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ASSESSING THE SOCIO-ECONOMIC IMPACTS OF ENVIRONMENTAL REGULATIONS: TOWARDS AN ACCEPTABLE METHODOLOGY

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Canada

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CHAPTER I

Introduction and Goals of the Study

The primary objectives of the study are to review and assess present techniques in environmental policy evaluation, with specific reference to the socio-economic impacts of water resource policies, to formulate and outline an alternative methodological approach of impact assessment, and to evaluate its expected utility when applied to recent management modeling efforts and water quality problems in the Great Lakes in general. The absence of an acceptable methodology for the assessment of the socio-economic and environmental impacts of government policies has affected the desire not only for an appropriate understanding of these impacts, but for a methodology that does not necessarily assume economic preeminence (23, 18, 32, 17). Traditional methods of policy evaluation concentrate on the monetary costs and benefits resulting from the adoption of a given policy or program and establish as an underlying goal the achievement of allocative efficiency; i.e., the reallocation of resources in ways which will result in a net value of output produced by those resources (68). Improvements in economic efficiency dictate the attractiveness of a particular policy, based on the difference between the value of the input (in dollar units, by definition) and the value of the output. The appeal of such an approach is unquestionable; it offers decision makers a simple arithmomorphic (yes/no) distinction and alleviates the problem of what one former U.S. Senator termed, "the need for one-armed scientists": individuals that respond a certain way, and invariably add, "but on the other hand ..." Policy makers can then apply the Kaldor-Hicks criterion (the net benefits of a policy must exceed the net costs) or the Pareto criterion (which has the much stricter, and quite unrealistic, requirement that a policy be accepted only if no one is adversely affected) and make the easy, and at least surficially consistent, decision on whether to adopt or reject the policy. The weaknesses in the cost-benefit methodology center on its inability to evaluate projects in terms of other goals, e.g., social/environmental. Additional internal problems also exist: the solution is explicitly dependent on the values chosen for two of the variables in the analysis (specifically, the discount rate and the time horizon). Criticism of cost-benefit analysis is prevalent and ranges from adherence to economic efficiency criterion (68) to dependence on a weak ideological base (the social order of capitalism) (70). Nevertheless, it remains the dominant policy evaluation tool with which to assess socio-economic impacts.

The limits of cost-benifit analysis in evaluating policies that involve economic and ecological trade-offs (termed, subsequently, as systems of man and nature) has resulted in the development of numerous alternative methodologies; few, however, with the appealing qualities of the original. Leopold <u>et al</u> (42) proposed the use of a large evaluation matrix, the rows and columns representing natural system components and categories of impact, respectively, and subjective weights are assigned to cells on the basis of the impact of a policy on each system component. The technique suffers from problems of linearity, which foreclose component interaction (53), and lacks a suitable framework for comparing economic and environmental factors. The use of the Delphi process has been proposed as a modification to this basic matrix evaluation technique (10, 39), employing a panel of experts to determine the relative importance of impacts. The U.S. Atomic Energy Commission developed a method similar to the cost-benefit formulation, involving the evaluation of impacts using different units of measurement (74). Deciding between policy alternatives, however, is difficult because of non-comparability. One of the initial analytical treatments combining systems of man and nature was developed by Isard (34, 35, 53). An input-output framework was expanded to include ecological components, and the flows between the economy and the environment identified, in an effort to evaluate the environmental impacts of increasing output in various economic sectors. While appealing, the technique suffers from problems of disparate unit measures (e.g. dollars and pounds) and the linearity assumptions accompanying input-output analysis.

The assessment of the impacts (social/environmental/economic) of regulatory policies, to be effective and applicable, must have at its foundation an objective, measurable criterion. Utilizing a combination of objective and subjective (or qualitative) measures (40, 10) can only result in a subjective outcome or a disregard for the qualitative criteria resulting from an inability to relate policy alternatives. The analysis, additionally, must be undertaken in terms of a general measurement parameter that is common to all systems under consideration. Adherence to a goal of economic efficiency (Kaldor-Hicks criterion), social welfare (Pareto criterion is a possibility) or environmental quality will dictate the measurement parameter one might use. Planning for human systems - which include subsystems of man and nature - a desirable objective might be to design systems that will survive in competition with alternative systems, whether economic, social or environmental. Lotka (47) presented an energy codification of Darwin's principle of natural selection (Lotka's maximum power principle) which stated that this objective can be achieved if the development of a system's energy resources into useful functions is maximized (i.e., the energy efficiency or total work potential in the system is maximized). Since most material objects and processes can be described and compared in terms of their energy involvement, energy might be a common denominator for systems of man and nature.

The discussion below presents a review of the "state-of-the-art" in policy evaluation and presents an alternative methodological framework with which to assess socio-economic impacts. Chapter II presents the present cost-benefit/policy evaluation paradigm, emphasizing both its strengths and its weaknesses. Chapter III focuses on energy analysis as an alternative policy evaluation technique, developing the theory of 'energetics' and its utility for socio-economic/environmental impact analysis. Chapter IV proposes an optimization framework for impact assessment and describes its adaptability to either monetary or energy measurement parameters Chapter V discusses the application of the above methodology to specific problems in the Great Lakes Region; its relevance to present water resource modeling efforts and data and computational requirements. Chapter VI presents the conclusions and recommendations for further research.

CHAPTER II

A Review of Traditional Methods of Socio-Economic Impact Assessment.

Policy evaluation, despite the objections of sociologists and political scientists, remains largely under the purview of economists and has become almost synonymous with the technique of cost-benefit analysis. The primary distinction between the two concerns the broad scope of policy analysis (theoretically) and the more formal and limited notion of cost-benefit and its singular goal of economic efficiency. Policy evaluation includes not only a traditional cost-benefit analysis, but considerations of distributional effects, political feasibility, legality, and so on. Once the political feasibility and legality (which are outside the scope of this report) have been ascertained, however, the distinction becomes less clear. The result has been not a rejection of the cost-benefit framework, or its treatment as merely a specific subset of policy evaluation, but an expansion of the traditional formulation to encompass social , economic and environmental concerns hence, the synonymous treatment of policy evaluation and cost-benefit analysis in most impact assessment studies. Economic efficiency, it is assumed, is a suitable measure of social (and environmental) welfare; a thesis that has not been readily accepted. The primary focus of this chapter pertains to the economic interpretation of policy evaluation and its extensions to accomodate social and environmental parameters. Implicit in the section, however, is a recognition of the important elements that must be confronted in any impact analysis, and their subsequent treatment by the traditional approach.

Policy evaluation, as was mentioned in the previous chapter, has traditionally concentrated, either explicitly or implicitly, on the allocative effects of a proposed policy or program. Equity (or distributional) effects have been omitted from most impact studies, although attempts to integrate distributional effects into the framework have recently entered the literature (28). The dichotomy between efficiency and equity considerations belies an additional problem inherent in tangible benefits (i.e., those that can readily be measured in dollar terms) and intangible benefits (notions such as aesthetics, ecosystem productivity or cultural development that exhibit an inability to be measured directly in terms of monetary value). Although it has been noted that the failure to monetarize certain intangible effects does not imply that they will be excluded in decision making (63), the result has been to arbitrarily assign misleading values to intangibles to promote the comparison of alternatives, or to disregard the qualitative information in the face of quantitative results. The inadequacies of the traditional approach in valuing many social and environmental variables (i.e., the intangibles mentioned above) is the basis for the present criticism of classical policy evaluation, and sets the stage for alternative formulations to assess the socio-economic/environmental impacts of government policies.

