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QUANTITATIVE ASSESSMENT OF NATURAL VALUES IN BENEFIT-COST ANALYSIS*

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ABSTRACT

Two methods of quantifying the contribution of natural ecosystems to man's economy in benefit-cost analysis are presented. The economic approach uses dollar costs to approximate the more tangible natural system contributions. The energetic approach uses energy flows of the natural ecosystems to quantify the contributions. Sample calculations of each approach are made of the impact of a highway on a floodplain.

Benefit-cost analysis in transportation planning has suffered from an inability to account for the value of natural systems. This inability, however, is not specific to transportation planning; rather, economic theory in general has not developed a conceptual basis for assigning value to natural systems [1]. Such limitation has been caused by the inclination to value only those commodities and services which enter the market economy. Natural systems, whose services to human societies are usually not purchased in the market, have thus been considered external to the economy. Consequently, recent efforts to quantify natural value have spoken of the need to "internalize" natural systems, that is, to make them visible to market pricing mechanisms [2].

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Many authors have enumerated the services that natural systems provide [3]. These services include maintenance of land and river forms, degradation of wastes, maintenance of soil structure, and maintenance of clean air and water. Such services sometimes are collectively called the public service functions. These functions enter the market because they are the basis of our existence. However, we seldom calculate their value, and when we do, it usually is after they have been degraded by human activity.

Because economic theory has not included the value of natural systems, benefit-cost analysis has been restricted to pricings which emerge directly from interactions in the market system. The restriction of benefit-cost analysis to such pricings is a very serious limitation of the methodology [4]. Because of this restriction, the value of natural systems has not entered into the calculation of benefits and costs in transportation planning. As a result, project cost impacts generally have been understated.

In order to rectify some of the inadequacies in current benefit-cost considerations, new ways of handling natural system value must be applied. This paper presents two methodologies which enable transportation planners to incorporate environmental degradation into the calculation of project costs. Two techniques for calculating natural value are demonstrated, as well as the means for integrating natural value into economic consideration. Essentially, these two techniques permit the planner to quantify certain external diseconomies. Thus, cost impacts can be more completely determined with previously neglected costs. In this discussion, quantified benefits are not emphasized as they normally accrue in the market economy and therefore are not as difficult to obtain. To simplify matters we have chosen to neglect those instances when projects have a beneficial effect on their surrounding environments. This is especially true of water resource projects which may create recreational value. Nevertheless, the methodological framework presented could just as easily be applied to these cases by reversing the symmetry and adding increased natural benefits to the market benefits.

Methodologies

The methodologies are presented as two alternative techniques for evaluating environmental degradation. The first methodology discussed is the economic approach, value is reflected through dollar flows, and one needs only to calculate dollar prices to determine value. The second methodology discussed is the energetic approach. This approach is recently developed from the life sciences and draws much of its theoretical basis from ecology. In the energetic approach, value is calculated from the energy flows in the ecosystems. Previous studies have indicated that quantification of such flows gives an estimate of the "total support work" that natural systems freely provide human systems [3]. This total natural work is available and used by human systems even though only a small portion may enter the pricing system.

The first section presents the basic assumptions and a general description of the two approaches. The second section is a demonstration of the approaches using a hypothetical highway with a specified impact on the surrounding environment.

Economic Benefit-Cost Analysis

The economic approach outlined here is a modification of the benefit-cost techniques that traditionally have been applied in the evaluation of highway projects. It is adjusted from the previous techniques in two ways to incorporate the value of natural systems. First, the opportunity costs of lost natural value are discussed and a method of integrating such costs into net benefits is shown. Second, a means for using the discount rate to account for the decreasing supply of and increasing demand for natural areas is depicted.

ENVIRONMENTAL COSTS

Traditional benefit-cost analysis does not include a specific category for environmental damage. All adverse effects of a project are calculated as induced costs which must be subtracted from benefits to produce net project benefits [7]. Typically, two such cost calculations are made for a single determination of adverse effects. Both the value of the inflicted damage and the cost of damage prevention are computed, then the smaller of the two is used as the induced cost value.

