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# How Much Are Nature's Services Worth?

## Measuring the social benefits of ecosystem functioning is both controversial and illuminating.


Walter E. Westman


*To me the meanest flower that blows can give*
*Thoughts that do often lie too deep for tears.*—WILLIAM WORDSWORTH (*1*)

How much was this mean flower worth to a poet like Wordsworth? What is the value to societies, present and future, of the inspirations that flowed to others from Wordsworth's poetry, and indirectly from nature? These questions seem safely relegated to the realm of the unanswerable because they deal with qualities upon which our society has not placed a quantitative value. And yet, in the inexorable quest to rationalize the activities of the civilization, policy-makers in Western societies have increasingly asked the monetary value of items and qualities formerly regarded as priceless: clean air and water, untamed wildlife, wilderness itself. Behind this search has been the hope that, by weighing the benefits to society of nature in the undeveloped state against the benefits of resource development, an objective basis for decision-making will be achieved. Commonly, policy analysts further seek to estimate the equivalence in currency of the values lost by damaging ecosystems. The assumption is often made that decision-makers will reach socially equitable decisions when they choose the alternative whose costs in terms of damage to the ecosystem are exceeded most by the benefits to be obtained from resource use (*2*).

In this article, I attempt to illustrate both the importance of accounting for the benefits of nature's "services" in such decisions and the difficulties in doing so. It is important at the outset to recognize some of the corollaries inherent in assuming that decisions that maximize benefit : cost ratios simultaneously optimize social equity and utility (*3*). (i) The human species has the exclusive right to use and manipulate nature for its own purposes (*4*). (ii) Monetary units are socially acceptable as means to equate the value of natural resources destroyed and those developed. (iii) The value of services lost during the interval before the replacement or substitution of the usurped resource has occurred is included in the cost of the damaged resource. (iv) The amount of compensation in monetary units accurately reflects the full value of the loss to each loser in the transaction. (v) The value of the item to future generations has been judged and included in an accurate way in the total value. (vi) The benefits of development accrue to the same sectors of society, and in the same proportions, as the sectors on whom the costs are levied, or acceptable compensation has been transferred. Each of these assumptions, and others not listed, can and have been challenged (*5–7*).


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Decisions concerning the use of resources are made daily, however. The task of elucidating the implications of such decisions is urgent even if difficult. It is appropriate to separate the task of measuring and predicting the extent of physical damage accruing from the use of resources from the task of evaluating the worth of losses and equivalent gains. The first is a relatively objective task, the second clearly normative. Recently Conn and I reviewed for the California Energy Commission the nature of physical damage resulting from air and water pollution arising from energy production and use, and techniques for evaluating such damage (*7*). We examined the physical damage to human health and welfare, to crops and materials, and to natural ecosystems, resulting from increasing pollution. We examined also methods of evaluating the benefits of minimizing these damages, using both economic and other measures.

One realm of benefits that has received little attention in economic cost-benefit studies to date is that due to ecosystem function (*8–10*). In the remainder of this article, I will expand on what is meant by ecosystem functioning, what tasks ecosystems perform for society, and how these might be quantified and evaluated, drawing substantially from the report by Westman and Conn (*7*). I will not provide a full list of benefits from the healthy functioning of ecosystems; indeed these are not fully known, nor will my quantification of a few of these be complete. I wish to emphasize, however, the quantitative significance of this realm of social benefit to environmental decision-making. In so doing, I do not seek to encourage the practice of cost-benefit analysis in decision-making. Rather, by exemplifying ways of expressing some of nature's services in dollar terms, I wish to illustrate ways in which the analysis of costs and benefits applied to natural ecosystem manipulation has been incomplete and why it is likely to remain so for some time to come (*11*).

## Goods Versus Services in Nature

Ecologists traditionally speak of natural ecosystems in terms of their structure and functions. The structure of an ecosystem includes the species contained therein, their mass, and their arrangement. This is the ecosystem's standing stock—nature's free "goods." From the structural aspects of ecosystems, society reaps two kinds of benefits: (i) the direct harvest of marketable products (for example, fish, forest products, minerals) and the procurement of the genetic resources of valuable species (for example, crop and timber plants, animals for domestication), and (ii) the use and appreciation of ecosystems for recreation, esthetic enjoyment, and study.

The functions of an ecosystem, on the other hand, are characterized by the ways in which the components of the system interact. They are the dynamics of ecosystems—nature's free "services." These functions impart to society a variety of benefits. They include the absorption and breakdown of pollutants, the cycling of nutrients, the binding of soil, the degradation of organic waste, the maintenance of a balance of gases in the air, the regulation of radiation balance and climate, and the fixation of solar energy—the functions, in short, that maintain clean air, pure water, a green earth, and a balance of creatures; the functions that enable humans to obtain the food, fiber, energy, and other material needs for survival.