Tangible Effects

The general aim of cost-benefit analysis is to maximize the present value of all benefits less that of all costs, subject to specified constraints (65). Theoretically, the cost-benefit approach to policy evaluation generates little complaint; if the total benefits of a particular policy exceed the costs (and a benefit/cost ratio can be utilized to choose among alternative policies), the policy should be adopted. Applicaton of the simplistic theory is wrought with problems, however, as a direct result of measurement difficulties. In the allocative economics utilized by classical policy analysis, aggregate consumption is taken as a rough measure of social welfare, and is calculated by measuring a consumer's "willingness to pay" for a specific good or service. If an individual purchases a newspaper subscription for ten dollars, it may be inferred that the subscription is worth at least ten dollars to the purchaser. Because the use value of the newspaper may be fifteen dollars to the purchaser (i.e., he would be willing to pay up to fifteen dollars for the subscription) the market price is an inadequate index of the value of that particular good to that individual. The value differential between the use and exchange value (the maximum willingness to pay value and the market price; in this case five dollars) is termed an individual's consumer surplus, and is the fundamental tenet in the measurement of "social" benefits in any cost-benefit calculation. Total consumers' surplus can be measured by determining what a group of individuals would be willing to pay for a given commodity (estimating a societal or market demand curve) if the market price of the good or service is given and no exogenous changes in the economy are allowed. In Figure 1, ABC is the derived market demand curve for product x, say, a newspaper subscription, PP' is the market price and PQ is the quantity purchased at that price. Total expenditure on subscriptions is represented by the rectangle PP'BQ and the total consumers' surplus is the triangle P'AB (it is assumed that the demand curve is linear for simplicity); the size of the consumers' surplus, therefore, is equal to 1/2 (P'A x P'B). If a policy or program is enacted that serves to reduce the cost of the product (e.g. technological improvements in printing techniques) the social welfare benefit can be estimated by measuring the change in consumers' surplus resulting from the new policy or process. If the cost is reduced to PP'' in the above example, the new quantity purchased will be PQ' and the consumers' surplus equal to P''AB' (Figure 2). The increase in consumers' surplus, P''AB' - P'AB, can be divided into two parts; the cost savings to previous purchasers (P''P'BD) and that gained by new subscribers (DBB'). It is more important, however, to note simply that the change in consumers' surplus is one direct and important measure of the tangible effects of a given program or policy.[1]

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1 Several restrictive assumptions underlie the simple notion of consumers' surplus discussed above. Prices of other goods, tastes and asset distribution, for example, all must remain constant; the product is freely available; all consumers are price takers (no person can influence the market price); and so on. Changes in consumers' surplus can be estimated if individual assumptions are relaxed, but the interpretation remains the same. It is also possible to estimate benefits from producer goods (intermediate goods) and in earning foreign exchange. Neither estimation, however, is particularly relevant to the objective of this paper.

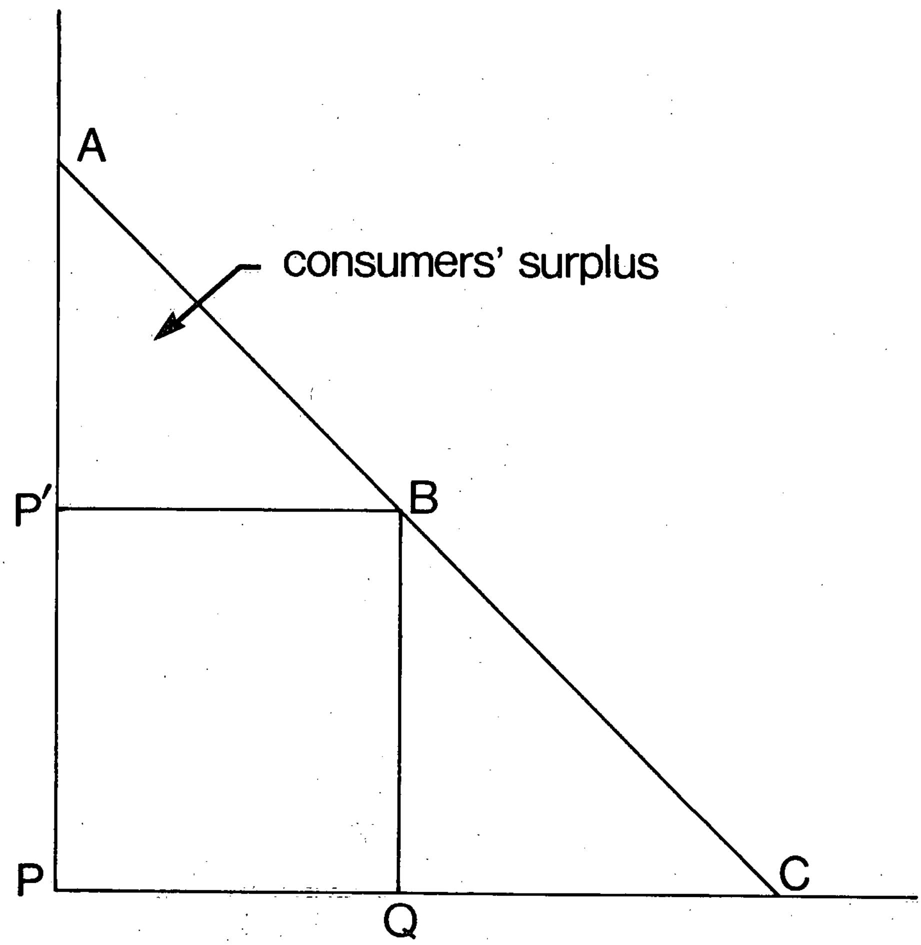

Figure 1. A typical market demand curve.

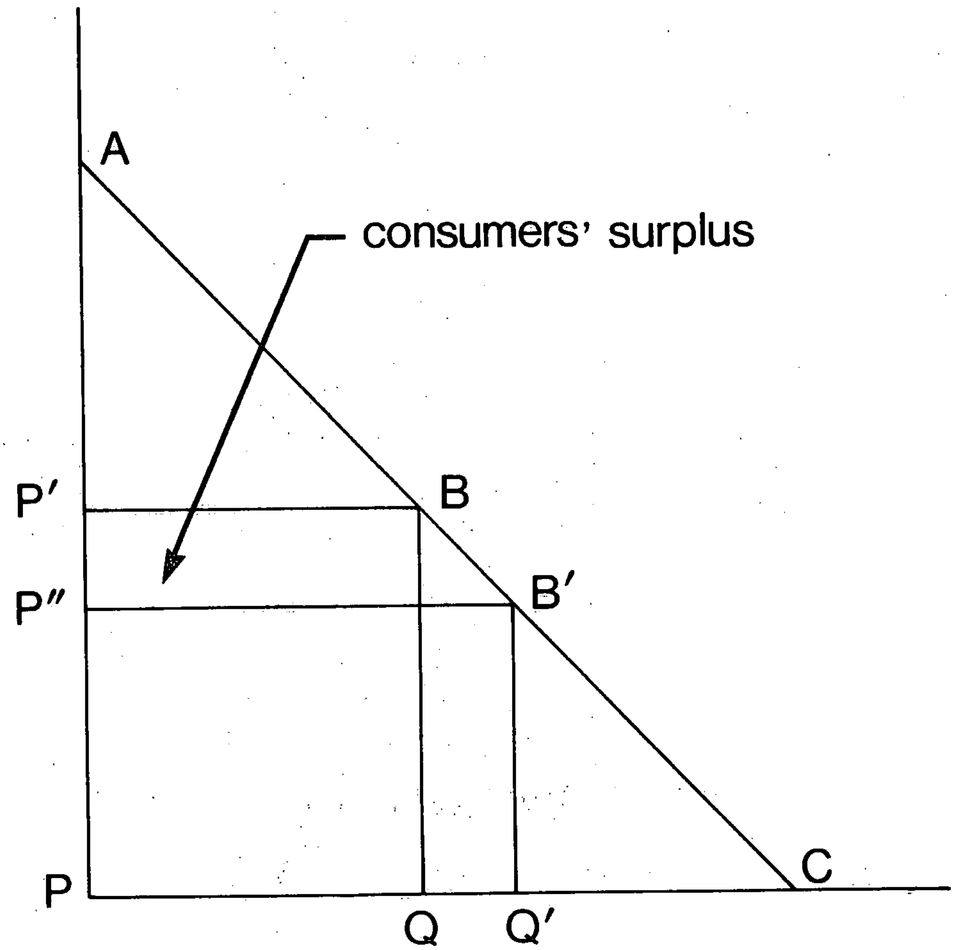

Figure 2. The change in consumers' surplus resulting from a simple cost savings.

