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MULTIOBJECTIVE RESOURCES PLANNING

by

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SUMMARY

This paper reviews the theory of multiobjective planning, current government proposals for its use in the water resources sector in the U.S.A., and research projects undertaken by the authors using multiobjective analysis. It is proposed that multiobjective analysis be used for Australasian resources planning.

Multiobjective analysis is a generalization of standard benefit-cost analysis. It requires that all socially relevant objectives of public expenditure be taken explicity into account in resources programme design. Current U.S.A. proposals would require programme design in terms of objectives relating to national income, regional development, environmental quality, and social well-being.

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which would be the point achieved by the programme maximizing the traditional net efficiency benefits. B represents a social utility inferior to that of A because it is on a lower indifference curve (not shown). This illustrates the point that, in general, explicit design in terms of all relevant objectives is superior to design in terms of a single objective. (In Figure 1, the social welfare and transformation curves have been drawn with convenient shapes; difficulties can arise if the curves are awkwardly shaped) (7).

An interesting aspect of the analysis is the slope of the tangent line to the transformation curve through the optimal point A. The negative of this slope represents the weight placed by society on an additional increment of net benefits for the objective plotted on the horizontal axis in terms of net benefits for the objective plotted on the vertical axis. In the present example, this weight is interpreted as the number of dollars of net benefit to the national account that society is willing to sacrifice in order to obtain the marginal acre of habitat. This weight can be used to form a multiple objective benefit-cost ratio for the project design at A(8).

Several important changes in terminology stem from multiobjective analysis in contrast to the traditional efficiency oriented analysis. These changes in terminology reflect important changes in concept. In the multiobjective approach, there are no "unquantifiable" or "intangible" benefits and costs. These words in the past referred to benefits and costs not measurable in the national income account. In the multiobjective approach, such factors are enumerated in terms of some convenient metric, such as acres of habitat in the example given, and attempts are made to arrive at policy decisions explicitly in terms of these metrics. A second change in terminology is with respect to "secondary" benefits, which in traditional benefit-cost analysis referred to certain types of national income benefits and to regional income benefits. In multiobjective analysis, there are no primary and secondary benefits and costs - either benefits and costs are relevant for a particular account, or they are not; whether the objectives themselves are important depends on social preferences.

The types of problems encountered in multiobjective investment programming will be evident from the description of the approach just given. These problems involve the careful selection of relevant objectives and the development of appropriate benefit and cost accounts for them; the development of feasible alternatives responsive to alternative weights on objectives; and the use of these alternatives to elicit information about preferences from decision-makers.

In 1970, the Special Task Force of the US Water Resources Council proposed the use of a new set of investment principles, which includes a wide range of important steps forward - for example, the use of explicit scheduling criteria; the use of sensitivity analysis, and others.

The most important advance in these criteria, however, is the explicit injunction to use multiobjective analysis in all Federally sponsored water resources and related land projects. In the report, objectives are categorized into four accounts - national development (the "efficiency" objective); regional development; quality of the environment; and social well being. These accounts are simply convenient groupings for objectives. The latter three are multidimensional: regional development, for example, can be measured in terms of income, jobs, diversity of economic base, and in other ways; and the other two include many subcomponents. In fact, a theoretically pure approach would eschew grouping of objectives in favour of a simple statement that any component of the entire vector of effects of a project might be an objective, and that benefits and costs might be measured with respect to it. However, the grouping in the task force report has a certain convenience in the US context (it reflects the embryonic approach to multiobjectives in the currently governing standards)(9), and serves as a useful set of categories for stimulating debate on objectives and for developing the relevant benefit and cost accounting rules. In the report, benefits and costs are outlined for each objective.

The report does not go the entire way toward full multiobjective decision-making (although it does not prohibit this) in that it does not call for the determination of weights on objectives at the present time. Rather, agencies are required to determine relevant objectives for the various programs under their direction, and then to design several alternative plans emphasizing different implicit weights on objectives. Decision-makers can then choose among these alternatives, and detailed design can be carried out in terms of the preferred alternative (10).

If approved as proposed, the new principles will constitute a very advanced set of investment criteria, perhaps the most advanced to be utilized by any country in its water resources sector. The proposed principles are at present (May, 1971) still being considered in the Executive branch of the government; they have met with favourable response from the Congress, which approved the use of the four proposed objectives for analysis in the Rivers and Harbours Act of 1970 (11).

