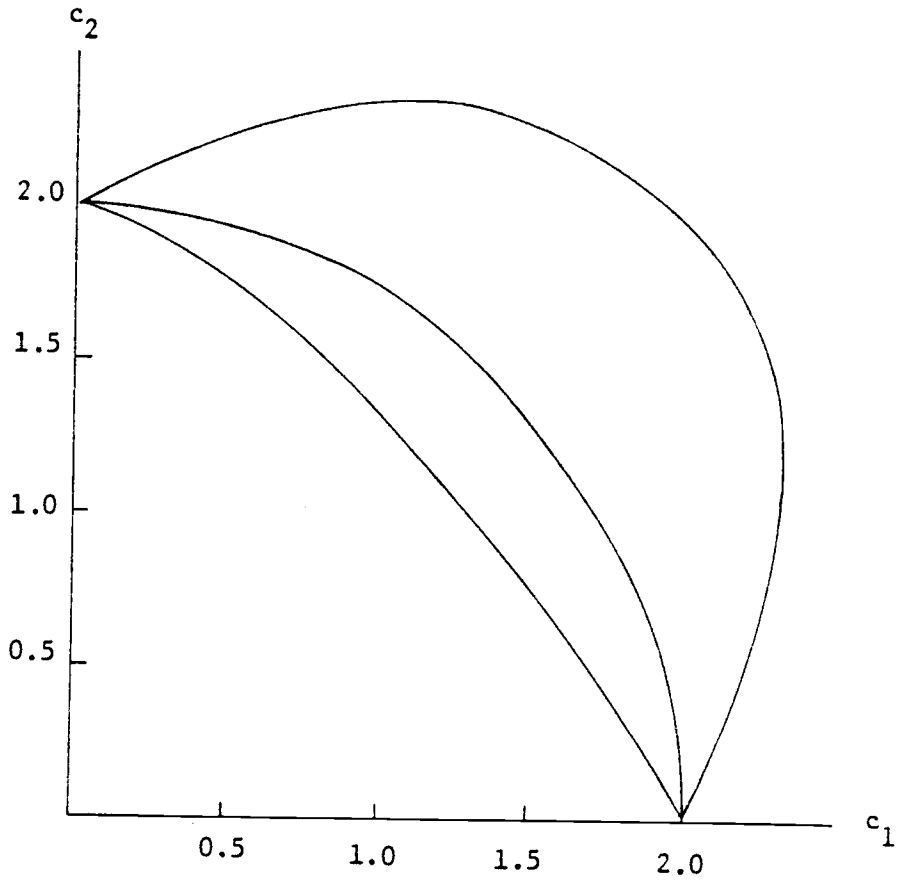

Figure 3. Production possibility curves for three different relationships among components of welfare, c_1 and c_2.

The concept of intermediate products is essential to an understanding of the following case:

$$\text{Case II} \qquad c_1 = f(x_1, x_2, x_3, x_4) \qquad (1.50)$$
$$c_2 = h(x_1, x_2, x_3, x_5, c_1).$$

In this instance, the two components of welfare are competitive with respect to resources. Also, one component (say education) becomes an intermediate product in the production of the other component (say national income). Substantial interdependence exists. Decision rules and techniques involving "trade-offs" will need to be quite sophisticated to sort out and account for both the complementary and competitive aspects. For example, c_1 might represent income from the private sector and c_2 might represent a component produced in the public sector. One activity is essential to the other, but it also is competitive with respect to the inputs.

Even greater interdependency is illustrated in the relation:

$$\text{Case III} \qquad c_1 = f(x_1, x_2, x_3, x_4, c_2) \qquad (1.60)$$
$$c_2 = h(x_1, x_2, x_3, x_5, c_1).$$

Each component of welfare is an intermediate product in the production of the other. Furthermore, the two components are competitive in the use of resources.

The procedures for calculating trade-off ratios may have to be quite sophisticated, given either of the cases represented in Equations (1.50) and (1.60). The possibility exists for two or more components of welfare to have some complementary as well as competitive aspects. Consider, for example, health level versus education level. The education level attained by members of a society may have a complementary effect on the level of health achieved; i.e., higher education levels may give greater medical knowledge which, in turn, may give rise to a higher health level. At the same time, a higher health level may improve the education level by allowing more attention to studies, less days spent away from school ill, etc.

Concurrently with these two interdependencies, both health and education levels may compete for some or all of the same resources. The calculation of a

trade-off ratio between health level and education level would indeed be more difficult with the presence of interdependencies.

Nature of Independence and Interdependence

At least two different types of interdependence (independence) must be distinguished. Production functions may be interdependent (independent) as well as the components. For example, assuming one resource, x, the production functions in Case I were of the general form:

$$c_1 = f(x) \qquad (1.41)$$

$$c_2 = g(x)$$

In this situation, the two production functions are independent; the components do not serve as inputs. Also, the components, c_1 and c_2, are independent; independence among components is given by the sign of the cross partial derivative, $\frac{\partial x}{\partial c_2 \partial c_1}$. [8/]

The production functions are considered interdependent and the components are independent in the following case, which is the same as Case II with only one resource:

$$c_1 = f(x) \qquad (1.51)$$

$$c_2 = h(x, c_1)$$

The components are classified, again, on the basis of the sign of the cross partial, $\frac{\partial x}{\partial c_2 \partial c_1}$.

