Environment and Development Economics 5 (2000): 259–288

Policy Options

Sustainability criteria and cost–benefit analysis: an analytical framework for environmental–economic decision making at the project level

DIRGHA N. TIWARI
PO Box 12609, Kathmandu, Nepal

ABSTRACT This article develops a framework for environmental–economic decision-making in a single project case that includes the ecological sustainability criteria, environmental costs, natural resource scarcity prices and local peoples' preferences and presents a case study of the lowland irrigated agriculture system. The geographic information system (GIS) technique has been used for evaluating ecological criteria and integrating information for use in the cost–benefit analysis at different levels of computation process. The environmental costs and economic value of water associated with the lowland irrigated agriculture are estimated using both the direct and indirect economic valuation approaches. Various sets of alternatives were designed for promoting sustainable use of resources, and the net present value is estimated in each of these cases by incorporating environmental costs and economic values of water obtained from different methods. The cost–benefit analysis (CBA) carried out in these different cases indicated that diversification of crops, rather than the conventional monocropping system, would promote sustainable resource use and generate higher benefits to the farmers and society, if external costs, such as environmental costs and scarcity value of irrigation water, and ecological sustainability criteria are also considered in the economic decision-making process. The results of the case study also indicated that sustainability criteria could well be incorporated into the CBA in a single project case by addressing local people's concerns, resource scarcity values and ecological sustainability criteria with the use of spatial analysis techniques such as GIS.

1. Introduction

The recognition of the concept of sustainability as a major guiding principle of economic policy has added a new dimension to the development of the decision-making process. Decision-making techniques at the project level have long been dominated by conventional cost–benefit analysis (CBA). CBA is considered a decision-making technique intended to improve the quality of public policy decisions using a monetary measure of the aggregate change in societal well-being resulting from a policy decision, and as a consistent procedure for evaluating decisions in terms of their consequences (Kopp *et al*., 1997; Dreze and Stern, 1987). The theoretical foundation of CBA is, thus, based on the social welfare concept, and has widely been used in the past for ranking policies on the basis of their improvements, or reductions, to well-being. However, in practice, many societal costs arising from the developmental activities and local peoples' preferences are often neglected, or not included in the analysis. Quantification and monetization of environmental impacts for use in CBA are usually not carried out due to the lack of information on the cause and effect relationships between the economic activities and the environment. In such cases, while multi-objective and multi-criteria techniques proved to be more useful tools for incorporating sustainability criteria and may complement economic analysis (Toman, 1998), CBA is still considered an important decision-making tool in economic analysis (Arrow *et al.*, 1996). Further, as Pearce (1996) pointed out, due to growing scarcity of resources, economic efficiency criterion has been even more important in the selection of projects for the developing countries, and CBA attaches even more importance to the development decision-making process in these countries. However, to what extent CBA can adequately account for sustainability concerns in project appraisal is subject to wide debate. There is the need for both re-evaluation of the underlying principles of CBA itself, and the need to develop procedures that help incorporate sustainability criteria and guide the decision-making process at the project level, especially in the context of developing countries.

The concept of sustainability, as defined by The Brundtland Commission (WCED, 1987) that the economic development path should be pursued in such a way as to meet the needs of the present generation without compromising the ability of future generations appears too vague to apply for operational purposes at the project level (Winpenny, 1996, Barbier, Pearce, and Markandaya, 1989). The generally advocated operational definition of sustainability indicates the need to maintain natural capital (such as forests, land quality, freshwater resources, air quality), or total capital stock over time (Barbier, Pearce and Markandaya, 1989; Daly, 1991), and preservation of the productive capacity of the resource base for the indefinite future (Solow, 1992). These operational concepts have further been classified into 'strong' and 'weak' sustainability cases. Whereas, the notion of 'strong sustainability' leads to a concern over resources, environment, and the ecological basis of development (Victor, 1991), the 'weak sustainability case' indicates the possibility of resource substitution between man-made and natural capital for maintaining the resource productivity over time. In the context of the developing countries, as the per capita resource stocks is usually low, or available stocks of natural resources are already declining, the applicability of the 'strong sustainability' criteria at the project level, with constraints on the maintenance of natural capital intact, looks a distant question. Likewise, as the per capita resource saving is low, resources available for reinvesting in natural capital are also seriously constrained. In such a context, the weak sustainability concept, rather than the notion of 'strong sustainability', may be a more relevant concept for incorporating sustainability concerns into decision analysis. This allows for making investment decisions by incorporating both the ecological sustainability and economic efficiency criteria as emphasized by Pearce (1996). Incorporation of the 'weak sustainability' criteria in the decision-making process is thus a basic step toward addressing sustainability concerns at the project level in the context of developing countries.

How can the operational concept of sustainability (weak sustainability, in this case)—a measure of change of societal welfare—be integrated with CBA for development decision making at the project level? After the concept of sustainability was put into the limelight by the Brundtland Commission (WCED, 1987), both the theoretical concepts and practical applications have been advanced towards integrating environmental concerns into CBA (e.g., Barbier, Pearce, and Markandaya (1989); Bojo, Maler, and Unemo (1992); Dixon *et al.* (1994); OECD (1995a, 1994). These various efforts made in the past provide some examples of the application of economic valuation methods, use of appropriate discount rates, and decision analysis using the cost–benefit framework. However, many issues are still unclear for extending the applications to the developing countries. First, integration of sustainability concerns into CBA requires a more comprehensive approach than just computation and incorporation of quantifiable environmental costs and benefits. While developing empirical measures of well being in CBA, it is also equally important to satisfy ecological sustainability criteria and local people's preferences at the same time. Second, the development decision-making process at the project level involves both spatial and temporal dimensions, and the concept of sustainability provides the basic foundation for societal welfare, addressing the dimensions concerned with the well being of both the present and future generations. Third, past attempts, such as the CBA framework developed to incorporate environmental sustainability criteria, for example, by Barbier, Pearce, and Markandaya (1989), is limited to the multiple project case. In a multiple project case, negative environmental costs generated by a project could be compensated for from the gains from another project while still maintaining the total natural capital intact. How this can be addressed in a single project case still remains an area for further research as, in practice, no compensation mechanism is designed and applied to mask the loss in societal welfare resulting from a single project case.

In this context, this paper attempts to provide an analytical framework for CBA combining ecological, economic, and social sustainability criteria at the project level in a single project case by presenting a case study of lowland irrigated agriculture. The plan of the paper is as follows. Environmental issues and sustainability criteria for lowland irrigated agriculture are briefly discussed in section 2. An analytical framework for integration of sustainability criteria and CBA using GIS techniques is developed in section 3. Section 4 presents the baseline information of the study area. Section 5 briefly summarizes the results of evaluation of ecological sustainability criteria using a GIS technique. The results of the estimation of environmental costs and economic valuation of irrigation water are presented in section 6. Results of the survey on farmer's preferences and estimation of incremental benefits are presented in section 7. Various alternatives satisfying both the ecological and social sustainability criteria are then designed and presented in section 8. Section 9 presents the estimation of net present value (NPV) for each alternative designed, and results obtained in each of the cases are discussed and compared. Finally, section 10 summarizes the results, and concludes with further recommendation on policy and research.

2. Environmental issues and sustainability criteria for lowland irrigated agriculture

Lowland areas have always been a major concern for sustainable intensification of agriculture. Concerns over maintaining food security as well as reducing pressure on the fragile upland ecosystem in developing countries are closely related to resource use patterns and productivity of the lowland ecosystems. On the other hand, increasing water resource scarcity and externalities associated with the irrigated lowland agriculture have raised serious questions about the capability of the lowland ecosystems to sustain long-term productivity and food security. Natural resource and environmental concerns such as water scarcity, increased use of agrochemicals for maintaining farm productivity, increasing waterlogging and soil salinity, surface and ground water pollution. Increased health effects from pesticide use, etc. are also drawing wide attention.

Defining sustainability criteria in operational terms is the first basic step towards integrating these wide concerns into CBA. Both the concept of sustainability and development of an analytical framework for CBA at the project level, on the other hand, largely depend on specific local conditions and the availability of the information required. Large-scale irrigation projects in many of the developing countries received wide priority during the 1970s and 1980s. But the past economic performance of these projects has been very disappointing (see, e.g., Easter, 1993; World Bank, 1993; Howe and Dixon, 1993). A survey on the economic rate of returns on World Bank assisted irrigation and drainage projects in the developing countries indicated that, while the average rate of return was estimated to be 17 per cent during 1974–82, it decreased to 13 per cent during 1982–92 (World Bank, 1994). In addition, the growing scarcity of irrigation water, especially during the dry season, is limiting the continuation of present agricultural practices; for example, rice cultivation during both the wet and dry seasons. Economic returns for the projects estimated on the assumption of incremental benefits from rice cultivation tend to decrease with decreasing water availability during the dry season. Likewise, cumulative environmental costs caused by the irrigation projects, and interactions with the ecosystem, have also not been seriously considered in the past (Feder and Moigne, 1994). Increased crop damage from floods, droughts, waterlogging, and insects; health effects of pesticide use; and potential on-site and off-site costs of increasing use of agrochemicals, etc. are more frequent and common in many developing regions. Moreover, local people's preferences and their knowledge are not well incorporated into the decision-making process. While setting out sustainability criteria at the project level, these various local specific concerns have to be addressed.

Although there is still plenty of disagreement about the operational definition of sustainability, some specific criteria can be set out as to what the implications are at the project level of incorporating various environmental, societal, and other local concerns. From the standpoint of the environment (or ecological sustainability criteria), less reliance on dangerous forms of agrochemicals (fertilizers and pesticides) is needed and diverse crop rotations are preferred to ones that are less diverse (OECD, 1995b). Moreover, the definition of sustainable agriculture can be widened further, as environmentally non-degrading, economically viable, and socially acceptable (FAO, 1991). Developing sustainability criteria at the project level thus varies from defining the concept as maintenance of resource productivity over time, to a socially acceptable agricultural system. The sustainability criteria in the context of the irrigated lowland agriculture can thus be outlined as: (i) maintenance of the resource base, such as soil quality; (ii) low dependence on external inputs and lower waste generation; (iii) economic viability; and (iv) local farmers' acceptance. Each of these criteria is briefly defined in the context of this paper.