Environmental damage may be included in benefit-cost analysis as an induced cost. It is necessary first to enumerate and specify values of the natural area involved. The recreational value of natural areas has long been appreciated, and a large body of literature exists that deals specifically with its calculation [8]. Recently, new natural system values have been specified and efforts are underway to quantify them [4, 9]. Natural system value is now seen to be comprised of many components, including recreation,

Table 1. Economic Values

Type	*Dollar value*
Educational	\$5.00/year/student/marsh
Secondary and Tertiary Sewage Treatment	\$0.025/year/m^2
Recreational	\$14.00-\$34.00/fishing or boating trip \$55.00/bird-watching trip

Source: Most references are from Wharton [10], except for Cost of Secondary and Tertiary Treatment of Sewage, which is from F. L. Boyt, S. E. Bayley, and J. Zoltek [11].

education, water storage capacity, and water quality control [10]. In calculating net benefits, the loss of any of these values must be incorporated as an induced cost. Several economic values received directly from natural systems are presented in Table 1. Such values are highly tentative since the methods by which they were calculated have only recently been developed. Educational and recreational value depend on supply of primitive area. If there are several natural environments in a given area, all but one of the natural environments may be expendable. This argument has been cited in studies of the Cross Florida Barge Canal (U.S. Corps of Engineers Economic Restudy of the Cross Florida Barge Canal, Jacksonville District, Florida, 40 pp.). For simplicity, we assume here that the natural area is surrounded by urban locations, and therefore is inexpendable. The function of natural areas in sewage treatment, however, is always of value, because scarce capital resources are liberated to other sectors of the economy when natural systems are put to this use.

In general, the net benefit is formulated as:

$$B_n = B_t + B_i - C_I$$

where:

B_n = net benefits
B_t = tangible market benefits
B_i = intangible market benefits
C_I = induced costs

Assuming that induced costs are comprised totally of the damage done to natural systems by project impact, we may calculate them as the difference in value between the unaffected and the project-affected environment:

$$C_I = (R_u - R_A) + (E_u - E_A) + (W_{su} - W_{sA}) + (W_{Qu} - W_{sA})$$

where:

Subscript u represents unaffected environment
Subscript A represents affected environment
R = recreational value
E = educational value
W_s = water storage capacity value
W_Q = water quality control value

As these services are frequently cited by ecologists as providing value to human systems we have arbitrarily chosen these. We emphasize again the possibility that recreational value may be created by the project. This seems less likely, though, with highway projects than other types of projects. By inducing urbanization and altering land use patterns, highways often undermine natural recreational values of the areas through which they pass.

Discount Rate

The discount rate is possibly the most controversial aspect of economic benefit-cost analysis. Much argument surrounds the process for selecting a discount rate for benefit-cost analysis. Recent work in resource economics suggests that benefits and costs could be more accurately estimated by applying different discount rates to project benefits and recreational losses [13]. Such a suggestion stems from evidence showing that in general benefits have been overestimated and natural costs underestimated. The concept of variable discount rates is extended here to include the total induced cost (C_I) function.

Traditionally, project benefits and costs have been evaluated at a discount rate, r, in order to convert all streams of future benefit and cost to present value. The benefit cost ratio is depicted as:

$$\frac{\sum_{i=1}^{n} \frac{B_n}{(1 + r)^n}}{\sum_{i=1}^{n} \frac{C_{ins}}{(1 + r)^n}}$$

B_n = net benefits
r = interest rate or discount rate
n = life of project or service life
C_{ins} = installation costs