A different situation arises with Case III where, again with only one resource:

$$c_1 = f(x, c_2) \qquad (1.61)$$

$$c_2 = h(x, c_1)$$

[8/] Components are considered interdependent and independent accordingly, as

$$\frac{\partial x}{\partial c_2 \partial c_1} \gtrless 0 \text{ and } \frac{\partial x}{\partial c_2 \partial c_1} = 0.$$

(See Sune Carlson [4, p. 80]).

The production functions are interdependent, while c_1 and c_2 may be independent or interdependent.

Based on the expressions in Equations (1.51) through (1.61), some definitions can be posited:

1. two production functions are considered interdependent (independent) if at least one of the components does (does not) enter as an input into the production of the other component,
2. two components are considered interdependent (independent) if the cross partial, $\frac{\partial x}{\partial c_2 \partial c_1} = \frac{\partial x}{\partial c_1 \partial c_2}$, is not equal (is equal) to zero.

Several possible situations can now be posited with regard to different types of relationships.

Given independent production functions, the components will always be independent. The converse does not hold, however; the existence of independent components does not imply that production functions are independent. In fact, production functions may be interdependent when the components are independent.

Given interdependent components, the production functions will always be interdependent. As in the previous situation, the converse does not hold; the existence of interdependent production functions does not imply that the components are interdependent.

The results of this section are summarized in Table 2. Given a particular case, only in Situations 1 and 4 can a definite statement be made regarding the relationship of concern. In the other two situations, 2 and 3, further analysis is necessary (Table 2).

Classification of Components

An understanding of the consequences of interdependence or independence among components of the welfare function is crucial to understanding the effects of various strategies of public investment. Any attempt at making a rational decision as to the types of investments to be encouraged must be tempered by knowledge of the relationships involved.

Table 2. Relationship Between the Classification Scheme for Production Functions and Components Produced

Situation	Given	Conclusion
1	Independent production functions	Components are independent.
2	Interdependent production functions	Components are independent, given production functions in Case II.
		Further analysis needed to classify components in Case III.
3	Independent components	Further analysis needed to classify production functions.
4	Interdependent components	Production functions are interdependent.

Public investment has the effect of moving the production possibilities curve for the desired components of the welfare function by two different means. The production possibilities curve will reflect greater production for two components, c_1 and c_2 for example, due to:

1. reallocation of resources towards the production of the desired components (c_1 and c_2); i.e., resources are removed from the production of some other component(s) (like c_3, c_4, etc.) in the public (private) sector,
2. allocating previously unemployed resources to the production of the desired components (c_1 and c_2).

The type of interrelationships prevailing among the components are observable from the way in which the amount of each component produced changes as a greater amount of resource is incorporated into the production processes.

Expansion of the amount of input employed in the production of components of welfare can result in the surfacing of two different types of interrelationships, namely, interdependent and independent. As alluded to earlier, components will be classified as interdependent (independent) if the cross partial, $\frac{\partial x}{\partial c_2 \partial c_1}$, is greater than or less than zero (equal to zero). Within the classification of

interdependent components, components may be further classified as complementary or competitive, according as the cross partial derivative is negative or positive, respectively. The meaning of these more specific categories can be made clear by reference to Figure 4.

Consider a change in the resources (ΔX) allocated to the production of c_1 and c_2, from the original production possibility curve $p_o p_o$ (Figure 4). The several different types of interrelationships can now be ascertained by looking at the sign on the value $\frac{\Delta}{\Delta c_2}\left(\frac{\Delta X}{\Delta c_1}\right)$, which is a discrete representation of the cross partial, $\frac{\partial x}{\partial c_2 \partial c_1}$.[9/]

Starting at Point A on $p_o p_o$, the sign of the cross partial will be positive (indicating competitive components), if the ending position is Point B on $p_2 p_2$. This is indicated by the change in c_1 (Δc_1) in the "discrete partial", $\frac{\Delta}{\Delta c_2}\left(\frac{\Delta x}{\Delta c_1}\right)$, as c_2 is increased (Δc_2), with Δx constant. In the movement from Point A to Point B, Δc_1 decreased, which resulted in $\frac{\Delta}{\Delta c_2}\left(\frac{\Delta X}{\Delta c_1}\right) > 0$, which implies a competitive relationship between c_1 and c_2. As illustrated in Figure 4, change in c_2 (Δc_2) resulted in a decrease in Δc_1 from AE to FB, giving an increase in $\frac{\Delta X}{\Delta c_1}$. The end result was a positive sign on $\frac{\Delta}{\Delta c_2}\left(\frac{\Delta X}{\Delta c_1}\right)$, which implies a competitive relationship between c_1 and c_2.