2.1. Maintenance of the natural resource base

In the case of irrigated lowland agriculture, this criterion is related to the maintenance of the soil resource base and agricultural productivity. However, it is rather difficult to measure the soil nutrient balance, monitor its productivity over time, and estimate the economic value. Nevertheless, spatial sustainability analysis combining land capability and suitability provide a sound basis as governing criteria for maintaining soil resource productivity over the long run and for integration into CBA. This involves selecting cropping patterns by the assigning and ranking of the threshold values related to different soil characteristics and topographic factors as a set of constraints affecting soil quality and agricultural productivity.

2.2. Low dependence on external inputs, and lower waste generations

Low-input agriculture is now widely discussed as an alternative way of making the transition towards sustainable agriculture. First, agricultural practices designed to incorporate ecological constraints are supposed to consume less external energy inputs. In this case, the energy output/input ratio estimated for each alternative, designed on the basis of land capability/suitability classes, can be considered as one of the governing criteria for decision making. Second, the type of wastes from lowland irrigated agriculture, such as nitrogen wastes from excessive use of chemical fertilizers and pesticide residues, are difficult to monitor. Usually, higher energy output/input ratio also indicates lower-level waste generation during the production process.

However, again it is rather complex to incorporate the energy output/input ratio as a constraint directly into CBA. To aid in the economic decision-making process, criteria such as minimum use of external inputs, for example, minimum use of agro-chemicals and irrigation water, provide an appropriate framework for incorporating these environmental considerations. First, excessive use of agrochemicals above the normally recommended dose, or base period dose, can also be considered as an indicator of high energy use, and a potential source of waste generation. Second, computation and internalization of external costs associated with the excessive use of agrochemicals above the recommended level, provide a sound basis for incorporating these concerns into CBA. These external costs associated with agrochemicals can be measured in economic units by applying both the direct valuation method (willingness-to-pay), or by using an indirect method (fertilizer-yield dose-response curve).

2.3. Economic viability

Economic viability refers to the ability of the irrigated lowland agricultural system to retain an acceptable level of profitability even when external costs, such as environmental costs and resource scarcity prices, are internalized or incorporated into the economic analysis. The economic viability concept is, thus, embedded in the notion of weak sustainability that natural capital and man-made capital can be substituted. The weak sustainability concept in this case implies that the discounted net present value is still embedded in the economic efficiency criterion, but with considerations of external costs and ecological sustainability criteria, and thus departs from conventional CBA. Various CBA principles are revisited and discussed further in the context of this paper in section 3.6.

2.4. Local farmers' acceptability

Another major concern of agricultural sustainability is the local farmers' acceptance. Local farmers' preferences play a very significant role both in the design and implementation of alternatives aimed at sustainable use of resources. Alternative methods designed without local farmers' acceptance, although they may appear environmentally sound, may not be easy to implement. Implementation of market-based instruments, such as a water charging system for efficient use of irrigation water, may also be difficult without knowing local peoples' willingness-to-pay (WTP) for it. Thus, it is important to know local farmers' preferences in order to determine the economic value of irrigation water, environmental costs, and in designing alternative cropping patterns. Local farmers' preferences, on the other hand, are determined by their household needs. Decisions are usually made by the households to meet these needs, and can be elicited using both the direct (willingness-to-pay) and indirect (ability-to-pay) economic valuation techniques. Farmers' preferences for alternative cropping patterns can also be known by directly asking their preferences for crop diversification under different water-availability conditions.

3. Analytical framework for integrating sustainability criteria and CBA

The practical application of CBA at the project level involves four major steps: (i) collection of baseline information, (ii) arraying of information about the benefits and costs of proposed alternatives, (iii) design of potentially cost-effective alternatives, and (iv) showing how benefits and costs are distributed (Arrow *et al*., 1996; cited in Morgenstern, 1997). The methodological framework developed for CBA with considerations of various sustainability criteria as outlined in section 2, is presented in figure 1.[1] The ecological

[1] The detailed methodological framework for measuring the economic value of irrigation water and environmental costs using various direct and indirect approaches, relevancy of the application of WTP approach in a developing country like Thailand, statistical analysis and the consistency of the results obtained, comparison of the results with other WTP studies, etc. have not been reported here due to the limitation of space and can be found in Tiwari (1998). This paper highlights on the overall methodological framework on these aspects and focuses especially on the integration of the use of GIS techniques and incorporation of sustainability criteria into CBA.

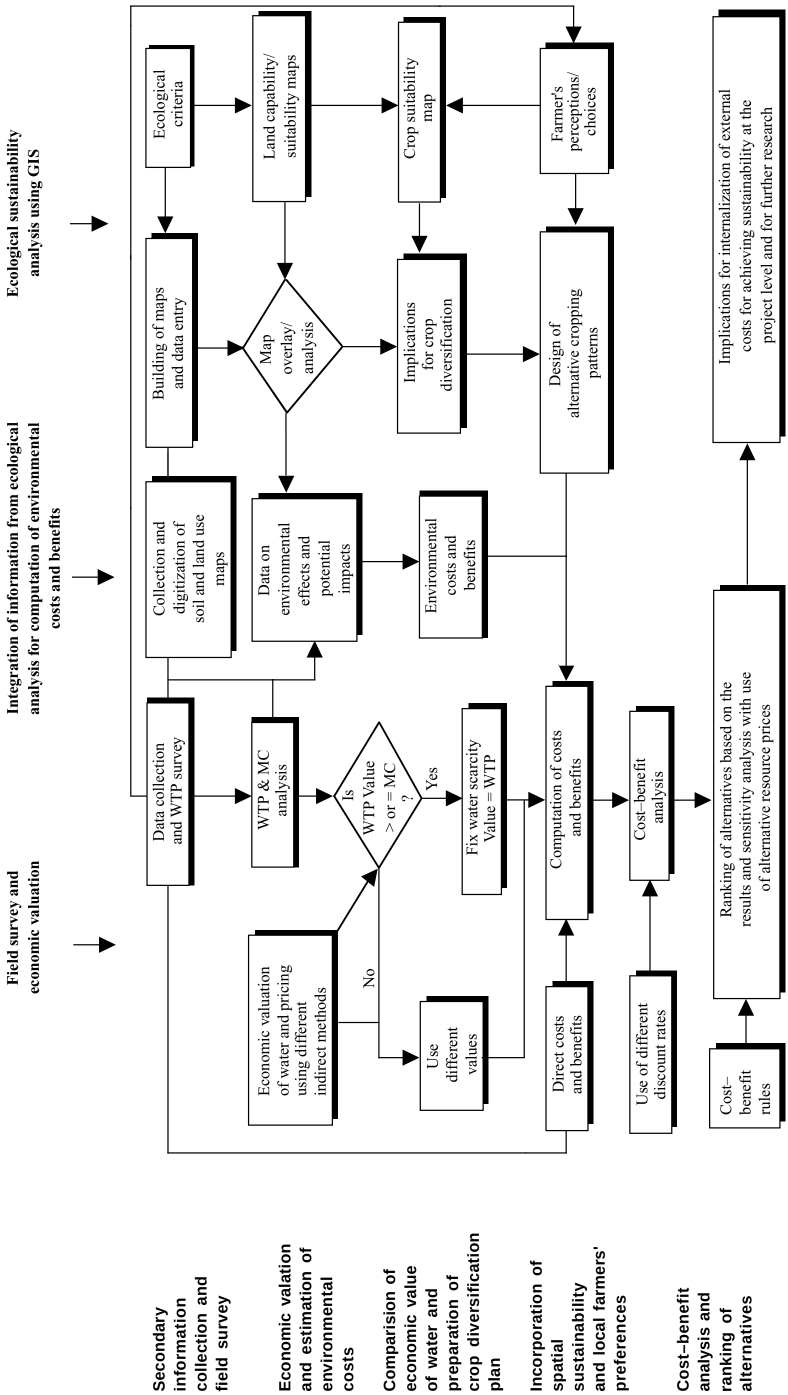


Figure 1. *Methodological framework for sustainablity criteria and cost–benefit analysis using GIS techniques for lowland irrigated agriculture.*

https://doi.org/10.1017/S1355770X00000176 Published online by Cambridge University Press

sustainability criteria, such as maintenance of resource and minimum waste generation, are incorporated using land capability/suitability analysis and ecological buffer zoning approaches. The economic sustainability criterion is based on resource use efficiency and the price of irrigation water and environmental costs. Thus, land capability/suitability analysis using GIS techniques, economic valuation of irrigation water and environmental costs, and measurement of local farmers' perceptions, form the major components of the methodological framework developed for incorporating sustainability criteria into CBA (figure 1).

3.1. Evaluation of ecological criteria using GIS techniques

Evaluation of ecological criteria as outlined in section 2.1 and integration of results into the economic calculus requires spatial analysis addressing several ecological constraints. These various criteria are related to soil characteristics, drainage conditions, and rainfall patterns. The application of GIS provides a sound basis for spatial analysis and integration of information for use in CBA. The GIS is a computer-based cartographic mapping system, which allows users to build-up a map database and perform map overlay analysis. The GIS has been used to perform spatial analysis, such as for database management and monitoring (Smith and Blackwell, 1980); land use planning and management (Woodcock and Franklin, 1983); land suitability mapping (Lyle and Stutz, 1987; Walsh, 1987); crop-specific physical suitability assessment (Juracek, 1988); physical carrying capacity and land suitability analysis (Tiwari, 1991); and in conjunction with multi-criteria decision-making processes (Campbell *et al.*, 1991; Carver, 1991). However, most of these applications are limited to the physical suitability analysis and use of results in conjunction with multi-criteria analysis. Integration of spatial analysis using GIS for use in the CBA is still very rare.