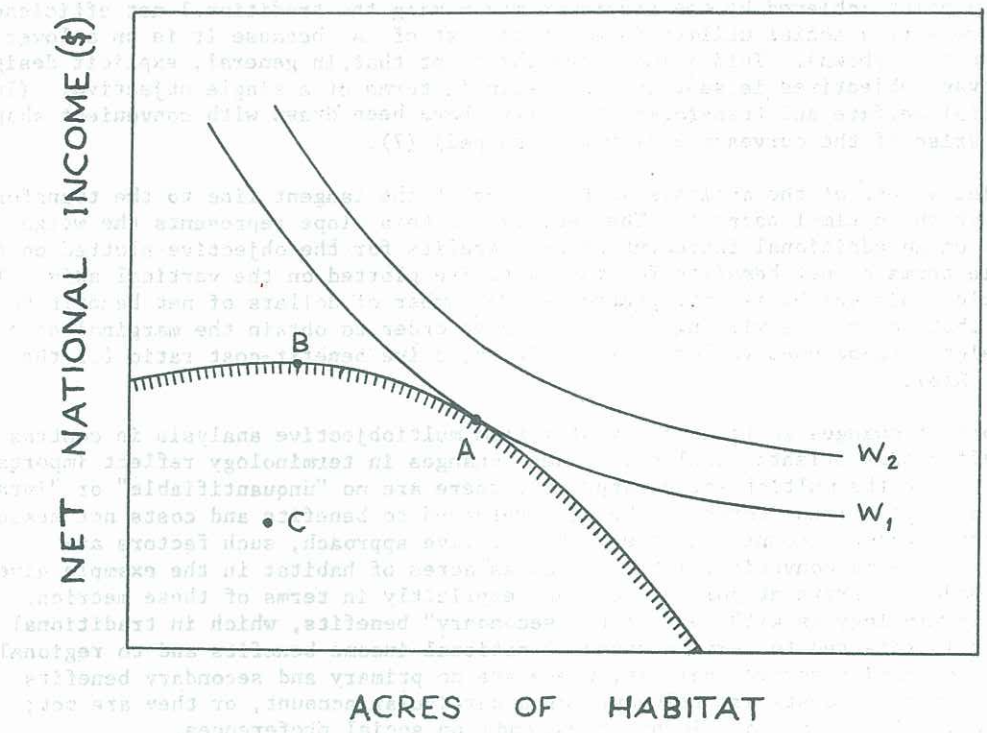

Figure 1 - Graphical Representation of Multiobjective Theory

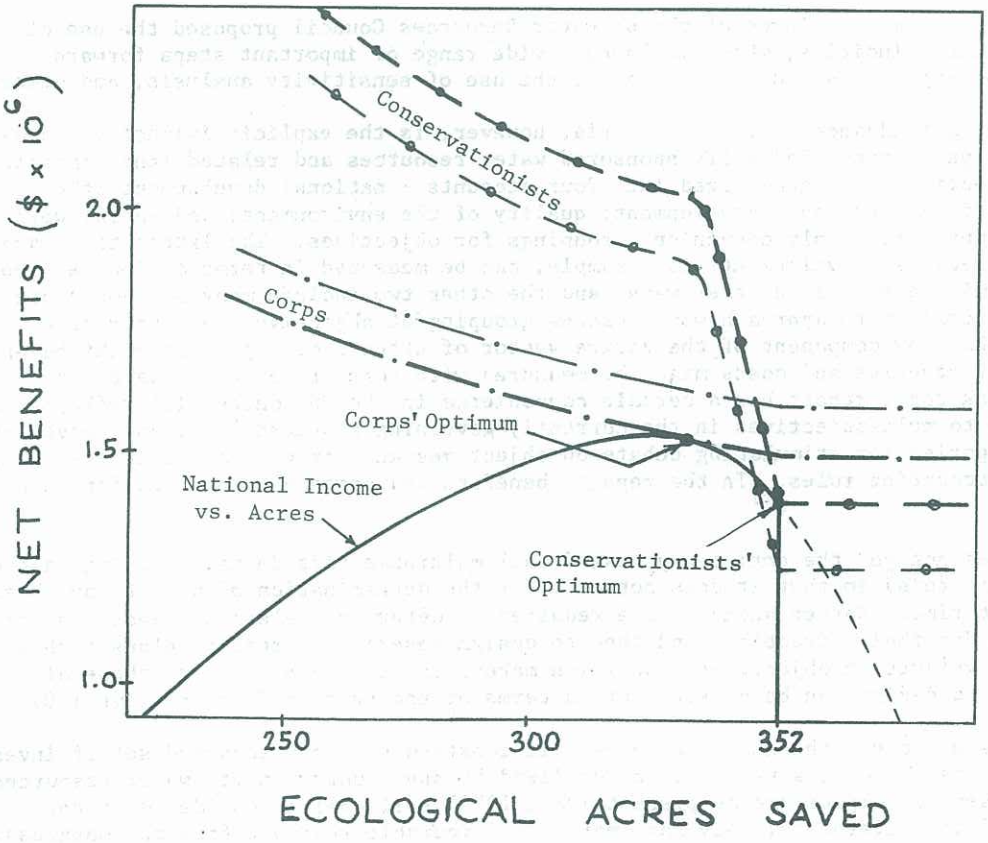

Figure 2 - Illustration of Trade-Offs

As one step in the development of the multiobjective rules proposed in the new standards, an earlier version (12) of the proposal was subjected to a series of tests, in which various agency and university teams (and one private firm) undertook to analyze existing projects in terms of multiobjectives (13). One of these tests was undertaken by a graduate seminar at M.I.T. in which both of the authors participated (14). This test dealt with a proposed Corps of Engineers dam in Indiana on a tributary of the Wabash river of railroad and song fame. The Big Walnut dam was proposed by the Corps as part of a comprehensive,multipurpose (but not multiobjective) basin plan for the Wabash (15). After the Corps proposed the dam, conservationists, led by the local Izaak Walton League and several college professors, condemned it because it would flood a unique (and very attractive, as the authors can testify) environmental area containing a glacial relict biota representing in some respects a Canadian "North Woods" environment (16).