Direct measurement of the cost segment of allocative policy evaluation also utilizes willingness to pay criteria, but from a slightly different perspective. The relevant cost of a policy or program is a mesurement of the maximum alternative benefits forgone, or the opportunity cost. In general, the social opportunity cost associated with a proposed program is equal to the benefit that might accrue if resources were applied to an alternative program. The inadequacy of the market price mechanism necessitates utilization of the value of marginal units of resources in alternative uses (i.e., social opportunity costs) to estimate cost. In perfectly competitive markets, the prices of inputs do represent the social opportunity costs of undertaking a specific activity. Imperfect markets, however, can result in an understatement (monopolistic situations) or an overstatement of social costs if the market price of inputs is utilized. Since costs are considered maximum benefits forgone, they can also be measured according to the criterion of consumers' willingness to pay. If relatively competitive markets are assumed, as is common in most conventional analysis, market prices are considered an adequate measure of social costs.

The costs of a particular program or policy, accordingly, are simply the net inputs, defined as the goods and services withdrawn from the rest of the economy that would not have been withdrawn in the absence of the project (73). The relevant methods of cost estimation concern producer goods (rather than consumer goods in benefit estimation), land and labour. If in the previous example, printing ink necessary for newpaper publication was diverted to facilitate the printing of a new book, the availability of ink to the newspaper economy is reduced by the amount used in book publication. The appropriate cost index, as a result, is simply the willingness to pay on the part of the newspaper publisher, for the ink that is no longer available. If competitive conditions prevail in the economy, the market price will reflect the producers' willingness to pay, as mentioned above. Similar arguments can be applied to land, labour and resource inputs.

Intangible Effects

The inability to quantify many intangible effects (indirect benefits and costs that are not reflected in traditional willingness to pay measures) resulting from policy adoption has been recognized as one of the most serious limitations of cost-benefit analysis (73). Although it may be almost impossible to assign monetary values to many indirect effects (also termed externalities or spillovers), unpriced, or inadequately priced, social benefits and costs are often valued by using a 'shadow' or 'accounting' price; i.e., a price that is deemed more appropriate than the existing market price (if one exists).

Various parameters may be used in particular situations for valuing a non-priced resource, e.g., recreational fishing. Traditional consumer surplus arguments can be utilized to determine what an angler would be willing to pay rather than go without the commodity (fishing) altogether. Extensions of consumers' surplus measures facilitate the quantification of certain non-user benefits as well. Option value (the premium that individuals would be willing to pay to assure future access for themselves to a resource use when there is uncertain supply), existence value (the willingness to pay for a resource derived not from knowledge of potential use, but simply from knowing a resource is preserved) and bequest motivation (desired by those who wish to preserve the option of resource enjoyment for future generations) can all be approximated in this manner (30). The measurement of intangible effects other than recreational and aesthetic becomes increasingly difficult. In some instances, the effect of the externality can be traced until it affects activities in society that have economic values associated with them (25, 40). Undiscovered values of living resources, scientific research and teaching values, ecosystem stabilization values and socio-cultural attributes, however, all pose serious problems to the allocative economic framework (12). The extensive use of shadow pricing to assess the value of time saved, the loss of life or limb, or the effects of pollution has entered many cost-benefit calculations, but is not without detractors (2, 15, 66, 67, 52).

Typically in the evaluation of transportation projects, a primary objective is to reduce journey time while increasing the convenience of travel. Theoretically, this parameter could also be measured by a willingness to pay survey, but in the absence of such a time-consuming and inherently unreliable technique other shadow prices are utilized. A measure common to the estimation of the value of a lost life is simply the amount an individual could earn during the time saved. The value of leisure time can also be calculated in this manner. The assumption that all individuals would be able to work (and generate income) during the time saved and that there is disutility associated with travel may not be realistic; evaluating time saved, however, must include these caveats.

Calculating the value of loss of life is becoming of increasing importance in assessing the impacts of large scale projects or developments. The most common way of estimating the economic worth of a person's life and, accordingly, the loss to the economy with his death, is simply the person's discounted expected future earnings. Alternative estimations include using net income figures (instead of gross output utilized above), or indirect calculations by evaluating other societal programs (and their implicit loss of life valuation) or using insurance premiums as a proxy.

Pollution damage has recently been approximated by observing variations in property values in areas affected by the externality. Although an appealing approach, no significant statistical relationships have been found relating pollution and property values. The notion that an ideally competitive property market subject to a single isolated form of pollution would accordingly reflect the social costs attributable to that pollution is also somewhat suspect.

Social Rate of Time Preference

Regardless of the methods utilized in assessing the monetary benefits and costs of a proposed policy, the implication of cost-benefit analysis is that effects occurring in future time periods must be taken into consideration, and that these effects must be assessed at their present value to promote comparison of both costs/benefits and alternative policy proposals. Fundamental to the analysis is the criterion of present discounted value; the sum of all benefits and costs (the benefit stream), discounted to their present value. The simplistic mathematical formulation of cost-benefit analysis (depicted as a benefit/cost ratio) is, as follows:

$$R_{B/C} = \frac{\sum_{t=0}^{t=n} \frac{B_t}{(1+r)^t}}{\sum_{t=0}^{t=n} \frac{C_t}{(1+r)^t}}$$

where: B_t, C_t = total stream of benefits and costs associated with the policy, respectively, over time period t.

r = discount rate or social rate of time preference.

Expressing policy evaluation in terms of discounted present value, while necessary to the objective of economic efficiency, introduces explicit subjective criterion into the framework, namely the selection of a social rate of time preference and a time horizon. In situations where project selection is dictated by the benefit/cost ratio (the implications are if B/C is greater than 1.0, the project will be undertaken) the selection of the value of these two parameters may have a direct impact on the outcome of the decision. Arithmomorphic decisions (yes if B/C is greater than 1, no if B/C is less than 1) can easily be reversed in many instances by altering the value of the discount rate or time horizon. Together with the above deficiencies, this implies that cost-benefit analysis may be little more than a "system of wisdom in the folly of hypothetical delusion" (29).

The above discussion has presented a brief review of the primary elements of policy evaluation, drawing heavily on the works of Mishan (52) and the United Nations (73) (for a more detailed discussion of policy evaluation and economic efficiency the reader is referred to either of these). The nuances evident in measuring costs and benefits and applying concepts presented herein are extensive, and beyond the limited scope of this review. The basic allocative economic framework, the relationship between tangible and intangible benefits and the present discounted value stipulation characterize the fundamental elements of what has been labelled 'traditional policy evaluation', and although deserved of considerably more exposition, present a singular method for assessing the socio-economic impacts of government regulations. The appealing features of the approach concern its surficial simplicity, its application to various contexts and the objective umbrella that is (mistakenly) associated with its use. Its weaknesses, however, are considerable: the subjective nature of parameter selection, equating social welfare and economic efficiency and the inability to adequately quantify intangibles, present the most obvious inadequacies.