It should be noted that C_{ins} includes construction, engineering, administration, right-of-way, relocation, operation, maintenance, and replacement costs. In actual practice there is probably a terminal value to some components of the project, but we have omitted this for simplification. Induced costs (C_I) have already been subtracted out in the numerator. Breaking down the net benefit function, we have:

$$\sum_{i=1}^{n} \frac{B_n}{(1 + r)^n} = \sum_{i=1}^{n} \frac{B_t}{(1 + r)^n} + \sum_{i=1}^{n} \frac{B_i}{(1 + r)^n} - \sum_{i=1}^{n+x} \frac{C_i}{(1 + r)^n}$$

where:

x = restoration time for natural systems assuming reversible damage
C_i = year dollar flow of induced cost

assuming that demand for natural areas increases and that supply decreases. As fossil fuels become increasingly expensive, it is reasonable to expect increasing demand for the services of natural systems. At the same time, the supply of natural systems will decrease if present trends of growth and urbanization are sustained. With this dynamic in the supply and demand of natural systems, it can be assumed that natural economic value will increase by some calculable factor. In order to accurately reflect value increment over time, an adjustment to the discount rate must be made as:

$$r - a$$

where "a" represents the rate of increasing value. A reverse argument for decreasing benefits has been made [13], but in this discussion it is not pursued. Discounted costs of environmental degradation thus do not decline as rapidly as discounted benefits by the factor:

$$\frac{1}{(1 + r - a)^n}$$

environmental costs, then, are represented as:

$$\sum_{i=1}^{n+x} \frac{C_i}{(1 + r - a)^n} = C_I$$

Use of this formula gives natural values a heavier weight in the calculation of net benefits. It must be remembered that C_I is a composite of several natural values, all of which may increase (or even decrease) over time at varying rates. Therefore, in applying such a discounting technique, extreme caution must be observed in determining the rate of increase in natural value. Breaking the function down and assessing each component value is a desirable approach.

Energetic Benefit-Cost Analysis

The energetic approach is a fairly recent innovation [14]. Using ecology as its theoretical basis, this approach equates natural value with the work produced by ecosystems. Thus, the value of a given ecosystem is the quantity of energy which the ecosystem processes. Normally we would use all the energies contributed from natural sources: wind, water, gross primary production, etc. For simplicity here, we use the gross primary productivity of vegetation as the index of value. This energy encompasses the total biotic power flow, as all higher organisms ultimately depend on photosynthesis. Abiotic energies such as water elevation head and chemical potential energy can also be calculated, but in this discussion they are not included. Kemp and Odum present further discussion of total natural energies [15-17].

The energetic approach also can translate energetic value into economic value, and vice-versa. Through the use of energy quality factors and the national $/energy ratio, one can translate an ecological impact into dollars. Such a dollar quantity can then be used as an induced cost in a benefit-cost framework. Alternatively, one can use energy as the basis of calculation for both benefits and costs.

GROSS PRIMARY PRODUCTIVITY (GPP)

In the energetic approach, the difference in GPP between the project and the non-project alternative is first calculated. This calculation presupposes knowledge of the type and extent of change that will occur if the project is built. GPP quantities for various ecosystem types can be found in the literature. Several quantities, used below in the example, are presented in Table 2. Algebraically, this calculation is quite simple:

$$(A x GPP_A) - (A x GPP_B) = E_{Loss}$$

where:

GPP_A = non-project or primitive energy flow/year
GPP_B = energy flow after project impact/year
E_{Loss} = natural energy lost by project impact/year
A = area of impact

Table 2. Gross Primary Productivity

Ecosystem	*Productivity*
Marsh	89.65×10^3 kcal/m^2/yr
Grassy Scrub	5.38×10^3 kcal/m^2/yr
Lake	4.07×10^3 kcal/m^2/yr

Source: S. E. Bayley, *et al.*, "A Comparison of Energetics and Economic Benefit-Cost Analysis for the Upper St. Johns River." Final Report to the U.S. Corps of Engineers, Center for Wetlands, University of Florida, Gainesville, Florida, 1976.