The methodological steps adopted in this paper for evaluation of ecological sustainability criteria include: (i) compilation of available information of the study areas, such as land use, rainfall, soil types, topographic characteristics, canal lay-out, and irrigation zoning maps of the area; (ii) digitization of land use, soil types, and topography maps on a suitable scale; (iii) classification of the study area by different land use, soil types, slope, irrigation zones, distance from the main canal, and buffer strips along the river flowing at the tail-end of the system; (iv) classification of major ecological limiting factors considered, such as drainage conditions, effective soil depth, soil reaction, soil texture, soil salinity, slope, soil nutrients (potassium, and organic matter content), etc. by assigning threshold values in each of these cases; (iv) preparation of separate maps for all of the limiting factors considered; (v) assignment of weights and overlay of all the limiting factor maps; (vi) development of land capability maps with classification of total area into resource rich areas (land having no major constraints), enhancement areas (land area with some constraints, but with potential for development), and resource poor areas (land area with poor drainage and soil conditions) for agriculture purposes; (vii) selection of dry season crops according to the farmers' preferences; (viii) assignment of values and weights to each limiting factor, according to crop requirements using the FAO framework for land evaluation (1985) and the soil suitability classification as developed by the Department of Land Use Planning, Thailand; (ix) development of land suitability maps for each crop; and (x) development of final crop diversification plan considering land capability constraints and particular crop requirements by overlaying both the land capability and crop suitability maps.

The land suitability analysis was carried out for rice and the other three dry season crops—corn, soybean, and mungbean, those preferred by the farmers in the study area. In addition, the ecological buffer-zoning concept was introduced, i.e., to set-aside a strip of cultivated land along the riverbank and convert it into wetlands in order to minimize the water pollution effects from the direct run-off from agricultural fields into the river. The GIS technique was also used to develop distance-based zoning maps from the main canal for crop planning and reducing total water use during the dry season.

3.2. *Integration of information from ecological sustainability analysis into CBA using GIS techniques*

Output from spatial analysis performed using GIS was integrated for computation of costs and benefits at three levels. First, information on land use and cropping patterns generated from GIS were used for the estimation of environmental costs. The basic information gathered through household surveys was entered to the irrigation zoning maps, and an overlay operation was carried out for estimating the total costs. Second, the use of GIS also facilitated identifying specific locations under each crop suitability class, promoting crop diversification in the project area, and designing alternative cropping patterns in order to minimize the water use while satisfying the farmers' preferences for different crops. Third, as mentioned in section 3.1, use of GIS techniques facilitated ecological buffer zoning, using an ecological engineering approach to reduce the effects of agriculture runoff on river water quality. A buffer strip of 1.0 kilometre was introduced and the reduction in cultivated area under each crop was then estimated using GIS overlay techniques. The conceptual framework presented (figure 1) shows operation modules for spatial analysis and integration of information for use in the cost–benefit analysis at different levels of the computation process.

3.3. *Economic valuation of environomental costs and irrigation water*

Economic valuation is essentially a process of measuring people's preferences and converting them into monetary values (Pearce, 1994, cited in UNEP, 1994). Both the behavioural approaches (for example, contingent valuation method) and revealed preference approaches (dose-response, production function, replacement cost, scarcity rent, etc.) are used for measuring environmental costs and scarcity prices of natural resources. Both of these direct and indirect approaches provide a basis for economic valuation of environmental costs and irrigation water costs.

Economic valuation using contingent valuation method

The contingent valuation method (CVM) contains several elements required to elicit theoretically valid measures of peoples' willingness-to-pay (WTP) during a household survey (Mitchell and Carson, 1989). The CVM is one way of measuring farmers' preferences and involves asking questions directly about their willingness-to-pay (WTP) for existing and improved irrigation water supplies. Various studies in the past have applied CVM to measure the economic value of drinking water and to avert health costs from air pollution in the developing countries. However, this literature, for example, Cropper and Freeman (1991), and Hanemann (1994), etc., has also outlined several inconsistency problems in the application of CVM. These problems are usually known as starting point bias and information bias. While the starting point bias is related to how respondents perceive the hypothetical experiment, the information bias is related to the lack of required information, the procedural steps in asking questions including starting of the bids, and the commodity specification bias. The latter occurs when the respondent has little or no knowledge of the public good subject to the economic valuation.

Although most of these inconsistency problems are also common to the applications of CVM in the developed countries, several additional difficulties arise in its application in the case of the developing countries. The first is the disparity in income and the subsistence nature of economy, which may lead to difficulties in measuring the true incomes of the households. Second, because of lower incomes and lower ability to pay, WTP for public services is also expected to be lower. Third, due to the nature of the political economy, it may be difficult to obtain good results from economic valuation techniques such as willingness-to-pay (Vincent *et al*., 1991).

To what extent do these issues limit the application of CVM to economic evaluation of irrigation water and the health effects of pesticides etc., in the developing countries? Many of these arguments, however, have not been supported by the past empirical studies. Hanemann (1994) pointed out that inconsistency in the households response applies to all kinds of household surveys and not only for CVM studies. Past studies for example, Briscoe *et al*. (1990), Whittington *et al*. (1990), Bohm, Essenberg and Fox (1993), Tiwari (1998) have shown that CVM studies can be carried out even at localities where the population is poor and illiterate. There are also ways for verifying the outcomes of survey responses, e.g., comparing the WTP value with the estimated price of water obtained using indirect valuation methods. In this paper economic values obtained from both of the approaches are used for comparative analysis (section 6.3).

The context of rural Thailand

In the context of the study area: (i) the majority of the farmers are facing growing scarcity of irrigation water during the dry season; (ii) irrigation water supplies are being highly subsidized and are still regarded as a public good; (iii) there is a lack of a sense of ownership owing to the lack of cost-sharing provisions and clearly defined water rights; (iv) both the level and collection of operation and maintenance fees are still very low; and (v) about 32 per cent of the population in the area still are well below the poverty line. In such a context, application of the public valuation technique may present some challenges such as: What can be the maximum, or minimum, amount to be asked using close-ended questions for knowing farmer's WTP? People may overstate their WTP if they know that some donor agencies, or the government, have already decided to provide water services to them. On the other hand, they may understate if they have actually to pay according to their stated WTP. Both the design and administration of questionnaires need to avoid such strategic bias if possible. Some measures taken to avoid some of these biases in the study design and survey carried out include: (i) prior knowledge of the supply price of the existing schemes, which provides a basis for determining maximum and lower limits for designing dichotomous choice questions and for comparing the results obtained; (ii) a description of the scenario of water scarcity and the likely effects on profitability of the rice farming practices if water charges were introduced; (iii) the design of questionnaires which successively lead to the respondent's reply to his WTP; and (iv) pre-testing of the questionnaires to avoid hypothetical bias.

The field survey was carried out for measuring farmers' WTP with three different sets of questionnaires: (i) on household characteristics and socio-economic conditions; (ii) on environmental conditions and farmers perceptions of water availability during dry season planting; and (iii) on farmer's willingness-to-pay under conditions of (a) existing water supply, (b) increased competition, or scarcity of water, and (c) improved water supply. Both the dichotomous choice and open bid questions were designed for measuring farmer's WTP under these conditions.

Economic valuation of irrigation water using revealed preference methods

While farmers' WTP provides a single measure of the economic value of water, the use of other indirect valuation methods provides a basis for comparing the economic value obtained from user's WTP analysis. Various indirect valuation methods used in this case study include: (i) estimation of the crop-water production function relating total rice production as dependent variable to the total depth of water applied in the wet season using cross-sectional data obtained from the project office; (ii) estimation of farmers' ability-to-pay by calculating net benefit after deduction of all on-farm costs from the total value of production generated for both the wet and dry crop seasons; (iii) project cost recovery amount over a project life span of 30 years including operation and maintenance cost per ha per year; (iv) marginal construction cost based on time series analysis of incremental investment made in the irrigation development and the additional area brought under irrigation in each year for the whole of Thailand for the years 1978–1988; (v) opportunity cost of water extraction from other sources, such as the unit costs involved for the use of ground water in nearby localities, and (vi) the scarcity rent of water based on the stepwise calculation of marginal construction costs.

3.4. Economic valuation of existing and potential environmental effects

Economic valuation of environmental effects usually involves quantification of impacts, and conversion into monetary units. In irrigated lowland

https://doi.org/10.1017/S1355770X00000176 Published online by Cambridge University Press

agriculture, especially, three kinds of environmental effects are of major concern: (i) health effects from pesticide use during its application, (ii) potential water pollution costs from excessive use of agrochemicals, and (iii) crop damage or decline in productivity due to waterlogging. The cost of health effects of pesticide use was estimated based on the reported cases of illness during pesticide applications and using the cost of illness approach. The cost of illness approach has widely been used in the economic valuation of morbidity cases. Cropper and Freeman (1991) focused on the estimation of restricted activity days, bed disability days, symptom days, and the reported cases of diseases related to the specific pollutants. Harrington *et al.* (1987) developed a relationship for the valuation of health risks of waterborne diseases incorporating leisure and expenditure variables as the determining factors into the individuals utility function. They showed that changes in the value of health risks associated with individual's response to increased water contamination, is related to direct disutility of illness, lost work productivity, value of lost leisure, and medical expenses. The application of cost of illness approach, however, has two major problems when applied to developing countries. The first is concerned with the value of time lost due to illness and the second is attached to an ethical question: this method does not include an individual's perception of suffering. The high level of disguised unemployment, especially in the rural sector of developing countries, raises the issue of an accurate valuation of the time or productivity loss due to illness. While this problem may be corrected to some extent by using a shadow wage rate, the second issue demands application of public valuation techniques to know individuals stated preferences.