CHAPTER III

Energy as a Basis for Relating Systems of Man and Nature

"If we have available energy, we may maintain life and produce every material requisite necessary. That is why the flow of energy should be the primary concern of economics." (71)

Energy is the basis for the survival, maintenance, organization and growth of all living systems. Energy, simply defined, is a measure of everything; a quantity that accompanies all processes and can be measured by the amount of heat it becomes (59). Additionally, all forms of energy can be related, and it seems intuitively reasonable that energy can be utilized as a common denominator for studies which integrate systems of man and nature into one framework (36). The acceptance of energy as a limiting and governing factor in the structure of human societies is not of recent vintage; Boltzman suggested in 1883 that life is primarily a struggle for available energy (8). Odum (55, 56, 57, 59, 60) provided the initial framework in attempting to create a unified theory for all systems based on the flows of energy and "energy laws". The dynamics of natural systems can readily be described in terms of the energy flows; recent work has extended these concepts to systems of man (sometimes called economic systems) and the interface between man and nature (21, 79, 41, 7, 9, 16, 8, 61, 75).

The principles of energy flows adhere to three fundamental laws and five corollaries (60). Human systems are subject to the same energy constraints as other natural systems and, accordingly, are governed by the following conditions:

1. The first energy principle: energy is neither created nor destroyed, but must be conserved. Energy flowing into a system is either stored, available for work, or dissipated into dispersed heat.

2. The second energy principle: in all processes some of the energy loses its ability to do work and is degraded in quality. A resulting concept is that the creation and maintenance of organization

requires work, without which the system will tend towards disorder. Dissipated energy flows are, additionally, irreversible and lost to the environment. Energy degradation can also be termed entropy, measured by the ratio of heat flow to the absolute temperature of the environment.

3. Lotka's maximum energy principle (47): systems survive and dominate that maximize their useful total power from all sources and flexibly distribute this power toward needs affecting survival. The system that ultimately survives (and this is assumed to be the ultimate criterion of value) is one which obtains the most energy and uses this energy most effectively in competition with other systems. Lotka's principle is as applicable to business competition as it is to forest ecosystems. The two elements, quantity and efficiency, are distinct, but interrelated; the tallest trees in a forest canopy receive the most energy (in the form of sunlight); to survive, shorter species must make efficient use of the limited energy they receive. Large urban areas are quite energy intensive; during periods of uninterrupted energy supply they are able to drain resources from outside and effectively dominate rural areas. It has been suggested, however, that this energy utilization is accompanied by inefficiency; volatility in supply may result in the decreased domination of these regions (e.g., the industrial Northeast United States) (44).

4. Development of order and interaction feedback: the variation in quality (i.e. the ability to perform work) between different energy flows (e.g., sunlight and electricity), necessitate that certain "high-quality" energy flows are used to upgrade larger, but lower quality, flows. Systems that develop an efficient feedback mechanism are able to draw more power because they are more effective at exploiting energy resources. As an opposing force to the energy degradation principle, order must be maintained to allow for the upgrading of energy.

5. Competitive exclusion: a fundamental of simple, competitive systems that do not have population control mechanisms specifies that one competitive unit will grow at the expense of others and result in their extinction. In diverse well developed ecosystems using many energy sources, co-operative forces will help maximize power, and negate competitive exclusion.

6. Compensation and contol loops: self organizing systems must exhibit return flows; the farmer supplying crops to the city must be returned commodities of equal value, or else the system would degenerate.

7. Energy/Money exchange: circulating currency travels in the opposite direction of energy. In the North American economy, one dollar is equivalent to about 25,000 kcal of high quality energy. Money often acts as a feedback mechanism, accelerating principle energy flows (through the demand and purchase of goods and services). If energy becomes unavailable to an economic system, the dollar loses value until it can buy nothing, since no energy is available to produce goods and services. Money, however, is only relevant to certain aspects of the man/nature system; most of the earth's energy budget is not included in the 'economy of money' and, accordingly, it is evident that traditional theories of value deal with only partial reality.

8. Self-organization and culture, religion and behavior: stored energies are developed and reinvested on the basis of human behavior programs. Social system behavior is adaptable and responsive to change; behavioral patterns follow, however, rather than lead the evolution of surviving systems. Attitudinal change, however, must accompany the planning for system survival.

The principles enumerated above were presented by Odum (60) and provide a base for an energy theory of value. The fundamental tenet of energy analysis accepts that although the economic system is responsible for the flow of goods and services to populations and cultures, it represents only a small percentage of the ecological components and social relationships that comprise our earth system. An alternative is to use energy as a unit measure of the global community, since in this way systems of man and nature can be interrelated. Additionally, if Lotka's maximum energy principle is adhered to, it is possible to design (and evaluate) systems of man and nature on the basis of energy. Two possible analytical approaches arise from the concepts outlined above; net energy analysis and energy cost-benefit analysis, both of which can be used in isolation, or to supplement traditional economic approaches.

Net Energy Analysis

Energy flows that generate more high quality energy than they use are considered net energy producers. If net energy is available, growth is stimulated, and, in turn, the inflow of energy from less rich sources can be subsidized. The ratio of energy yielded to energy used (yield ratio) can be used to evaluate the feasibility of alternative projects, similar to a benefit/cost ratio. The evaluation of net energy can be explained using the simplistic systems diagram in Figure 3. Extraction and refinement of reserve oil necessitates goods and services which, initially, require X kcal of energy for formation. Some of this is degraded in the production process, and the remainder is available to the oil company (e.g., in the form of drilling equipment) to facilitate resource extraction. The resulting outlow of energy is equal to Y, of which X must be returned to the societal storage of fossil fuel to allow for the additional production of drilling equipment. This is the feedback quantity required by the system. The net energy (E_N) is simply equal to Y - X (the interaction with low quality energy (e.g., solar) is not illustrated in the diagram). As energy becomes less available, and more difficult to extract, the amount of feedback energy required to continue drilling is greater than the amount yielded; there is negative net energy. An energy yield ratio can then be calculated ($\frac{Y}{X}$) to allow for comparison of alternative projects. If the yield ratio is greater than 1.0 (in the example above, the ratio is 90/80 = 1.1, a positive, but small, net energy yield), there is net energy. Odum (59) notes three possibilities for investing net energy for a system to maximize its chances of survival:

1. Net energy can be stored, in the form of system growth.

2. It can be used to diversify and develop additional sources of energy or more efficient processing.

3. It can be exchanged as yield in order to obtain special imports from the outside.

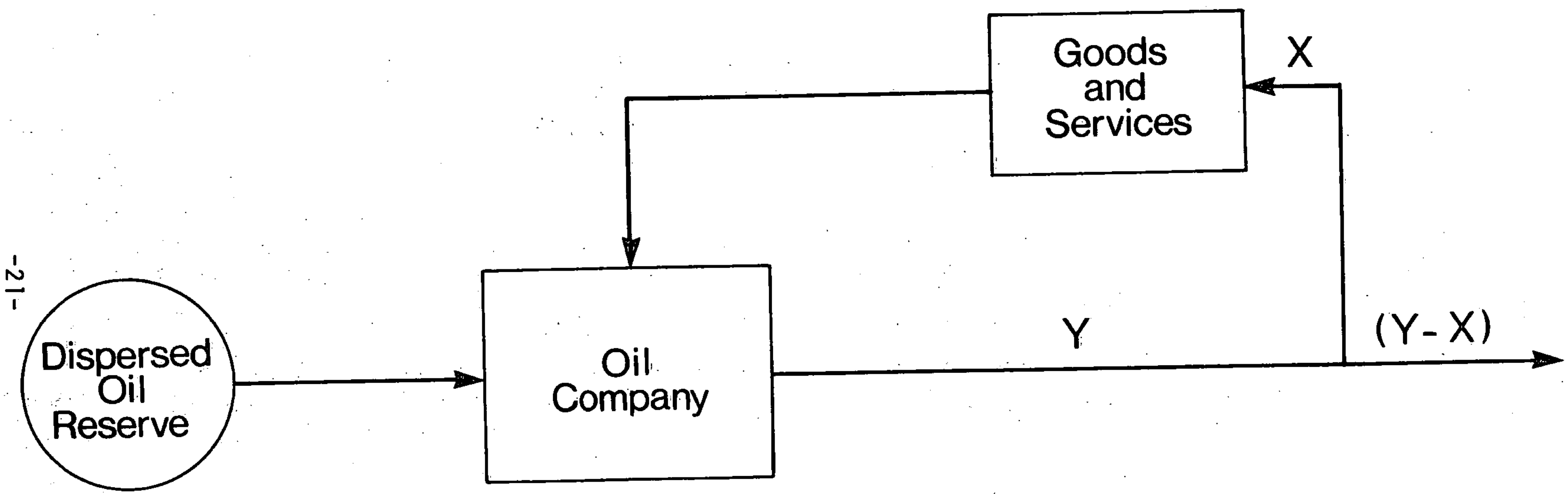

Figure 3. Example of an energy source producing net energy (i.e. Y - Z > 0)

Energy cost-benefit analysis

The natural extension of net energy determination is to evaluate the energy effectiveness of public projects, policies and the like by relating systems of man and nature using energy cost-benefit analysis. Proposed projects could be assessed according to the effects on the energy budget of the region. The procedure has been used to evalute the effects of power plant construction (39), assess a proposal for offshore oil drilling (59), evaluate the stability of a regional system, Gotland, Sweden (36), and is presently being utilized as an alternative to economic valuation in a regional assessment study of the Chesapeake Bay, Maryland (46). In addition to allowing for the interrelationships between man and nature, energy analysis also absolves a serious deficiency in traditional cost benefit analysis; discounting is not applicable to energy flow calculations, since economic efficiency is no longer the overall objective.

Energy analysis is in its comparative infancy, and, characteristically, not without problems. Two difficulties concern energy quality and the inability to treat demand factors. Conversion tables for energy quality comparisons have recently been developed, standardizing values in fossil fuel equivalent units, but problems with incorporating demand remain. Regardless of the fact that gasohol development yields negative net energy, the resulting product may be more desirable (to operate automobiles) than the inflowing energy (e.g., electric). If the primary concern lies with system survival, the demand argument is moot; long term normative planning (i.e., this is the way we should operate), however, has not been well received.

Although energy can be viewed as a possible common denominator between socio-economic systems and natural systems, there are still things which have no meaningful energy measure, such as human health, welfare and happiness, recreation. And in many ways the criteria of maximum net energy is no better than the old criteria of maximum net dollar benefits. For instance, most industrial agriculture produces less in the form of food energy than it uses. Does that mean we should stop modern agriculture? Also, in energy terms, Lake Erie captures more net energy in biomass than Lake Superior because it is eutrophic. Does that mean that Lake Erie is better than Lake Superior or that if Lake Superior were as eutrophic as Lake Erie, we would all be better off. And how could energy analysis account for toxic substances? Energy analysis is not a panacea. It is simply an alternative approach to evaluating the effect of regulatory policies on social/economic/environmental systems. Dollar/energy conversions allow for the expression in either unit, the only change being a non-adherence to allocative economics and an acceptance of energy/related macro-system behaviour. It is also conceivable that an eclectic framework can be devised, using economic criteria in areas in which it is most suited, and supplementing inter-system determinations with energy analysis. The remainder of this paper presents a possible framework for assessing the socio-economic/environmental impact of water resource policies, utilizing both the contexts mentioned above, in an effort to devise a practicable and flexible policy evaluation structure.

CHAPTER IV

A Conceptual Framework for Socio-Economic Impact Assessment

The subsequent discussion outlines a proposed framework for policy evaluation, utilizing the information on value metrics (monetary or energy) presented above, and presented in a mathematical programming formulation, in which elements of optimization, simulation, and general decision theory can be combined to promote program assessment. The design of the methodology is inherently flexible and will accept decision criteria from various perspectives; economic efficiency, energy flow, cultural variables, or combinations of these. Although the primary focus of the framework presented herein is the evaluation of social/economic/environmental impacts on the basis of energy flow, the procedure is presented in generalized form to facilitate adaptation to other unit measures. The utility of using energy as a unit measure has been discussed in previous chapters; the remainder of the paper will concentrate on the analytical framework suggested, its strengths and weaknesses, and its application to present modeling efforts and general problems concerning the Great Lakes region.

Mathematical Programming and optimization

The fundamental problem addressed by optimization is to solve for the best possible decision under a given set of conditions or constraints. The approach has recently been suggested as 'the paradigm' for planning (22) and the advent of mathematical programming procedures has facilitated the application of optimization to large scale problems. The formulation of the general constrained optimization problem is, as follows:

Maximize or Minimize $z = F(X)$

subject to the given constraints $g_i \leq, =$ or $\geq r_i$ $(i=1,\ldots,m)$

and $X \geq 0$.

The objective function F(X) is defined for a vector of n main variables ($X = s_1, \ldots, x_n$) and is subject to the set of conditions stated as g_i (X), and the non-negativity restriction on all x_n. If both F(X) and all g_i (X) are linear functions of the variables x_n, the problem is a linear program. Conversely, if F(X) or one or more of the g_i(X) is nonlinear in any of the variables, the problem is a nonlinear program. Solution procedures have been extensively developed, and the theory, methods and applications of optimization have been amply expounded (76, 19, 20, 56, 3, 64) . Utilizing the unit measure of energy flow within the framework of an optimization program is relatively straight forward; the primary objective is to maximize the net energy yielded by regulatory policies, subject to constraints on energy supply, resource availability, socio-cultural limitations, and the like. Lotka's maximum power principle suggests adherence to principles of maximum energy flow; optimization can be used in regional planning, although, until recently, it had been confined to simulation modeling and systems ecology (36, 46).

Multi-objective programming

The optimization framework outlined above - and most applications of optimization in the past three decades since its inception - have been single-objective optimization models. The use of uni-dimensional criteria (whether linear or nonlinear, static or dynamic) does not always reflect decision makers' preferences. Accordingly, optimization can be extended to accomodate multiple objectives; the analytical framework is termed multi-objective programming. An example might be to maximize output, minimize energy consumption and minimize environmental damage (54, 5, 6, 69, 78). The multi-objective situation exhibits additional utility not only in explicitly recognizing the various objectives of different segments of society, but in evaluating these objectives within a single framework. The multi-objective problem can be structured as follows:

Max. (Min) $B(X)$

subject to: $g_i\ (X) \leq,\ =,\ \text{or} \geq r_i\ (i = 1, \ldots, m)$

and $X \geq 0$.

where: $B(X)$ is termed a vector-valued function, encompassing successive decision criteria $B_1(X), \ldots, B_k(X)$. In general, the objectives are conflicting, and maximization of a specific objective $B_k(X)$ precludes the attainment of the maximum $B_k'(X)$. The solution methods of multi-objective problems necessitate assigning weights to various decision variables or solving for independent functions and assigning the remainder of the objectives to the constraint set. The discussion of multi-objective programming was included to present an extension of optimization when economic valuation is utilized. The maximum power principle dictates the maximization of net energy yield as a singular objective. Utilizing different unit measures, or simply dollars, the multi-objective framework presents an appealing option.