As when the structure of an ecosystem is damaged, costs to society appear when the functions of an ecosystem are impaired. Examples include the filling up of dams and basins with sediment when the soil-binding function is disturbed, the smothering of eggs in estuaries and the resulting fishery losses from such erosion, the changes in local or regional climate that affect human and crop performances, and the putrefaction of lakes and pollution of swimming holes from excessive accumulation of organic wastes from land clearance.

Evidence of the potential magnitude of these costs is beginning to accumulate. Gosselink *et al.* [table 1 in (*10*)] calculated the cost of duplicating the role of wetlands in providing tertiary waste-water treatment facilities and fisheries by other means; their estimate of $205,000 per hectare does not take into account the value of the site for gas flux [sulfate reduction, carbon dioxide fixation, oxygen release (*12*)], as a site for waterfowl support and so forth. Wharton (*9*) obtained a minimum annual value of $1.8 million for the services of a 930-ha Georgian river-swamp-forest ecosystem in groundwater storage, soil binding, water purification, and streamside fertilization.

Although the cost of repairing services lost bears no necessary relationship to the cost of damage, estimates of repair costs are relevant to decision-making insofar as they can be used to reduce the residual costs of damage. Some indirect evidence of the nationwide magnitude of the repair costs of polluting wetlands and water bodies comes from the recent report of the National Commission on Water Quality (NCWQ) (*13*). The NCWQ was asked to estimate the cost of meeting the 1983 objective for cleanup of the nation's entire surface waters as specified in the 1972 Federal Water Pollution Control Act. The act's objectives were designed to help restore and maintain the physical, chemical, and biological integrity of the natural aquatic ecosystems. The NCWQ estimated that to treat point sources and storm water by current technology to meet water quality objectives, total federal capital expenditures amounting to as much as $594 billion would be required by 1983. This figure is much higher than the current annual federal expenditure on waste-water facilities, which is $4 billion to $6 billion. The $594-billion figure represents not only the cost of maintaining existing water quality, but the cost of upgrading treatment to restore natural structure and functioning to aquatic ecosystems. As such, the figure gives an indication of the partial costs of restoring natural services (assimilative capacity of water bodies) that would otherwise have been able to absorb at least part of the waste load.

Attempts to estimate the benefits of reducing damage to ecosystem functioning by estimating the costs of repairing or replacing damaged functions have limited applicability. One could argue that such an approach could be implemented by estimating the costs of rehabilitating cleared vegetation, the costs of air-conditioning buildings in an urban heat island, the costs of dredging sediment from basins, and the costs of treating aquatic wastes. In practice, however, we rarely repair all the damage (for example, who pays to restore earthworm populations decimated by erosion?), and in many instances, we do not have the technology to replace the function (for example, what inventor can lay claim to a machine that regulates the global climate?).

## Valuation of Nature's Services: Examples

Although ecosystem functions can yet be neither fully quantified nor fully evaluated, the estimation of monetary costs associated with the loss of nature's free services illustrates the minimum magnitude of the value lost. The ability of soils and vegetation to absorb air pollutants is a useful example of a service of an ecosystem, the loss of which can be at least partially evaluated. In our report (*7*), Conn and I summarized studies on absorption of air pollution by soil and vegetation (*14*). Numerous limitations on the use of these data exist. For example, most studies of absorption of pollution have taken place in environmental chambers at a limited range of pollutant concentrations. Nevertheless, such data can begin to provide information on loss of a valuable function of an ecosystem. From data of Inman *et al*. (*15*), it is possible to estimate a net loss of pollution absorption of 440 kilograms of carbon monoxide per hectare per year for every hectare of San Bernardino Freeway built through pasturelands (*16*). The costs of this loss can be calculated either in terms of the resulting pollution damage or in terms of the costs of equipment to remove the carbon monoxide now being removed by the vegetation. It is well to remember that these calculations represent only partial costs of the loss of the pasture, since the plants will at the same time absorb other pollutants, bind the soil, maintain a certain radiation balance, and fulfill other functions.