For these various reasons, both the cost of illness and the WTP survey approach were used. Farmers were also asked to express their WTP for maintaining the present rate of use of pesticides and chemical fertilisers. The set of questions asked also consisted of their willingness to reduce the existing fertiliser dose and their WTP if they wanted to retain the existing level of fertiliser use on their farm. The cost of waterlogging effects was estimated based on the information on crop damages, or decline in crop productivity in the past, as reported by the farmers. More details on the use of economic valuation methods can be found in Tiwari (1998).

3.5. Calculation of on-farm crop damage costs

Farmers in the lowland irrigated areas also face problems from changing physical environmental conditions, such as droughts and floods. These can be considered as additional on-farm costs to the farmers caused by changing resource use patterns and hydrological conditions. Additionally, they also sometimes face crop damages from increased attacks of pests. These costs, which are not usually taken into account, were estimated based on the information provided by the farmers on the loss of total crop area during the past five years. The loss of total value of production was then calculated by estimating the total loss in production and multiplying by the market price of the product.

3.6. Sustainability criteria and CBA

The incorporation of sustainability concerns, especially criteria such as maintenance of the resource base and minimum waste generation, or environmentally non-degrading criteria into CBA in a single project case, needs more explanation. Economic interpretation of environmentally non-degrading criteria, or the constancy of the natural capital stock, can be considered as the constant economic value of that stock. While developing sustainability criteria for CBA, this concept can be modified as to mean that a project yielding environmental damage should be zero, or negative (Barbier, Pearce, and Markandaya, 1989). This rule, however, can be applied only across a set of projects, assuming that the loss of natural capital stock from one project can be compensated for from another project, while still maintaining the constancy of the total natural capital stock. Thus, the CBA framework developed and used in this paper differs slightly from conventional analysis and earlier attempts in incorporating environmental sustainability criteria into CBA. Table 1 provides some comparative analysis based on the conventional CBA principles outlined

Table 1. *Conventional and environmental CBA as applied in this paper*

Conventional cost–benefit analysis principles	*Environmental cost–benefit analysis principles (this paper)*
1. Total benefit of the project exceeds	1. Total benefit of the project exceeds the total costs, but with considerations of environmental and social sustainability criteria as well.
2. Changes in welfare are given by the difference of welfare with and without the project.	2. Changes in welfare are given before and after the project
3. Cost measurement is founded on social opportunity costs, but often only direct costs are considered.	3. Cost measurement is founded both on the environmental costs and scarcity price of resources, which together define social opportunity costs.
4. Producer benefits are measured as producer surplus changes.	4. Producer's benefits are measured by producer surplus changes and at the same time by comparing their willingness-to-pay with the supply price of the resources.
5. Temporal aggregation employs discounting.	5. Rates of time preferences or the discount rate applied is usually lower than in conventional CBA.
6. Unmonetized welfare changes are to be disclosed.	6. Wherever possible impacts are monetized.
7. Sensitivity analysis is made using different assumptions.	7. Net present value is computed from three different perspectives.

https://doi.org/10.1017/S1355770X00000176 Published online by Cambridge University Press

in Griffin (1998) and the environmental CBA applied in this paper. It also differs from Barbier, Pearce, and Markandaya (1989) in that it assumes several ecological and economic constraints in a single project case rather than taking into consideration multiple projects.

3.7. CBA rules for making decisions

In a single project case, as more than one alternative cannot be implemented at a time, the environmental damage caused by implementing one alternative cannot be compensated for by implementing another alternative. While the weak sustainability criteria still applies in a single project case, a separate set of rules have to be introduced in this case to satisfy non-positive environmental damage criterion while making a decision using CBA. The decision rule satisfying various sustainability criteria (section 2.1 to 2.4) in a single project case can be set out as:

Rule 1: Within a set of alternatives based on the land capability/suitability criteria as well as on local people's preferences, choose that alternative which generates largest NPV.

Rule 2: Where there are no resource scarcity effects, but a decision must be made from mutually exclusive alternatives, choose that alternative which generates the largest NPV.

Rule 3: The NPV of the alternative chosen for action should be positive.

The land capability/suitability factors in this case appear as an initial set of physical constraints for satisfying environmentally non-degrading criteria. Local people's preferences can be incorporated both in terms of alternatives designed according to their preferences, as well as while calculating the NPV using resource prices equal to that of farmers' willingness to pay. The CBA expression for the computation of NPV of alternatives designed with internalization of natural resource scarcity and environmental effects can be expressed as:

$$\Sigma_t(B_t - C_t - E_t - R_t)\cdot(1 + r)^{-t} > 0$$

Where, B = direct benefits

C = direct costs

E = environmental benefits (+) and costs (−)

R = unpriced natural resource costs, such as the value of irrigation water, which is not included into the direct costs.

r = discount rate

t = time

Finally, two different discount rates of 12 per cent, and 6 per cent have been used. Use of the lower discount rate has both been widely suggested and criticized as well. For this reason, estimation is based on both the higher and lower discount rates. The project period considered was 48 years including 8 years of project completion period (1976–84).

3.8. Estimation of NPV and sensitivity analysis

Sensitivity analysis is usually considered as an integral part in CBA. Because of several assumptions made about resource prices, income, employment rates, etc., it is carried out in order to show the decision maker how the project's social profitability is affected if central assumptions are changed (Johansson, 1993).

In the past, while carrying out CBA of an irrigation project, usually the supply price of irrigation water used to be considered equal to that of the cost recovery amount of the project including operation and maintenance costs. This is illustrative of past practices of carrying out CBA for many donor-assisted irrigation projects without addressing societal concerns. Sensitivity analysis can be carried out using irrigation water prices obtained by different methods, reflecting supply price, demand price, and scarcity value of irrigation water rather than only the supply price based on the cost-recovery mechanism. The results obtained can also be compared to show how the case differs when resource prices are incorporated equal to that of economic value of water estimated based on the demand and scarcity rent as well.

The estimation of NPV and sensitivity analysis carried out in this paper follows the standard CBA procedure using three alternative prices of irrigation water: (i) supply price equal to that of the cost-recovery amount; (ii) demand price equal to that of farmers' mean WTP; and (iii) scarcity value of water equal to that of scarcity rent as discussed in section 3.3.

The computation of NPV using the water price obtained using different levels of supply and demand price however, should not be confused with normal CBA procedures, which by definition are a type of analysis that is made from the view of society. For example, if a project is found optimal in the view of society, it is not optimal for all the individuals that are affected by the project, and paying them compensation for the loss they suffer can be one way to proceed. In practice, however, the compensation mechanism is never truly planned and applied (Morgenstern, 1997), or only applied in a few cases, such as to compensate for direct environmental loss (Laslett, 1995). Usually they are shown just for the purpose of sensitivity analysis, when the prices of the resources change with the change in demand or in physical conditions, such as droughts.

From a theoretical perspective, the demand price based on the farmers' WTP should reflect the economic value of water, as the value of a resource is considered to be what people are willing to pay for it. In practice, however, farmers' WTP may not always be equal to, or reflect the scarcity value of water computed using indirect valuation approaches. In such a case, estimation of farmers' WTP also provides a basis for measuring sustainability of resource use. Especially in the case of droughts, use of the economic value of irrigation water equal to that of the scarcity rent may help promote more efficient use of scarce water resources. Thus, sensitivity analysis using different alternative prices provides a basis for comparing the NPV of the alternatives designed under different water demand and physical scarcity conditions, such as droughts.

Use of alternative prices in the economic analysis also have some policy implications for designing irrigation water-pricing mechanisms, as there are always several issues involved in the design of irrigation water prices in the developing countries. For example, what should be the base-volumetric or flat rate pricing system, and at what level should it be based—on the cost-recovery price, demand price, marginal-cost or scarcity value of water (Sampath, 1992; Tiwari, 1998)? Computation and consideration of the economic value of irrigation water using different economic valuation approaches provide a sound basis for the design of an irrigation water pricing system in the developing countries where estimation and adoption of scarcity rent may not be a feasible option (for example, see Rogers, 1993).

4. Study area

The remaining sections of this paper present a case study of irrigated lowland agriculture located in the Northern Plains of Thailand. The study area is a subproject of the Phitsanulok Irrigation Project, one of the largest irrigation systems in the country. The irrigation system consists of a main canal having 96 km from the headwork to the end of this sub-project (here after referred as a project) and is divided into 39 sub-zones for the purpose of irrigation water management. The total area was divided into three zones—head, middle, and tail. The field survey was carried out in May 1994, immediately after the rice harvest.

4.1. Baseline information

The total sample population surveyed consisted of 209 households out of a total 12,000 households. About 86 per cent of the population surveyed were entirely dependent upon agriculture with the remaining 14 per cent having some family members employed in government jobs, private companies, and daily wage activities. By landholding size, the majority of farmers (55 per cent) held between 1.6 and 3.8 ha, 27 per cent above 3.8 ha and the remaining 18 per cent with less than 1.6 ha per family. The level of income generated from agricultural activities alone showed the likely impact of the project on raising the living standards of the people. However, based on family income, and on average family size of 4.6, about 32 per cent of the farmers in the project area were estimated to be living below the basic needs level.

The average rice yield during the dry season (1993) varied from 4.31 t/ha to 4.6 t/ha and the average on-farm cost (excluding on-farm crop damage costs and water price) was estimated at 5,931 Baht/ha. The project construction cost estimates were taken from the World Bank Project Report (1989). The operation and maintenance (O&M) cost per ha as reported in the report increased from US$ 12.8 in 1986 to US$ 25.56/ha/year in 1990 (WB, 1989). The project O&M cost was thus estimated to be 102 Baht/rai (640 Baht/ha) at 1993 prices. However, only a nominal amount was collected for O&M from the farmers (World Bank, 1989). Among the total households interviewed, only 12 per cent reported that they paid just a nominal amount (10–80.0 Baht/household/year) for O&M.[2]

4.2. Farmers' perceptions on irrigation water availability

Out of a total of 37,488 ha, only 8,064 ha were found cultivated using available water supplied by the project during the dry season. Rice was

[2] Conversion rate 1 US$ = 25.0 Baht at 1994 prices, and area unit 1 ha = 6.25 rai with conversion factor of 0.25 while converting from Baht/rai to US $/ha.

https://doi.org/10.1017/S1355770X00000176 Published online by Cambridge University Press

cultivated on 6,930.4 ha and soybean on 1,153.9 ha. Among the total respondents, only 131 farmers (63 per cent) planted dry season rice and the rest could not cultivate due to unavailability of irrigation water. Among those who cultivated, only 16 per cent said that water was sufficient during the dry season, 29 per cent said water was not sufficient, 39 per cent used ground water and the remaining 6 per cent were not certain about whether water was sufficient or not. About 97 per cent of the total respondents said that the amount of water available was decreasing over the period and 38 per cent said that water was not distributed equitably.