Simulation

Simulation modeling has long been the mainstay of systems ecologists in depicting the dynamics of natural populations, and is easily adaptable to accepting energy flow as a unit measure (62, 4, 43). Simulation has recently been utilized to model social systems at a macro-scale as well (13, 14, 49, 50). The models are generally composed of a system of normal first-order differential equations of the following form:

$$F(t, x, \dot{x}, z) = 0;$$
$$\text{or } \dot{\tilde{x}} = \tilde{A}\tilde{x} + \tilde{B}\tilde{z},$$

where the state variables are represented by the vector $\tilde{x}$ and the driving forces by the vector $\tilde{z}$, and $\tilde{A}$ and $\tilde{B}$ are constants. Aside from their utility as a means of better understanding the dynamics of natural systems, simulation models can be used in two ways to facilitate both policy evaluation and natural resource management:

1. Simulations of man/nature can be developed, using energy as a unit measure, and policy alternatives tested to determine the one yielding the most net energy (79).

2. Simulation models can be coupled to optimization models (single objective or multiple-objective) to allow for explicit decision criteria input.

The proposed methodology discussed herein concentrates on the latter use of simulation; although if differential equation models of social systems can be developed, the use of these formulations to promote social/economic/ environmental impact assessment would be equally desirable.

Linking simulation and optimization models to promote natural resource management is not without precedent, although only recently has the suggestion of using energy flows rather than dollar flows been entertained. Swartzman and Van Dyne (72) espoused interactive planning to accomodate ecosytsem complexity and meet planning objectives. Their study involved the conversion of government owned lands in Australia to a combination of private management and a system of "commons", with the primary objective of maximizing returns over the region from raising cows and lamb. The resultant model was a linear optimization routine, with constraints on resources, optimal slaughter weights and the maximum number of animals which could be slaughtered (based on information derived from the natural system simulation).

Mathematically:

$$\text{MAX} \quad \underset{\sim}{c}^{T} \underset{\sim}{x}$$

$$\text{s.t.} \quad \underset{\sim\sim}{Ax} \begin{Bmatrix} \leq \\ \geq \end{Bmatrix} \underset{\sim}{b}, \qquad \underset{\sim}{x} \geq \underset{\sim}{0},$$

$$\text{and } \dot{\underset{\sim}{x}} = \underset{\sim\sim}{Dx} + \underset{\sim\sim}{Ez}$$

where the vector x comprises the main variables (animals), the vector z the driving forces in the simulation model (climatic variables), the vector c and the matrices A, D and E are constant coefficients, and b is a vector of contraint constants. The primary objective of the differential equation model is to supply information to the right-hand-side of the constraint function, and the model is then executed as a linear program.

A somewhat different approach was taken by Kelly and Spofford (37) in attempting to identify the least cost of various management strategies, with particular interest in reducing wastewater discharge into the Delaware River to a certain level. The basic model was, as follows:

$\min F = cW$ (the total costs of reducing wastewater discharge)

s.t. $A_1W + A_2Z \geq B$ (models of waste generation)

$H(Z) = X$ (steady state equations of the natural system model)

$X \lesseqgtr s$ (ambient water quality standards)

$Z \geq 0,\ W \geq 0.$

where W equals waste reduction and Z equals waste discharge. To rid the model of the non-linearities existing in the natural system equations, it was converted to a linear model utilizing penalty functions, and was structured as follows:

$$\min F = CW + P(Z)$$

$$\text{s.t.}\quad A_1W + A_2Z \geq B$$

$$Z \geq 0,\ N \geq 0.$$

$$\text{where } P(z) = \sum_{i=1}^{n} p_i\ [S_i,\ x_i = h_i(z)]$$

(i.e., there is an individual penalty (p_i) assessed whenever x_i exceeds the water quality standards S_i).

The management problem is not strictly bounded by standards, but when certain standards are violated, a high monetary penalty results to the objective function.

A similar model was developed to facilitate regional planning efforts in the Chesapeake Bay region of the Eastern United States (45, 46). The model is presently being extended to accept energy flow data, and adapted to solve for various objectives (e.g. food output, energy, contribution to G.R.P.).

Simulation and optimization models can be coupled in three ways; in all cases the information supplied by the simulation model becomes input to the optimization routine:

1. The set of initial conditions providing input to the simulation model will yield, after a specified time, a comparable set of terminal conditions that are generally utilized in impact analysis. The dynamics of natural populations based on certain driving variables, for example, can be monitored and management decisions (e.g., whether or not to harvest a certain crop, or what catch limits should be for fish populations) can be made at discrete time intervals. This information is normally provided to the optimization model by dictating the right hand side of certain constraint functions and, while useful in this limited context, fails to impart information concerning the dynamics of natural systems directly to the optimization scheme.

2. If the simulation model rapidly reaches a steady-state, it is possible to derive a steady-state equation by setting the differential quantity (x) equal to zero.

   e.g. $\dot{x}_1 = a_1 x_1 + b_1 z_1 = 0$

   and $x_1 = \frac{-b_1 z_1}{a_1}$, which gives a steady-state equation for variable x_1.

Kelly and Spofford (37) utilize steady-state equations when deriving water quality relations and, ultimately, in assigning penalties when ambient standards are exceeded. The weakness of this method is simply that natural systems, in most cases, are less than accommodating in rapidly achieving a steady-state.

3. A third linkage procedure involves estimating the function f(x) by taking weighted averages of x/t curves for varying quantities of the other state and driving variables. This necessarily limits the equations to a minimal number of variables, a fact not necessarily considered detrimental, particularly in light of the disrepute recently accorded large scale (and extremely costly) simulation models.

The model is typically run in discrete time intervals, depending on the perceived time necessary to adopt alternative regulatory policies. Initial conditions are provided to run the simulation model, which can subsequently be coupled to the optimization framework. The results of the optimization establish initial conditions for the next round of the simulation (Figure 4). The result is an inherently flexible, normative model that can supplement present natural resource and economic impact assessment.