QUALITY FACTORS

Quality factors are necessary to bring all energy types to a common basis. Certain types of energy are more highly concentrated than others. That is, a single kilocalorie (Kcal) of a highly concentrated energy is able to do more work than a Kcal of an energy that is not so highly concentrated. Various quality factors are presented in Table 3. The Kcal unit in GPP represents photosynthetic work done in producing plant sugars. As such, it is a dilute form of energy and is not equivalent to the concentrated energy of fossil fuel. Because fossil fuel is the basic power source of our industrial civilization, it is necessary to translate photosynthetic energy into units of fossil fuel energy. Only in this way can the work processes of natural systems be realistically compared to those of human systems.

Quality factors are multiplicative constants which transform the kilocalorie units of various types of energy into Fossil Fuel Work Equivalents (F.F.W.E.). They are applied in the following manner:

$$E_{Loss} \div Q_L = E_{F.F.W.E.}$$

where:

Q_l = quality factor for particular energy relative to fossil fuel

$E_{F.F.W.E.}$ = energy loss in fossil fuel work equivalents/year

$/ENERGY RATIO

The value derived above is in energy units. In order to directly compare this value to economic values, a conversion factor is necessary. One method to find a factor is by using the ratio of Gross National Product to national fossil fuel consumption plus national natural energy value (GNP/(F.F.+N.E.)). This ratio has been compiled historically in various energy studies and it is easily computed

Table 3. Energy Quality Factors

Energy type	*Coal equivalence factor (kcal coal per kcal)*	*Quality*
Sunlight	5×10^{-4}	2000
Sugar of Gross Primary Production	0.05	20
Coal	1 (by definition)	1
Electricity	3.7	0.27

Source: H. T. Odum and E. C. Odum, Energy Basis for Man and Nature , McGraw-Hill Book Company, New York, 1976 [4].

from statistical abstract data [18]. More precise calculations are possible by comparing dollar and energy cost for individual economic sectors or energy conversion processes [19]. Essentially, these ratios estimate the dollar value of a unit of energy. The dollar value of an impact can then be computed as:

$$E_{F.F.W.E.} \times \$/\text{energy} = T_{\$}$$

where:

$T_{\$}$ = total dollar loss of impact on environment/year

This total dollar loss in turn can be used in benefit-cost calculations as an induced cost. Note that

$T_{\$} = C_i$, a yearly loss of value.

We can write, then, as in the economic approach (assuming reversible damages):

$$C_I = \overset{n+x}{\underset{i=1}{}} C_i$$

This value in turn can be used in the net benefit formula:

$$B_n = B_t + B_i - C_I$$

It should be here mentioned that discount rates are not employed in the energetic approach. This fact reflects the underlying assumption that natural systems, when considered on the large scale, are not in a growth phase. Rather, they are either self-sustaining, or declining, usually due to man's activities; thus it is not possible to speak of interest in natural systems.[1]

[1] For example, 5 acres of a natural system 10 years from now does not equal 2 acres now, as it is impossible for the 2 acres to produce 5; rather, the 2 acres remain constant over time (unless of course, they are replaced by a human system, in which case the natural interest would be negative).

Sample Calculation of the Effect of a Highway on a Marsh System

An example is presented to elucidate the application of these two methodologies. The sample problem is a hypothetical highway constructed on an earth berm which crosses a marsh ecosystem, assuming a priori a hydrologic impact exists. Thus, our example only shows calculation of environmental costs on the basis of a presumed successional pattern. There are two parts to the example: first, the economic approach is demonstrated; next, the same costs are evaluated using the energetic approach. These methods are presented as alternative techniques, although some comparison of their relative merits is made.