The farmers provided various suggestions for possible improvements in the distribution of available irrigation water. About 20 per cent of the respondents suggested improving physical infrastructures, while 63 per cent suggested that putting a price on irrigation water could be an alternative way to achieve the same result. The rest (17 per cent) were not certain about how to solve the water scarcity problem.

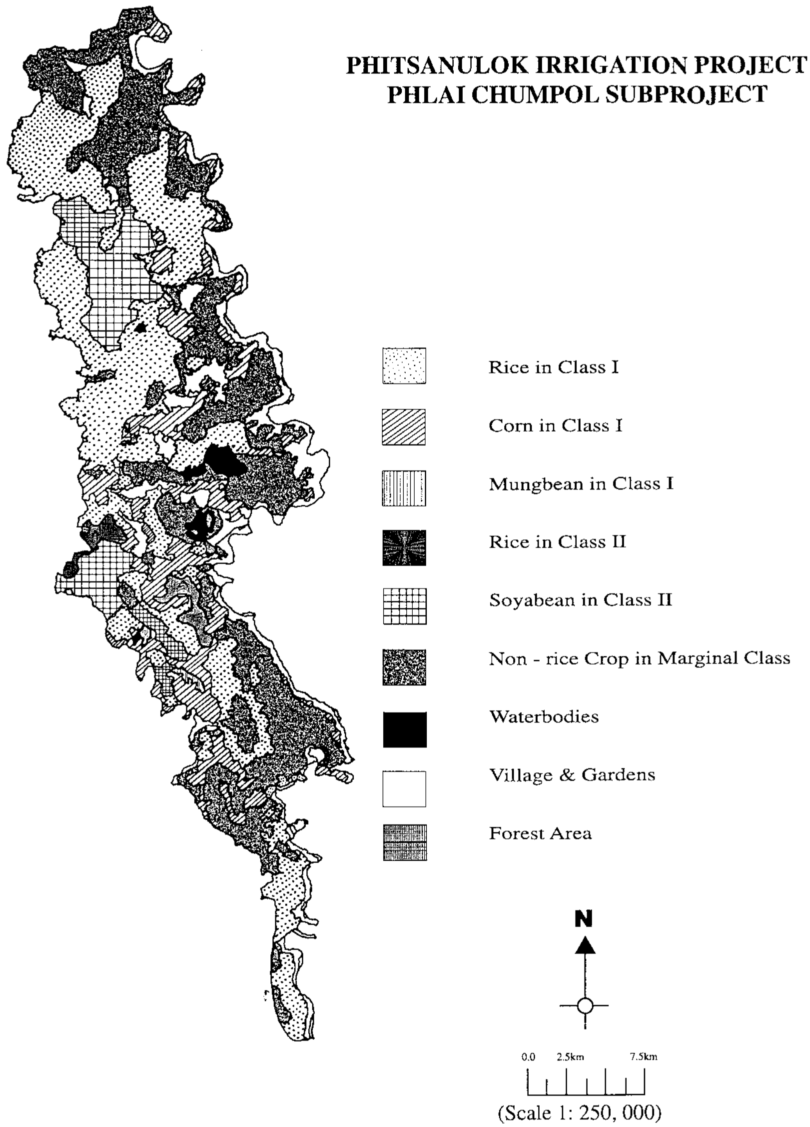
5. Ecological sustainability analysis using GIS techniques

5.1. Land capability analysis

The land capability analysis carried out using GIS techniques as outlined in section 3.1 indicated 20 per cent of the total area (9,035 ha) as resource rich areas, having no major limitations for agricultural use. About 46 per cent of the area (15,727 ha) was classified as enhancement areas having good soils and low risks. The rest (22.5 per cent or 10,164 ha) of the total area was classified as having major limitations for agricultural productions. This indicated that in total, only 66 per cent of the total area were found suitable for agricultural intensification without presenting a major threat to sustainable agriculture. The rest of the areas mainly lie at the tail portion of the system and some along the Yom riverbanks. The risks of floods, drainage and nutrient deficiency in the soil were identified as the major limiting factors. Only 90 ha of the total area (0.2 per cent) was found left as forest area. About 10.1 per cent (4,563 ha) was found covered by fruit trees. The proportion of remaining tree cover to cultivated area was very low (0.1 per cent).

5.2. Land suitability analysis

The land suitability analysis carried out was based on the soil and topographic characteristics and the agro-ecological needs of a particular crop. The crop diversification plan (map 1) was developed on the basis of both land capability and suitability analysis. The analysis carried out using GIS techniques indicated that transition from the present monoculture pattern to crop diversification is possible during the dry season only over about 35 per cent of the total area. The study area has a slope between 1 and 4 per cent only and has two rivers flowing on both sides of the command area. The major limiting factor is the drainage conditions for upland crops, the area near the canal being the most suitable for these crops. Including areas classified as enhancement areas, about 66 per cent of the total area was classified as suitable area for crop diversification. The land area distribution matrix (table 2), obtained from spatial analysis considering both the land capability constraints and suitability criteria, provides a basis for



Map 1. *Crop diversification plan (based on the land capability and suitability analysis).*

the design of alternative cropping patterns and for the estimation of areas for carrying out cost–benefit analysis.

6. Estimation of environmental costs and economic value of irrigation water

6.1. Estimation of environmental costs

Some of the existing and potential environmental costs were estimated using both the direct and indirect economic valuation methods, as briefly

https://doi.org/10.1017/S1355770X00000176 Published online by Cambridge University Press

*Table 2.0 Land capability and suitability area distribution matrix (agricultural land only: area in ha)**

Crop suitability class	*Land capability class* No major limitations	Enhancement resource areas	Low areas	Total area	Percentage of total area
Rice in class I	7253	6932	136	14321	41.2
Corn in class I	51	4237	123	4411	12.7
Mungbean in class I	1	−13	13	14	0.1
Rice in class II	250	13	637	900	2.6
Soybean class II	3383	23	3	3409	9.8
Upland mixed	27	4486	7162	11675	33.6
Total area (ha)	10965	15691	8074	34730	100
Percentage of total	32	45	23	100	

outlined in section 3.4. These included the potential cost of water pollution from the high use of chemical fertilisers and pesticides, health effects from pesticide use, and crop damage due to waterlogging.

The estimation of these costs was largely based on the farmers' WTP, and other basic information provided by the farmers during the survey. Farmers were asked to make a choice between the direct reduction in the use of fertilizer and paying some amount in cash (as water pollution charge) if they wished to maintain the present level of fertilizer use. Of the total respondents, 150 farmers (72 per cent) said they wanted to reduce fertilizer use, and 54 farmers (26 per cent) said they would like to pay some cash rather than reduce the present level of fertilizer use. The rest provided no answer. The average WTP of those who preferred to pay cash was estimated at 40.0 Baht/rai ($10.0/ha). The potential cost of pesticide application was considered the same as in the case of chemical fertilizer, although, clearly, it can have different level of impacts.

About 50 per cent of the farmers surveyed said that they were affected during each application of pesticides during both seasons. This shows a comparatively large percentage of agricultural workers being affected during pesticide application, compared to the national average figure of 8.1 per cent. The reported average medical treatment costs ranged from Baht 100.0 to Baht 1,100.0 per season. In addition, one day's earnings forgone was added. The average health costs of pesticide use was estimated at 35 Baht/rai ($8.75/ha).

About 13 per cent of the farmers surveyed said their crop was damaged due to waterlogging during the wet season. The average value estimated for crop damages due to waterlogging was 10 Baht/rai ($2.5/ha), based on the information provided by the farmers. The total environmental costs (potential water pollution cost, health costs of pesticide use and waterlogging) were estimated at 115 Baht per rai ($28.75/ha) for the dry season and 121 Baht/rai ($31.25/ha) for the wet season.

6.2. Estimation of on-farm crop damage costs

Farmers were also asked to report on crop damage by insects, flood, and droughts. Of the total respondents, 17 per cent said insects damaged their crop and 41 per cent said floods. Average values estimated for crop damage were 82 Baht/rai (due to flood), and 39 Baht/rai (due to insects).

The cost of production forgone to the farmers due to the reduction in fertilizer use was calculated using a fertilizer-rice yield function developed by the Department of Soil and Water of Thailand (1992) for the Northern Region. The estimated figures were 82.0 Baht/rai ($20.5/ha) and 46.0 Baht/rai ($11.5/ha) for the wet and dry seasons. Figure 2 shows different categories of these environmental and on-farm damage costs for both the dry and wet seasons.

6.3. Economic value of irrigation water

The economic value of irrigation water was estimated using different valuation approaches as briefly outlined in section 3.1 (more details can be found in Tiwari, 1998). Figure 3 shows comparative values for irrigation water obtained from different valuation methods and costs of supply. The results indicate that:

- Compared to the ability to pay, farmers' WTP is significantly lower and is almost half the amount of the full cost of recovery including O&M costs. However, the WTP amount is almost equal to the O&M cost per year per ha.
- Farmers' ability to pay is slightly higher compared to both the marginal value of water estimated using both the crop-water production function during the wet season, and the farmer's information on the incremental value of water during the dry season.
- The incremental productivity of water calculated on the basis of farmers' perception of the incremental production of rice was only slightly different to the value obtained from production function analysis.