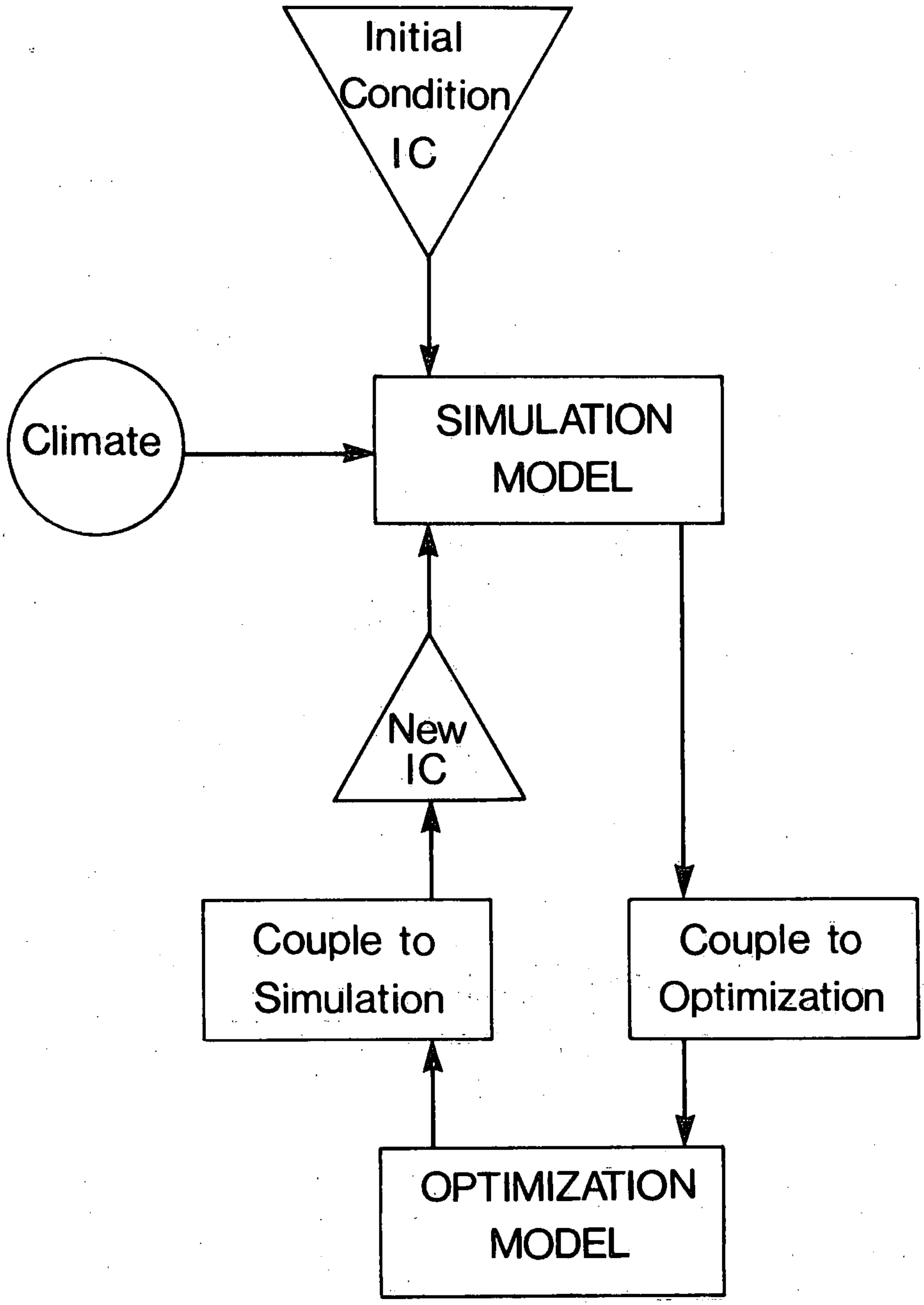

Figure 4. Interrelationships of the simulation-optimization structure. (Swartzman and Van Dyne '72)

CHAPTER V

A Methodology for Assessing Social/Economic/Environmental Impacts of Regulatory Policies

Although it is beyond the scope of this paper to review the water quality simulation models developed for the Great Lakes region e.g., (11, 1, 31) the natural system simulation is an essential element in socio-economic impact assessment. This methodology requires an adequate simulation model which will predict variations in water quality given changes in point and non-point loadings. The behavior of the social/economic system can be estimated either by the use of a simulation or an optimization model, as mentioned in the previous chapter. Two feasible options are then available to the regional planner:

1. Trade off the dollar costs associated with a particular policy using economic efficiency as a measure of social welfare, with the water quality improvements in physical units (this can be offset somewhat if water quality directly impacts an economic sector. e.g., commercial fishing, and the monetary effects can easily be estimated), and listing other social welfare indicators where possible (qualitative metrics).

2. Utilize energy units as a common denominator between systems; explicitly recognizing the singular objective of maximizing net energy yield as the mechanism controlling system survival.

The former framework can be useful if a multi-objective programming model is utilized; different metrics are accounted for by the multiple objectives, but decision makers must identify the relative importance of each objective (revealed preference). As mentioned previously this is an appealing framework, but does little more than combine various systems models under a unique structure. The latter approach is more reasonable; although decision makers may feel uneasy due to its normative implications (it solves for the best decision policy) and the relative ignorance of energy measurement (dollars are simply more familiar - utilizing a dollar/energy conversion, presently $1/25,000 kcal, this can be resolved). Figure 5 presents a simple systems diagram of the Great Lakes region, identifying major components and their interactions, and suggests a general framework for an initial analysis. Symbols of the energy systems language are shown in Figure 6. Energy flow data is readily obtained from the natural system simulation by simple conversion and the basic data for energy flows in most human activities - or the methods for obtaining these flows - are also available (24, 7, 26, 27). In order to compare energies of different concentrations as to their ability to do work the concept of energy quality could be used (Table 1). Urban systems in contemporary society are dominated by two sources of energy. Man-made energy, a slight misnomer for fossil fuels, are supplied to human systems in the form of liquid petroleum, natural gas, and electricity. Natural energy, on the other hand, is a direct result of the actions of natural systems; photosynthesis, winds, tides and wave action, for example. Agriculture plays a rather unique role in the system because it converts natural energy into food, which is a vital source of energy for man. This form of energy, in turn, can be exchanged for money, presenting almost a direct link between natural energy and the economic system.