Members of the MIT seminar group visited the site on several occasions, and in addition interviewed representatives of all of the major parties to the controversy. The seminar group decided on the basis of these visits and interviews and a review of documents on the case that two significant objectives are relevant for the Big Walnut investment problem: the national income objective, and the objective of preserving acres of the environmental quality area (17).

To demonstrate how a complete multiobjective analysis might be made by an agency, it was first necessary to develop a net benefit transformation curve. The initial step in constructing this curve was to estimate net discounted national income benefits for various feasible levels of storage for a dam at the Big Walnut site. These benefits were then related to acres of the environmental area preserved by plotting them against flood pool elevation, which in turn was related to acres preserved by analysis of topographic maps of the area.

After discussion with participants in the controversy and analysis of the various documents available in Corps files and elsewhere the group suggested the probable shapes of the indifference curves of two parties to the controversy, the Corps and the conservationists. The indifference curves suggested for the Corps represent the then (at the time of planning) prevailing national view as embodied in traditional benefit-cost analysis that national income is the basic objective of investment, but that minor concessions can be made to accommodate other objectives on an ad hoc basis. The conservationists' curves represent their concern with the integrity of the area - if the first few acres were to be taken, the land would still be valuable to them, but a signigicant part of its uniqueness would be lost.

The transformation curve developed by the group gave a straightforward result: on the assumptions used, the optimal size of the dam for national income was such that the environmental area would not have been affected. In these circumstances, presumably both the Corps and the conservationists would have chosen the national income maximizing project. In order to illustrate the nature of a decision in which a tradeoff between objectives would have been required, the transformation curve was arbitrarily shifted so that some of the approximately 352 acres of environmental quality land would have been taken had national income been maximized. The indifference curves hypothesized by the group were then laid over this shifted transformation curve yielding the two optima shown in Figure 2. For the optima shown, the marginal acre of the environmental quality area is worth $1700 in average annual net national income benefits to the Corps, and $24,000 to the conservationists. It should be emphasized that these values are by way of illustration. Had the seminar had the resources available to a government agency for detailed examination of the problem, the values would undoubtedly have been estimated differently.

At the present writing, the Corps is reconsidering the Big Walnut dam at the direction of the Congress, specifically with reference to the environmental consequences of the dam, and it is hoped that the Corps will utilize the multiobjective approach outlined here.

An Australian application of multiobjective analysis has also been undertaken by one of the authors (18). This application relates to the management of forest resources including timber, water, soil, minerals and wildlife. It is proposed in the study that multiobjective analysis procedures,along the lines of those now being implemented in the water resources sector, should be applied to the management of Federal and State forests in both the United States and Australia.Forest management objectives would thus be categorized into four accounts, corresponding to those used for water resources: national development; regional development; conservation of environmental quality, and social well being. All benefits and costs of alternative management plans would be calculated for each objective and each alternative would be used to elicit information as to social preferences for the relevant objectives of forest management.

A small-scale case study of the proposed theory has been completed for Mt.Macedon Forest Park, a high-quality environmental area of 3300 acres situated about 40 miles north of Melbourne Four major components of this natural resource system were selected as being of primary importance in the establishment of management objectives for the Forest Park: water quality (for

domestic use); softwood timber production (from plantations of introduced Pinus Radiata); recreational developments and conservation of wildlife habitat. As in the Big Walnut study, these components were grouped into two objectives: increasing national income (through outputs of timber, water supply and recreation development) and preserving environmental quality, especially in regard to wildlife habitat and visual amenity. Critical areas of conflict in the Forest Park were identified by a computer mapping and evaluation technique (19) and transformation curves were then developed for each of the two major conflict areas, using dollars of national income and acres of undisturbed natural habitat as the appropriate metrics. Preference curves were suggested for the Victorian Forestry Commission, several public Water Trusts and a local conservation group. The results of this work are at present being evaluated by several government agencies in Australia and by the United States Forest Service.

On the basis of the general progress made in multiobjective programming and the authors' own experiences with the technique, we believe that efforts are warranted to expand the applications of this technique in the Australasian area for water, forest, and other resources studies. For Australia we could recommend early application to water resource developments such as the proposed (and highly controversial) flooding of Lake Pedder in Tasmania; the regional development and conservation of watershed systems such as the Latrobe Valley in Victoria, and the management of natural resource systems such as State forests and the Australian Alpine region.

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12. United States Water Resources Council,"Report of the Special Task Force: Proposed Standards for the Evaluation of Water and Related Land Resources"(June 1969).

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14. The material that follows is drawn from David C. Major and Associates,"Multiple Objective Redesign of the Big Walnut Project", Water Resources Council - M.I.T. Cooperative Agreement WRC-69-3 (April 1, 1970) which contains relevant references.

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