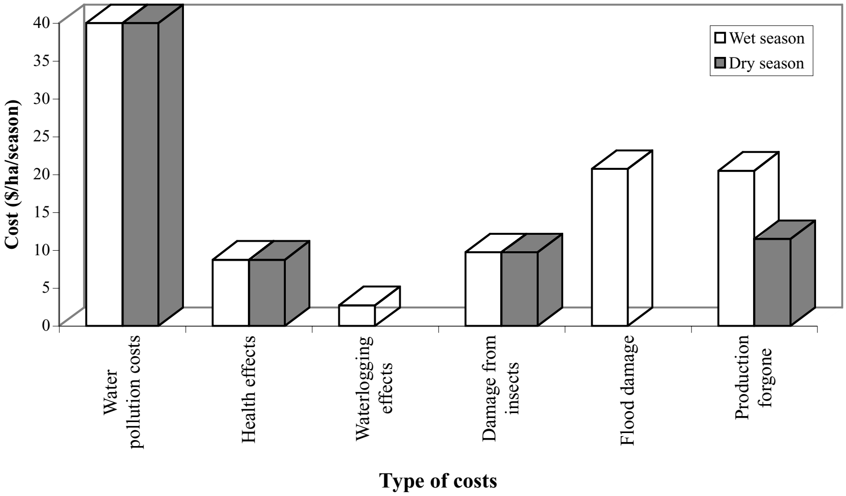


Figure 2. *Environmental and other on-farm costs.*

https://doi.org/10.1017/S1355770X00000176 Published online by Cambridge University Press

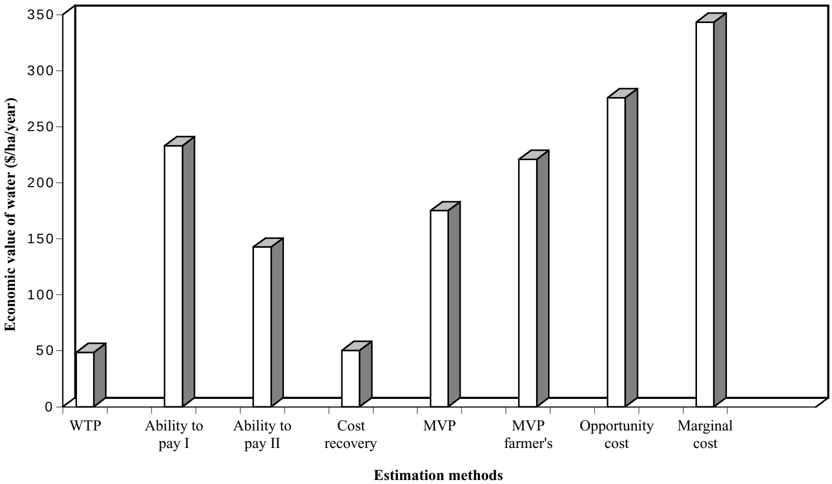


Figure 3. *Economic value of irrigation water obtained from different methods.*

- Compared to the opportunity costs of water, the marginal value of water was less than half, indicating the case of drought. Charging for irrigation water equal to the marginal value will still lead to the sub-optimal use of resources.
- Both the opportunity cost and marginal extraction cost were almost equal and significantly higher, respectively, compared to the values obtained from other methods which shows growing scarcity of water.
- As both the opportunity cost and the scarcity rent were found to be higher than the maximum willingness to pay of farmers as measured by the ability to pay, the analysis indicates unsustainable use of irrigation water for rice cultivation in the project area.
- Although the scarcity rent calculated for the whole Thailand showed a lower value compared to the maximum willingness to pay of farmers as measured by the ability to pay, it is difficult to arrive at definite conclusions as the way in which the farmer's ability to pay is supposed to vary according to water availability conditions during the dry season. Also, when environmental costs are considered, then farmers' ability to pay lies well below the scarcity rent.

7. Evaluation of farmers' preferences for crop diversification and estimation of incremental benefits

7.1. Evaluation of farmers' preferences for crop diversification as a basis for incorporating social acceptability criteria

Farmers were also asked to express their preferences for crop diversification if they faced water scarcity for rice cultivation during the dry season. While about 2 per cent preferred maize, 55 per cent preferred soybean, 3 per cent mungbean, and about 2 per cent preferred vegetables. The total area preferred by farmers for crop diversification was about 62 per cent

(442.24 ha) of the total landholding (713.12 ha) of those of the households interviewed. This indicated farmers' preferences for crop diversification in more than half of the present rice cultivated area. The farmers' preference also was nearly the same compared to the results obtained from the physical suitability analysis for crop diversification. This also reflected local people's familiarity with the local environmental conditions and such information can be extremely helpful, especially when sufficient information and facilities are not available for using GIS techniques.

7.2. On-farm and incremental benefits

The on-farm incremental benefits for the past years (before 1994) were calculated on the basis of actual cropped area, yield and price of different crops. The employment benefit was also calculated by estimating total labour requirements for additional area brought under cultivation during the wet season, and all the area cropped during the dry season. The labour wage rate was taken as 35 Baht/day from 1983 to 1988 (Project Report, The World Bank, 1989) and 50 Baht/day after 1988 based on the information obtained from the field survey. As farmers used to cultivate rice during the wet season, even before the project was introduced, this benefit was considered as 'without' project benefit and was deducted from the total project benefits. The benefit estimation of the without project case was based on the project evaluation report (The World Bank, 1989).

8. Design of alternative cropping patterns satisfying ecological and social sustainability criteria

Alternative cropping patterns were designed for incorporating sustainability criteria as outlined in section 2.1 and 2.4 (in terms of crop diversification according to land capability/suitability analysis, water scarcity aspects, and social sustainability criteria). These different sets of alternatives include:

- A1: assigning priority for rice cultivation only in highly suitable areas,
- A2: priority for non-rice crops in highly suitable areas,
- A3: avoiding cultivation in low resource areas,
- A4: reductions in the rice cultivation area to reduce total water demand (area allocation with distance less than 4km from the main canal),
- A5: reductions in the rice cultivation area to reduce water demand (area allocation with distance greater than 4km from the main canal), and
- A6: creation of an ecological buffer strip of 1 km for increasing the waste assimilative capacity of the lowland ecosystems, considering both the ecological sustainability and sustainable water use criteria;
- A7: cropping patterns according to farmers' preferences (A4), considering social sustainability criteria; and
- A8: continuation of existing cropping system,
- A9: alternative with rice cultivation in all areas, and
- A10: the worst case with no cultivation during dry season (with the assumption that farmers can sell their share of water at least equal to their WTP to urban consumers), as additional alternatives based on the existing situations and included for the purpose of comparisons.

The cropping areas for four crops (rice, corn, soybean and mungbean) were estimated under each alternative using GIS and farmers' information on their preferences for crop diversification during the dry season. The cost and benefits as well as NPV in each alternative case were then calculated using the expression (−1).

9. Results of cost–benefit analysis carried out using different supply price and economic value of irrigation water

The results of the NPV calculated at a 6 per cent and 12 per cent discount rate for each alternative are shown in figures 4 and 5 as outlined in section

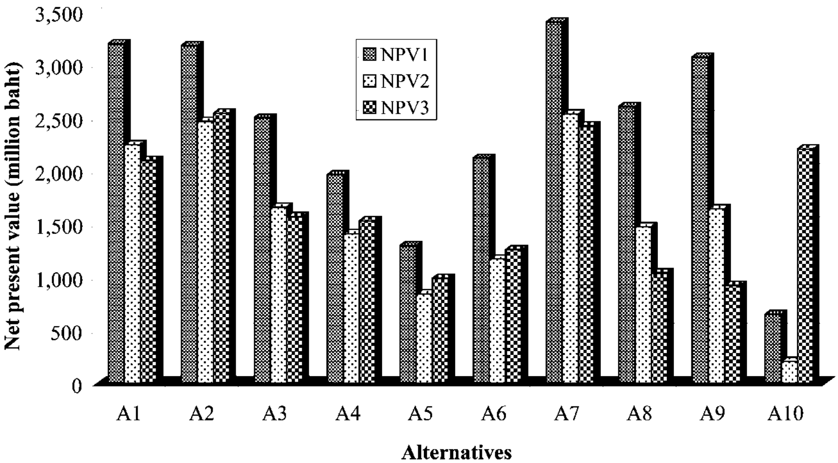


Figure 4. *Net present value computed using different values of irrigation water and at 6 per cent discounted rate.*

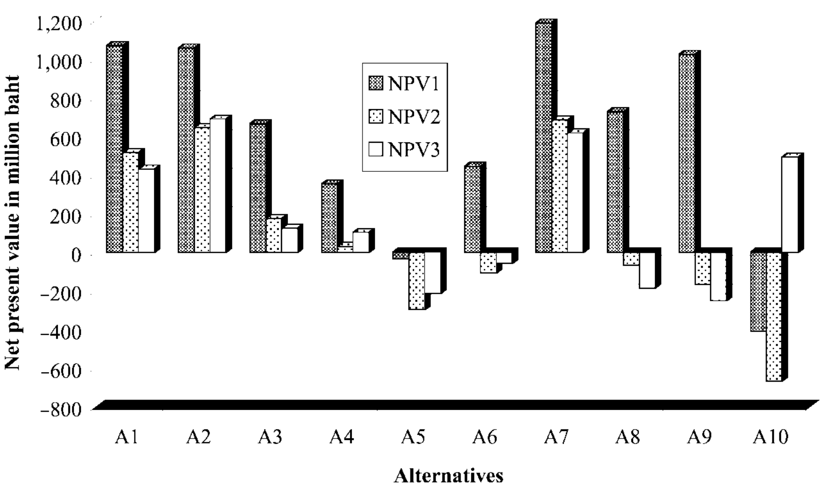


Figure 5. *Net present value computed using different values of irrigation water and at 12 per discounted rate.*

https://doi.org/10.1017/S1355770X00000176 Published online by Cambridge University Press

3.4. The following paragraphs summarize and provide a comparative analysis of the cost–benefit analysis obtained using resource prices at different levels.