Given an independent relationship, a change in X (ΔX) will give rise to the cross partial, $\frac{\partial x}{\partial c_2 \partial c_1}$, equal to zero. This situation is exemplified in Figure 4 by the movement from A to C; the discrete partial $\frac{\Delta X}{\Delta c_1}$ doesn't change (AE = FC), which implies that $\frac{\Delta}{\Delta c_2}\left(\frac{\Delta X}{\Delta c_1}\right) = 0$.

The complementary relationship is exemplified by the movement from Point A

9/ This presentation is based upon insights gained from discussion with Dr. A. N. Halter, Department of Agricultural Economics, Oregon State University.

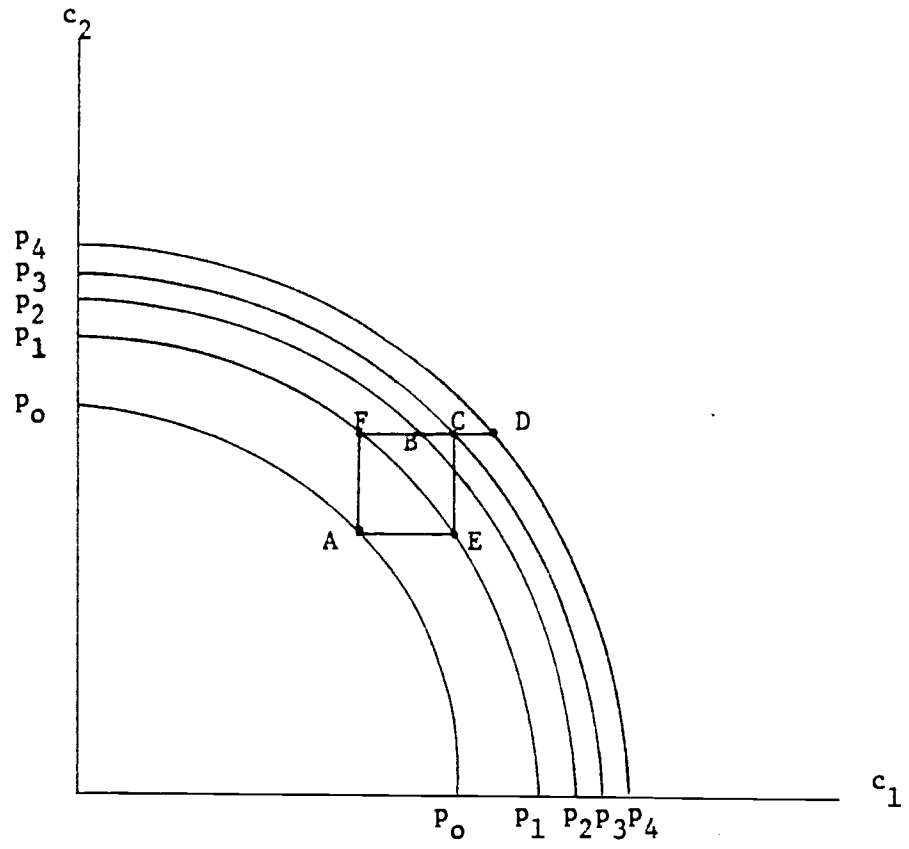

Figure 4. Classification of relationships between c_1 and c_2, diagrammatic representation of the cross partial

$$\frac{\partial x}{\partial c_2 \partial c_1}$$

to Point D. With the same ΔX as before, the discrete cross partial $\frac{\Delta}{\Delta c_2}\left(\frac{\Delta X}{\Delta c_1}\right)$ is negative. This occurs as a result of Δc_1 increasing (FD > AE), which gives rise to a decrease in $\frac{\Delta X}{\Delta c_1}$. Expanding X gave rise to an increase in c_2 and in Δc_1: the components are necessarily complementary.

CONCLUSIONS AND RECOMMENDATIONS

Several conclusions can be drawn from this study of multiple objectives and means of solving the "multiple objective problem", given various types of relations among objectives. Some of the more significant conclusions are.

1. The "evolution" of the multiple objective function has really been only a process leading to recognition of multiple objectives; i.e., multiple objectives have just recently been made explicit in planning literature, although they have long existed in the legislation authorizing public investment in resource development projects.
2. The type of relationships among objectives will affect the trade-off ratio calculations in terms of the process of calculation and the ultimate value obtained.
3. There are at least two different types of relations of concern, namely, the relations among product (component) functions and the relations among components themselves.

All of these conclusions are tentative, and should be subjected to further study.

Research funds should be directed toward identifying the various possible types of relations among objectives. Given that information, a framework should be developed to facilitate the calculation of trade-offs by action agencies. The Special Task Force on Evaluation Practices, appointed by the Water Resources Council, recommended ". . . the use of a systematic process to formulate alternative plans keyed to varying levels of achievement for each of the components of the multi-objectives relevant to the planning study. This process . . . provides for the ordering of priorities among alternative plans in terms of explicit trade-offs" [49, p. 7]. The "systematic process" mentioned here requires knowledge of the types of relations that could possibly be encountered, and a means of handling all possible situations such as to arrive at "explicit trade-offs." The results of this study, although tentative, indicate such a framework can be developed through further research.

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