The hypothetical ecosystem is a marsh over which water is transmitted in surface sheet flow. The highway fill thus impounds water upstream and drains water downstream. For the purpose of this example, it is assumed that no drainage structures are constructed to maintain the water flow pattern. Recent studies have indicated that properly designed and spaced culverts in fill roads can maintain sufficient flow to preserve ecosystem productivity. In Figure 1, the ecosystems with highway and range of impact is illustrated. The zone of impact is a marsh slough which flows into a lake. The proposed highway which traverses the marsh cuts off part of the water circulation from the uplands through the marsh to the lake. The result is twofold. Upstream from the highway water is impounded and forms an aquatic system, while downstream, water flow from upstream is blocked and the marsh is dried out, producing a terrestrial system. For the example highway, 2,000,000 square meters of marsh undergoes succession to unproductive grassy scrub and lake ecosystems (Table 3). It is assumed that the marsh in its primitive state is highly productive. Such a high energy circulation gives it the ability to rapidly assimilate the nutrient loads of sewage waste. In addition, because of its biological diversity, the hypothetical marsh attracts people. Fisherman (500/year assumed) use the small marsh creeks. Boaters (100/year assumed) enter the marsh for its natural scenery. Bird-watchers (50/year assumed) use the marsh to observe the bird populations. Finally, students use the marsh in yearly field trips (50,000/year assumed). Construction of the proposed highway is assumed to obliterate all recreational and educational use, as well as 2,000,000 m^2 of nutrient recycling potential.

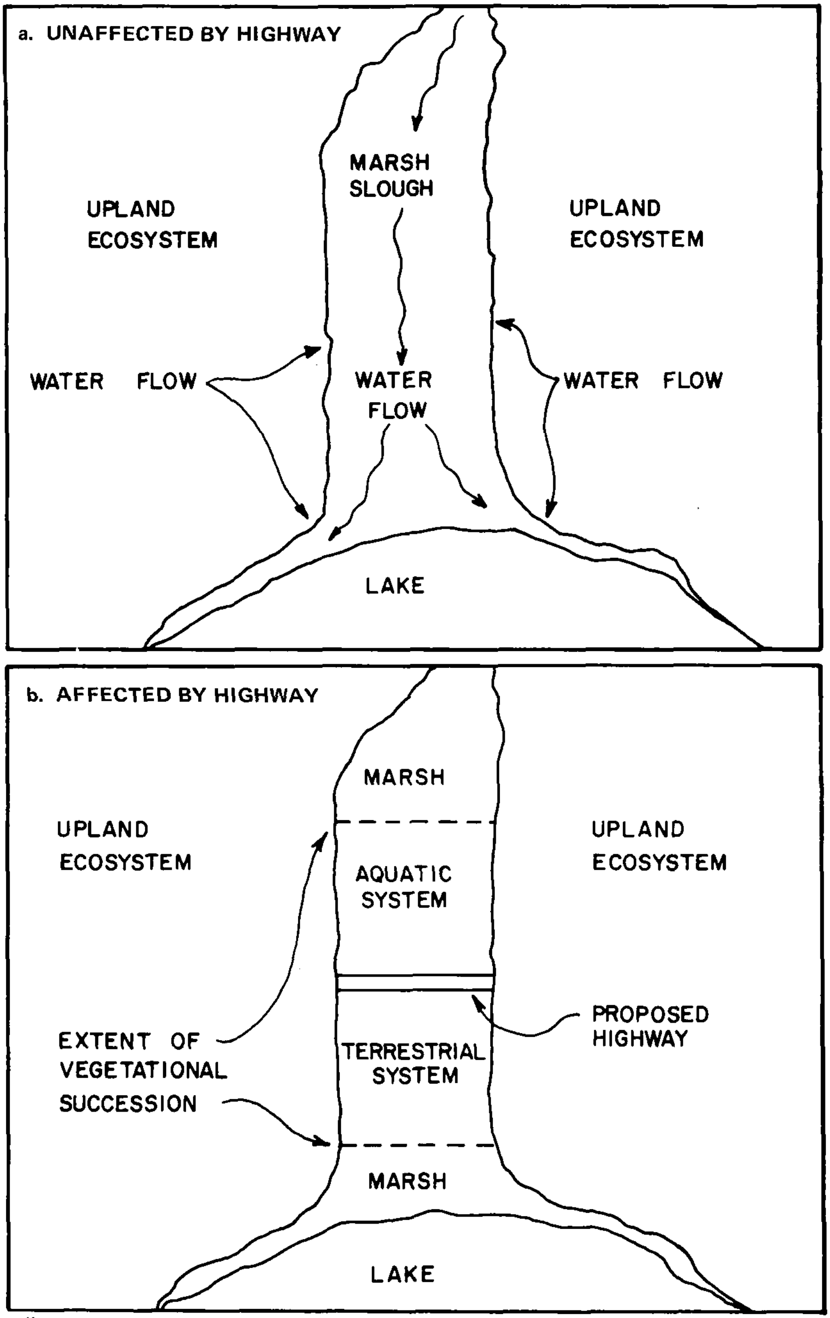

Figure 1. Hypothetical marsh systems.