9.1. NPV computed using supply price of irrigation water equal to the cost recovery amount and including environmental costs (NPV_1)

In this case, among the alternatives designed and analysed, the highest positive NPV was obtained in the case of alternative (A7) representing farmers' preferences. The results indicated that, when a social sustainability criterion, as indicated by farmers' preferences, and environmental costs are also taken into account, the ranking of alternatives might change. Alternative A1 with priority for rice cultivation in highly suitable areas appeared as the second-best alternative. This later case also represents the case of conventional CBA, where the supply price of irrigation water is equal to that of the cost recovery amount, and mono-cropping system would usually be considered while carrying out CBA of the irrigation projects.

9.2. NPV computed using resource price (R) considering water demand price equal to that of Farmers' WTP values and excluding environmental costs (NVP_2)

When the economic value of water is considered equal to the demand price or equal to the mean maximum WTP of farmers, the same alternative (A7) was found to be the best alternative. The results indicated that farmers choice and allocation of their land for different crops in the case of water scarcity during dry season was highly rational. However, it should also be noted that no environmental costs were included in the computation of costs, and only the on-farm crop damage costs were added. Likewise, alternative (A2), with priority for upland crops in highly and moderately suitable areas, was found more suited compared to alternative (A1). The continuation of the present cropping pattern was found less viable compared to all other alternatives. The NPV calculated at 12 per cent showed negative values in the cases of all alternatives designed for addressing water scarcity (A4 and A5) and the alternative with no cultivation during the dry season (A10). This indicates that, in the face of growing water scarcity, farmers would be in position to lose if they did not make a shift towards crop diversification during the dry season.

9.3. NPV computed using supply price equal to the scarcity rent of water and including environmental costs (NVP_3)

In this case, the alternative (A2) with priority for non-rice crops in highly suitable areas generated the highest positive NPV, and alternative (A7) appeared to be the second best compared to the others. Alternative (A10) based on the assumption of no cultivation during dry season was ranked as the third best. This later case indicates that society may benefit more by not growing crops during the dry season than by adopting cropping practices other than alternative (A2) and (A7). However, this is not so surprising as there will be no associated environmental costs incurred during the dry season if farmers do not cultivate. On the other hand, they can derive benefits by selling their share of water to urban consumers or other users at a price at least equal to their WTP. Both of these aspects were considered while computing the NPV for alternative (A10). When a higher discount rate at 12 per cent was used, the negative NPV was obtained in the case of alternatives (A4), (A5), and (A9).

9.4. Comparative analysis of results

Cost–benefit analysis carried out with the incorporation of irrigation water priced at different levels and environmental costs, and alternatives designed with incorporation of farmers preferences, provided some important practical and theoretical insights into the theory of cost–benefit analysis practiced in the developing countries in the past.

- First, from the sustainability viewpoint, the continuation of the existing cropping pattern (alternative A8) was in no cases a feasible cropping pattern. It was not an economically viable alternative compared to all of the other alternatives, except for (A5) and (A9) when irrigation water was considered equal to that of the scarcity value of water. Even the worst case scenario, with no crops during the dry season, was found more economically viable compared to the case of continuation of present practices, if water rights were provided to the farmers to sell their share of water during water scarce period.
- Second, the results also indicated that in most cases, the NPV calculated when the water price was equal to that of the cost-recovery amount was the highest compared to the other two cases. This no doubt represents the CBA usually carried out in the past for investment decision making by the government or donor agencies in developing countries. This also provides a clear explanation as to why irrigation projects developed in the past failed to achieve the estimated rate of returns.
- Third, while the alternative based on farmers' preferences appeared to be the best alternative in the first and second cases (NPV_1 *and* NPV_2), the alternative based on physical suitability analysis was found to be the most preferred when the scarcity price of water and the environmental costs were incorporated into the CBA (NVP_3). However, as mentioned earlier (section 4.7), the area allocated according to physical suitability analysis and farmers preferences did not vary much. This indicates that alternative (A2) for non-rice crops designed according to the physical suitability conditions, is the best alternative satisfying all the rules as outlined in section 3.5.
- Fourth, the analysis indicated that giving priority to non-rice crops in physically suitable areas during the dry season is the best solution for maintaining the resource base, addressing the water scarcity problem, reducing environmental costs, and satisfying social acceptability criteria. Farmers may lose slightly, an amount equivalent to the difference in NPV between the two alternatives (A7) and (A2) in this case.
- Finally, the results provide some answers to the ongoing theoretical debate on incorporating sustainability criteria into CBA, especially in a single project case. The comparative analysis reveals that it may not be necessary to carry out sensitivity analysis and compute NPV from different cases, if the scarcity value of a resource in question is considered

https://doi.org/10.1017/S1355770X00000176 Published online by Cambridge University Press

rather than consideration of the supply price based on cost recovery estimation usually practiced in the past.

10. Conclusions

10.1. Implications for policy

As the result of the study indicated, incorporating sustainability criteria both in terms of physical constraints and monetization of quantified costs and benefits can change the ranking of available options. Likewise, the analysis carried out with the incorporation of the irrigation water price at different levels indicated that conventional cost–benefit analysis based only on the supply price of irrigation water equal to that of cost recovery would have resulted in the overestimation of the NPV of the irrigation projects. This had serious implications, with the misallocation of scarce resources in the developing countries in the past.

Unlike the traditional emphasis on rice cultivation as a means of increasing incremental benefits from irrigated agriculture during the dry season, the result of the study showed that making a shift to non-rice crops in the highly and moderately suitable areas would result in more profit to the farmers, and less burden to the society which is also a pre-requisite for sustainable use of scarce resources. The burning question related to the case study presented is that—why was it that farmers did not make a shift towards crop diversification during the dry season even though they were aware of the benefits during the water scarce period?

The answer as evident from the analysis however, is not a complex one. As the results indicate, this could happen only when resource scarcity prices and environmental costs are internalized so that farmers would have incentives to cultivate according to their own stated preferences and/or land capability and suitability conditions. The right mix of policies for adopting economic instruments for internalizing these costs at the local level and promotion of crop diversification practices in the study area are thus needed through: (i) introduction of economic incentive schemes, such as charging of irrigation water; (ii) facilitating transfer of water rights to the farmers to provide them with the opportunity to weigh the cost of water supply with the benefit of rice cultivation during the dry season; and (iii) minimization of existing and potential environmental costs by taxing chemical fertilizers and pesticides. Some policy options are briefly outlined based on the outcome of the case study.

Introducing water charges and handing over water rights to farmers

As shown in the case study, internalization of scarcity price of irrigation water maximizes social benefit. Gradual introduction of a water charge is necessary for recognizing irrigation water as an 'economic good' and minimizing the inefficient use of irrigation water. Although successful implementation of water pricing schemes requires fixing water fees equal to that of farmers' WTP, the economists golden rule suggests that it should be equal to the marginal value, or the scarcity value of water, that reflects the real price of water during water scarce periods. As lack of political will is the greatest obstacle for successful introduction and expansion of water charges in the developing countries (Yodelman, 1989), gradual introduction of an irrigation water price at different levels may be a feasible option to introducing a water price based on the scarcity rent. Institutional arrangements such as a clear definition of water rights is no doubt a pre-condition for introducing such schemes in government-managed irrigated systems. Strengthening the farmers' organization is the basic pre-requisite for this. This would also help to make them pay the water user charges at lower collection costs. Many successful farmer-managed irrigation systems in the developing countries have shown that the sense of ownership of water provides an incentive for the farmers to successfully manage the systems, charging water fees and imposing penalties in the case of water stealing (Tiwari 1992). In the study area, water charge schemes could be introduced equal to that of the cost recovery, ability to pay, scarcity rent, or marginal value product of water by handing over water rights to the farmers below the main canal system level. A more detailed discussion on charging for irrigation water and estimation of welfare gain/loss for the farmers under each alternative charging schemes in the project area is provided in Tiwari (1998).

Taxing the excessive use of agrochemical

The declining agriculture output/direct energy input ratio in Thailand estimated over the period 1975–1990 (Tiwari, 1995), farmer's willingness to reduce fertilizer use, and the results of CBA which showed greater social benefits than loss of benefit to the farmers from reduced fertilizer use, etc. demand a policy shift in the use of agrochemicals in Thailand. Economic incentives in the form of a fertilizer tax would be the more appropriate policy for encouraging farmers to make efficient use of agrochemicals. Adopting a mix of organic and non-organic fertilizers and encouraging integrated plant nutrition management systems in the project area could help. The level of charges on chemical fertilizer could be designed by equating the marginal productivity loss due to reduction in these inputs with the marginal social benefit from the reduction in the use of chemical fertilizer. In the case of pesticides, some level of taxes and introduction of integrated pest management systems, would help to minimize both the use of pesticides and reduce health and potential impacts on water quality.

10.2. Implications for further research

First, this paper provided a more comprehensive analytical framework for incorporating sustainability concerns into the environmental–economic decision-making process using CBA. Use of the GIS technique facilitated the design of alternatives based on land capability/suitability analysis, introducing ecological buffer zoning concepts and integration of spatial analysis with economic theory. In addition, incorporating farmers' perceptions as well as their preferences into the decision-making process was a consideration for incorporating social sustainability criteria. All of these efforts provide a major step forward in the theory of economic analysis using CBA.

Second, this paper demonstrated that when social costs—potential and actual environmental effects as well as water resource scarcity—are considered, the ranking of alternatives can be changed, indicating the use of the decision-making process promoting unsustainable resource use and overestimation of the project benefits.