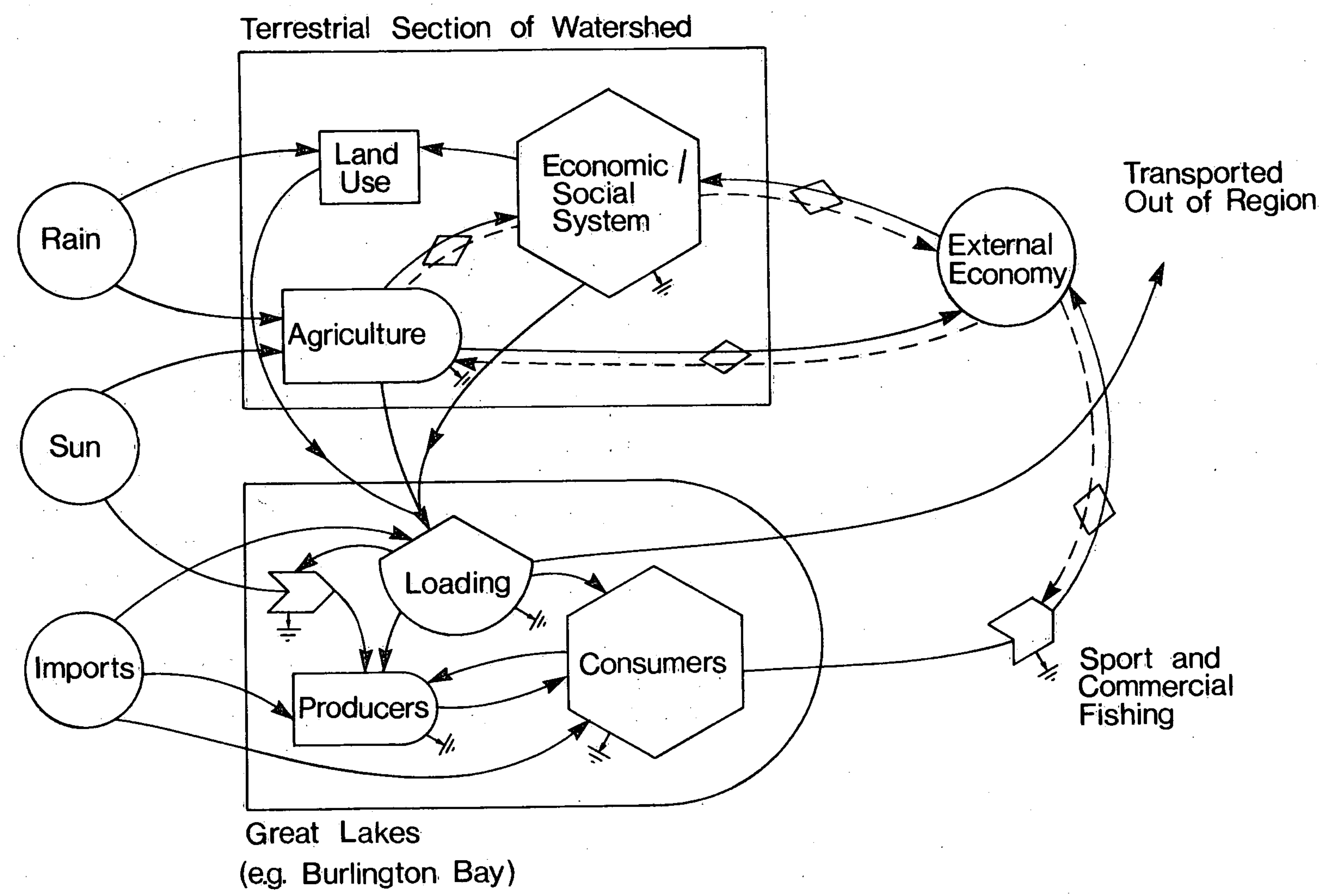

Figure 5. Generalized diagrammatic model of a typical Great Lakes ecosystem, depicting man-environment interactions

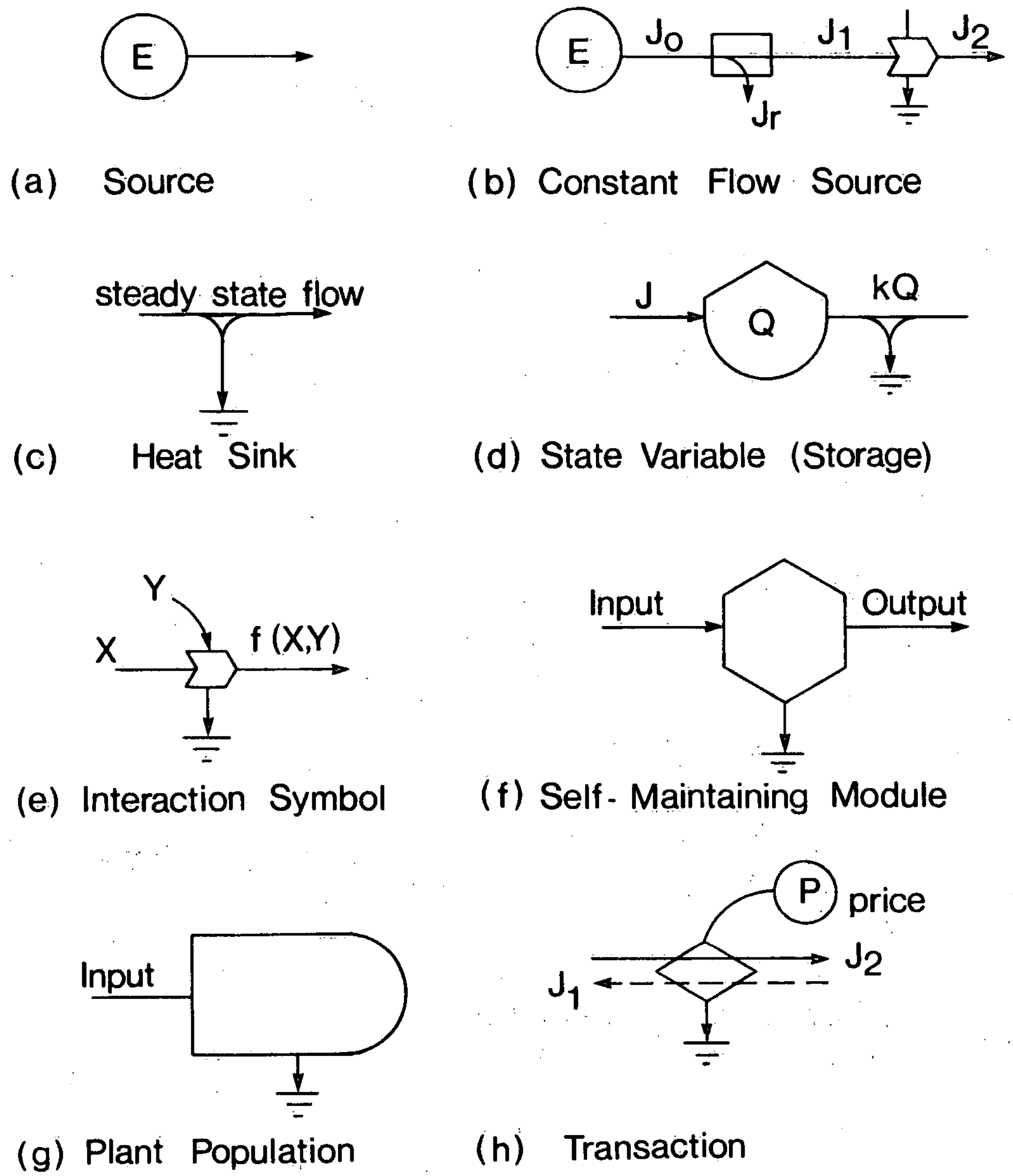

Figure 6 Symbols of the energy systems language utilized in model illustration.

Table 1

Energy Quality (Concentration) Factors relating different work processes

Energy conversion process	Energy Quality (Concentration) Factor*
Sunlight to gross production	100
Gross production to wood	10
Wood to fossil fuel	2
Wood to electricity	8
Gross production to fossil fuel	20
Sunlight to fossil fuel	2,000
Tidal energy to fossil fuel	0.3
Hydrostatic head to fossil fuel	0.3
Fresh/salt water concentration gradient to fossil fuel	10 (?)
Total work done in U.S. per dollar	25,000 kcal/dollar

* The Energy Quality Factor is a ratio of total energy inputs (including all subsidies) to energy output from the conversion process. By using appropriate sets of ratios, different forms of work can be converted to the same equivalent type and then compared or summed. Energy Quality Factors are preliminary and subject to readjustments (58, 77, 38) .

Natural energies are important to the supply of oxygen, pollution dispersal by winds, fish production, and so on, none of which are exchanged for dollars. Direct free energies also include fishing, beautiful beaches and natural areas; a direct subsidization of human systems by the natural environment.

CHAPTER VI

Summary

The preceding discussion concentrated on a review of present socio-economic impact methodologies, with specific respect to the analysis of systems of man and nature, utilizing energy flow information. Energy analysis, although still in its infancy, presents an alternative to the restrictive allocative economic framework of traditional policy evaluation, and is inherently appealing in its ability to synthesize social, economic and ecological systems with the same unit of measurement. Optimization, additionally, presents an explicit structure for identifying the best choice in selecting among policy alternatives, and is appealing for both its organizational framework and solution technique. Cost-benefit analysis, impact analysis, and policy evaluation all suffer from an inability to relate natural and social systems. The energy approach, coupled with a macro-system simulation or optimization model, is an alternative that should be explored. Adherence to traditional approaches can only lead to serious policy deficiencies and an increased dependence on economic mandates. To rephrase a statement by Arnold Toynbee, maximum welfare, not economic efficiency is our human objective.

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