Economic Approach

The economic approach accounts for the loss of value caused by destruction of the natural environment. Dollar values for natural system usages are calculated for project and non-project alternatives, and the difference observed is included in the net-benefit calculation as an induced cost. In addition, this induced cost of environmental degradation is discounted as a rate less than that used for the other components of the benefit-cost ratio. For the hypothetical ecosystem, economic values for various natural system functions are presented in Tables 1, 2 and 3.

In the example, we assume that the ecosystems created by the highway have no economic value to human consumers. When dealing with specific, real-life situations, this may not be the case and the new values would have to be subtracted from the induced cost. For this example, the induced cost can simply be calculated as the value of the unaffected, non-project environment. Using the values from Tables 1, 2 and 3 in addition to knowledge of the area involved, and the area of impact, one can calculate the environmental costs as follows:

1. Enumerate Values Lost

Sewage treatment value:	
$0.025\$/yr/m^2 \times 2{,}000{,}000\ m^2$	= 50,000$/yr
Educational value:	
5.00$/yr/student × 50,000 students[2]	= 250,000$/yr
Recreational value:[3]	
24$/fishing trip[4] × 500 fishing trips/yr	= 12,000$/yr
24$/boating trip[4] × 100 boating trips/yr	= 2,400$/yr
55$/bird-watching trip × 50 bird-watching trips/yr	= 2,750$/yr
TOTAL VALUE	317,150$/yr

thus, C_i = 317,150$/yr

2. Apply Adjusted Discount Rate

Now assuming a discount rate (r) of 6 per cent, an increasing value rate (a) of 2 per cent,[5] one may calculate the total

[2] This quantity is the number of students in primary and secondary school within busing range. College students are not included. Graduate research is also excluded from this value, which represents the value of a one-day field trip.

[3] Recreational use values must be taken from observation of concerned area. Here we assume 500 fishing trips/yr, 100 boating trips, and 50 bird-watching trips.

[4] 24$ is mean of range $14-$34 presented in Table 1.

[5] This value is purely assumed. In actuality, such a factor would have to be determined from demand and supply analysis of the particular area involved.

environmental damage, where project life n = 20 years, and restoration time x = 5 years.

Total environmental damage:

$$C_I = \sum_{i=1}^{(n+x)=25} \frac{C_i}{(1+0.04)^{(n+x)}} = (15.6221)(317150\$)$$

$$= 4{,}954{,}549\$$$

Note that had the discount rate been left unaltered by an increasing value factor, this calculation would be

$$C_I = \sum_{i=1}^{(n+x)=25} \frac{C_i}{(1+0.06)^{(n+x)}} = (12.7834)(317150\$)$$

$$= 4{,}054{,}255\$$$

and much natural value would have been left unaccounted for. In fact, use of the 2 per cent factor results in enhancing the natural value by 900,294\$. The cost, 4,954,549\$, is the value which then enters the calculation for net benefits:

$$B_n = B_t + B_i - 4{,}954{,}549\$$$

Energetic Approach

The energetic approach accounts for changes in energy flows which occur in the natural environment. Gross Primary Productivity (GPP) is used as an index of the energy flows in the ecosystem. First, the loss in productivity is calculated by comparing the unaffected environment to the project-affected environment. This productivity loss is computed as an algebraic difference. The productivity loss is then translated into a dollar figure via the successive applications of a quality factor and a conversion ratio. Once in dollar form, the productivity loss can be entered into the traditional benefit-cost framework. On the other hand, dollar values of costs and benefits can be converted into energy units, and the analysis can be performed entirely on an energy basis. Because it requires more computation, we shall disregard the later alternative in the example.