Third, water scarcity has been a national problem in Thailand. In this context efforts to promote non-rice crops are the best way towards solving the water scarcity crisis and to achieve the objective of sustainable intensification of lowland irrigated areas. Both the growing water resource scarcity and environmental costs of increasing use of agrochemicals indicate that the project evaluation criteria should be shifted towards evaluating and incorporating these concerns.

Finally, setting out of sustainability criteria as well as an economic valuation of environmental and resource scarcity costs are not easy and not always complete. It leaves sufficient room for the improvement of economic valuation of environmental costs and benefits compiling and analysing more information. Farmers' WTP itself can change over time depending upon the availability of scarce resources, environmental changes and other socio-economic conditions. Continued research on these aspects will no doubt help to provide theoretical insights and strengthen methodology for practical applications of CBA in investment decision making in the developing countries.

Acknowledgement

The author would like to express his sincere thanks to Prof. David Pearce and two anonymous referees for their very helpful comments and suggestions on earlier versions of this paper. However, the views expressed here are those of the author alone.

References

Arrow, K.J., M.L. Cropper, G.C. Eads, R.W. Hahn, L.B. Lave, R.G. Noll, P.R. Portney and M. Russell (1996), 'Is there a role for benefit–cost analysis in environment, health and safety regulations?', *Environment and Development Economics* **2**: 196–201.

Barbier, E.B., D.W. Pearce, and A. Markandaya (1989), 'Environmental sustainability and cost–benefit analysis', *Environment and Planning A* l. **22**: 1259–66.

Bohm, R.A., T.J. Essenberg and W.F. Fox (1993), 'Sustainability of potable water services in the Philippines', *Water Resources Research* **29**: 1955–63.

Bojo, J., K. Maler, and L. Unemo (1992), *Environment and Development: An Economic Approach*, Dodrecht: Kluwer Academic Publishers.

Briscoe, J., P.F. Castro, C. Griffin, J. North, and O. Olsen (1990), Toward equitable and sustainable rural water supplies: a contingent valuation study, *The World Bank Economic Review* **4**: 115–34.

Campbell, J.C., J. Radke, J.T. Gless and R.M. Wirtshafter (1991), 'An application of linear programming and GIS: cropland allocation in Antigua', *Environment and Planning* **32**: 531–49.

Carver, S.J. (1991), 'Integrating multi-criteria evaluation with GIS', *International Journal of Geographic Information Systems (GIS)* **5**: 321–39.

Cropper, M.L. and A.M. Freeman III (1991), 'Environmental health effects' in *Measuring Demand for Environmental Quality*, J.B. Braden and C.D. Kostlad, eds), Elsevier Science Publishers, North-Holland.

Daly, H.E. (1991), 'Towards an Ecological Economics', The World Bank Working Paper, Environment Department, The World Bank, Washington, DC.

Department of Soil of Thailand (1992), 'Crop yield-fertilizer response curve for central and northern Thailand', Ministry of Agriculture and Co-operatives, Thailand.

Dixon, J.A., F. Scura, R.A. Carpentar, and P.B. Sherman (1994), *Economic Analysis of the Environmental Impacts*, London: Earthscan Publications.

Dreze, J. and N. Stern (1987), 'The theory of cost–benefit analysis', in A.J. Auerbach and M. Fieldstein, eds, *Handbook of Public Economics*, Elsevier Science Publishers, North-Holland.

Easter, W. (1993), 'Economic failure plagues developing countries' public irrigation: an assurance problem', *Water Resources Research* **29**: 1913–22.

Easter, W. (1991), 'Intersector water allocation and pricing', in G.L. Moigne, ed., *Country Experiences with Water Resources Management: Economic, Institutional, Technological and Environmental Issues*, Technical Paper No. 175, The World Bank, Washington, DC.

Feder, G. and G.L. Moigne (1994), 'Managing water in a sustainable manner', *Finance and Development* **31**: 24–28.

FAO (Food and Agriculture Organization of the United Nations) (1991), 'FAO / Netherlands Conference on Agriculture and the Environment', S-Hertogenbotsch, The Netherlands, 15–19 April 1991, FAO, Rome.

FAO (1985), 'Guidelines: Land Evaluation for Irrigated Agriculture', FAO Bulletin No.55, FAO, Rome.

Griffin, R.C. (1998). 'The fundamental principles of cost–benefit analysis', *Water Resources Research* **34**: 2063–71.

Hanemann, W.M. (1994), 'Valuing the environment through contingent valuation', *Journal of Environmental Perspectives* **8:** 19–43.

Harrington, W., A. Krupnick and O. Spafford (1987) 'The economic losses of a waterborne diseases outbreak', *Journal of Urban Economics* **25**: 116–137.

Howe, C. and J. Dixon (1993), 'Inefficiencies in water project design and operation in the third world: an economic perspective', *Water Resources Research* **29**: 1889–94.

Johansson, Per-Olov (1993), *Cost Benefit Analysis of Environmental Change*, Cambridge University Press.

Juracek, K.E. (1988), 'A GIS based crop specific model for physical suitability assessment', GIS / LIS'88, Proceedings Accessing the World, San Antonio.

Kopp, J.R., A.J. Krupnick and M. Toman (1997), 'Cost–benefit analysis and regulatory reform: an assessment of the science and art', Resources For the Future Discussion Paper No. 97–19.

Laslett, R. (1995), 'The assumptions of cost–benefit analysis', in K.G. Willis and J.T. Corkindale, eds, *Environmental Valuation New Perspective*, CAB International, London.

Lyle, J. and F.P. Stutz (1987), 'Computerized land use suitability mapping', *The Cartographic Journal* **21**: 81–92.

Mitchell, M. and T. Carson (1989), *Using Surveys to Value Public Goods*, Washington, DC: Resources for the Future.

Morgenestern, R.D. (1997), 'Conducting an economic analysis: rationale, issues, and requirements', in R.D. Morgenstern, ed., *Economic Analysis at EPA: Assesing Regulatory Impact*, Washington, DC: Resources For the Future.

OECD (Organization for Economic Cooperation and Development) (1995a), *The Economic Appraisal of Project and Policies: A Practical Guide*, Paris: OECD.

Organisation for Economic Co-operation and Development (OECD) (1995b), *Sustainable Agriculture: Concepts, Issues and Policies in OECD Countries*, Paris: OECD.

Organisation for Economic Co-operation and Development (OECD) (1994), *Project and Policy Appraisal: Integrating Economics and Environment*, Paris: OECD.

Pearce, D.W. (1996), 'Benefit–cost analysis, environment and health in the developed and developing world', Draft paper CSERGE, University College London.

Rogers, P. (1993) 'A comprehensive approach to water resources management', WB Draft Working Paper, The World Bank, Washington DC.

Sampath, R. (1992) 'Issues in irrigation pricing in developing countries', *World Development* **20**: 967–977.

Smith, A.Y. and R.T. Blackwell (1980), 'Development of an information database for watershed monitoring', *GIS for Resource Management: A Compendium*, The American Society for Photogrametry and Remote Sensing, USA.

Solow, R. (1992), 'An almost practical step towards sustainability', RFF Discussion Paper, Resources For the Future, Washington, DC.

Toman, M. (1998), 'Sustainable decision-making: the state of art from an economic perspective', Resources For the Future Discussion Paper No. 98–39.

Tiwari, D.N. (1991), 'Ecological-economic approaches to Watershed resource use, assessment and management', submitted to the International Center for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal.

Tiwari, D.N. (1992), 'Co-evolutionary analysis of environmental change and traditional irrigation organizations in Nepal', paper presented at the Third International Conference of IASCP, Organized by IASCP and Rutgers University, September 1992, Washington, DC.

Tiwari, D.N. (1995), 'Measurement of sustainability indicators and implications for macroeconomic policy modelling in developing countries', *Economie Appliquèe* **48**: 181–214.

Tiwari, D.N. (1998), 'Determining economic value of irrigation water: comparison of willingness to pay and other indirect valuation approaches as a measure of sustainable resource use', CSERGE Working Paper No. 98–05, CSERGE, University College London.

United Nations Environment Program (UNEP) (1994), 'Report of the consultative group meeting on valuation of environmental and natural resources', Report of the Meeting, Environmental Economics Series, Paper No. 11, UNEP, Nairobi.

Victor, P.A. (1991), 'Indicators of sustainable development: some lessons from capital theory', *Ecological Economics* Vol. **4**: 191–213.

Vincent, J.R., E.W. Craford and J.P. Hoehn (1991), 'Valuing environmental benefits in developing countries', Proceedings of a seminar series held Feb.–May 1990 at Michigan State University, Special Report, Editorial Summary, Michigan State University, USA.

Walsh, S.J. (1987), 'GIS for Natural Resources Management, GIS for Natural resources Management: A Compendium', American Society for Photogammetry and Remote Sensing and the American Congress for Surveying and Mapping.

Whittington, D.J., J. Briscoe, X. Mu and W. Barron (1990), 'Estimating the willingness to pay for water services in developing countries: case study of the use of contingent valuation surveys in Southern Haiti', *Economic Development and Cultural Change* **38**: 293–311.

Winpenny, J. (1996). *The Economic Appraisal of Environmental Projects and Policies: A Practical Guide*, Economic Development Institute of the World Bank, Washington DC.

Woodcock, C.E. and Franklin J. (1983), 'Remote Sensing for Land Management and Planning', *Journal of Environmental Management* **7**: 223–238.

World Bank (1994). *World Development Report 1994: Infrastructures for Development*, Oxford University Press, Oxford.

World Bank (1993). *Water Resources Management: A Policy Paper*, Washington DC: The World Bank.

World Bank (1989). 'Project performance audit report: Phitsanulok Irrigation Project', Operations Evaluation Department, Report No. 7935. The World Bank, Washington DC.

World Commission on Environment and Development (WCED) (1987), *Our Common Future*, Oxford University Press.

Yodelman, M. (1989), 'Sustainable and Equitable Developments in the Irrigated Environment', Environment and the Poor, Overseas Development Council, Washington, DC.