In the hypothetical highway impact, we assume that downstream a grassy scrub system is formed and that upstream a lake system is formed. GPP values for the ecosystems involved are presented in Figure 1. Knowing the extent of impact (2,000,000 m^2) and the

GPP values of the successional systems, one can compute the productivity loss:

1. Unaffected Marsh.

The energy value of the unaffected marsh on a yearly basis may be calculated as:

$$2{,}000{,}000 \text{ m}^2 \times 89.65 \times 10^3 \text{ Kcal/m}^2\text{/yr} = 1.79 \times 10^{11} \text{ Kcal/yr}$$

2. Marsh Affected by Highway.

The energy value of the affected areas is:

upstream:

$$1{,}000{,}000 \text{ m}^2 \times 4.07 \times 10^3 \text{ Kcal/m}^2\text{/yr} = 4.07 \times 10^9 \text{ Kcal/yr}$$

downstream:

$$1{,}000{,}000 \text{ m}^2 \times 5.38 \times 10^3 \text{ Kcal/m}^2\text{/yr} = 5.38 \times 10^9 \text{ Kcal/yr}$$

3. Difference between Unaffected Marsh and that Affected by the Highway.

The energetic cost of the project in terms of GPP is then calculated as the difference of these two power flows:

$$1.79 \times 10^{11} \text{ Kcal/yr} - 4.07 \times 10^9 \text{ Kcal/yr} - 5.38 \times 10^9 \text{ Kcal/yr} = 1.69 \times 10^{11} \text{ Kcal/yr}$$

4. Application of Quality Factor.

Applying a quality factor of 20, the fossil fuel work equivalent of the energy loss can now be calculated:

$$1.69 \times 10^{11} \text{ Kcal/yr} \div 20 = 8.45 \times 10^9 \text{ F.F.W.E./yr}$$

5. Conversion of Loss to Dollar Value.

The dollar value of this cost may in turn be calculated by using the \$/energy ratio which in 1974 was valued at 0.000053 \$/F.F.W.E.:

$$8.45 \times 10^9 \text{ F.F.W.E.} \times 0.000053 \text{ \$/F.F.W.E.} = 447{,}850 \text{ \$/yr}$$

This final value of 447,850\$/yr is the $T_\$$ value which is a dollar per year flow of induced cost or C_i. To calculate total environmental damage done, it is only necessary to sum the value C_i over the life of the project plus restoration time. A discount rate is not applied.

Total Environmental Damage (where n = 20 and x = 5):

$$C_I = \sum_{i=1}^{n+x} C_i = \sum_{i=1}^{25} 447{,}850 = 11{,}196{,}250\$$$

The cost, 11,196,150$, is the value which can be used in the benefit-cost framework. It would be used analogously to the value calculated by the economic approach:

11,196,150$ versus 4,954,549$

Conclusion

These two methodologies demonstrate that it is possible to integrate natural system value into an economic benefit-cost framework. Thus, for transportation planning, there is no longer a reason to disregard this type of externality in benefit-cost analysis. Natural system value can get fair representation in the design of transportation projects. By the same token, there is no longer a need to exaggerate externalities by implementing unnecessary expensive environmental technology for projects which have no significant effect on the natural environment. These methods improve the ability to optimally allocate natural resources and scarce economic goods.

One may question methodologies which exhibit such a discrepancy in the final total environmental costs. Our reply is twofold. First, the hypothetical nature of the example may distort the results. For instance, there is no way of estimating a feasible demand for recreational and educational services for such an example. Second, the techniques for calculating natural value have only been recently developed and the experimental results and calculated values have only been made for a few ecosystems. The emphasis of this paper is not on the precision of the values calculated, however, but on the fact that natural systems have economic value, and that this value can be quantified. It is essential that this natural value be quantitatively appreciated in future analysis so that natural resources are no longer needlessly squandered.

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