A second example is the role of ecosystems in radiation balance and, ultimately, as a component in the regulation of global climate. A number of recent studies have been concerned with the economic costs of climatic change (*17*). Few have drawn the connection between climatic change and the specific contribution of the destruction of a particular hectare of forest (with associated changes in carbon dioxide fixation, water vapor release, and radiative flux) to the effects on climate (*18*). Refinement of our knowledge about the role of gas and energy exchange from the biosphere on global climate may permit some quantification of the effects of those actions. Yet one is plagued here, as when assessing other isolated development projects, with the fact that there may be a nonlinear relationship between the destruction of a certain amount of habitat and the resulting perturbation of the climate. As with other instances of environmental disturbance (*19*), it is essential to know not simply the effect of removal of a single unit but also how the damage varies with the degree or extent of impact.

A third example of a free service of nature is the role of vegetation in soil binding. Plant roots play a vital role in preventing soil erosion in most ecosystems. Air pollution, by destroying vegetation, can indirectly cause major damage from soil erosion. The costs of such detrimental effects are those resulting from erosion and sedimentation, which cause continuing damage to organisms and to physical structures such as dams. A "replacement cost" approach to evaluating these costs would include the costs of fertilizers, soil conditioners, and labor to replace the lost soil. An "impact control" approach would estimate either (i) the cost of dredging sediments from structures and water bodies in which they accumulate and treating water to decrease turbidity, or (ii) the cost of constructing catchments directly below major erosion sites. Wharton (*9*) estimated the cost of sediment control by calculating the annual cost of constructing sediment basins to capture particles formerly deposited in a natural swamp before channelization. His estimate for the Alcovy River Swamp in Georgia was $3200 per year (1970 dollars).

As an example of the potential cost of sediment removal, we can estimate the case of erosion from air pollution damage in the San Bernardino Mountains, 100 kilometers from Los Angeles. As of 1969, 1.3 million pine trees (*Pinus ponderosa* and *Pinus jeffreyi*) in an 18,700-ha area of the San Bernardino National Forest were moderately or severely affected by exposure to oxidants, a chief component of photochemical smog (*20*). During a 3-year period in the late 1960's and early 1970's, ozone-related mortality of ponderosa pines in this region averaged 8 to 24 percent (*21*). As of 1972, the U.S. Forest Service estimated that 57 percent of the trees on a 4000-ha area were in the declining phase (*22*). If we assume that (i) 50 percent of the area on 4000 ha currently covered by trees will soon be replaced by a mixture of successional grasses and forbs, and that (ii) erosion losses will be comparable to those experienced when the nearby native chaparral has been replaced by planted grasses (*23*), oxidant damage could result in a cost of $27 million per year (1973 dollars) for sediment removal, as long as the early successional stages lasted and assuming sediment runoff to be equally partitioned among streets, sewers, and debris basins (*24*).

Plant roots, in addition to retaining larger particles, help to store nutrients in the biomass and reduce losses from leaching. In the first 2 years after the clear-cutting of a hardwood forest in the White Mountains of New Hampshire, the deciduous forest ecosystem experienced a net loss of 57 kg of nitrate-nitrogen per hectare and 62 kg of calcium ion per hectare, among other nutrients (*25*). A replacement-cost approach might evaluate this loss as the cost of an equivalent amount of calcium nitrate fertilizer ($14.80 per hectare, 1976 dollars) plus spreading costs and the external costs associated with the repair process. Such an approach, however, is plagued with ecological uncertainty about the repair process. One would need to know the extent to which the ecosystem will assimilate the nutrients applied as fertilizer, whether partitioning of nutrients among components will occur in the same way that they were lost, whether the imbalance of nutrients returned is harmful, and whether losses over time can be effectively replaced by an instantaneous gain through a single dose of fertilizer (*26*). Further, such an approach accounts for only the loss of soil fertility and does not measure the damage induced downstream from increased calcium (hardness) and nitrate levels. Damage to aquatic organisms from increased alkalinity or eutrophication, to materials from scale accumulation, and to human health would be among the social costs of this loss in plant nutrient uptake. Clearly such cost estimates are dependent on the site and difficult to generalize.

As a final example, consider another aspect of the role of ecosystems in nutrient cycling, the fixation of nitrogen by microorganisms. Nitrogen-fixing organisms perform the critical conversion of gaseous elemental nitrogen in the atmosphere to nitrogen fixed in organic form in organisms. The reported rates of nitrogen fixation in nature range from 34 kg $ha^{-1}$ $year^{-1}$ in arid Australian soils (mostly from blue-green phycobionts in surface soil lichens) to 720 kg $ha^{-1}$ $year^{-1}$ from free-living soil microorganisms under regenerated African bush (*27*). Values in economic crops range from 15 to 90 kg $ha^{-1}$ $year^{-1}$ in Indian rice paddies (blue-green algae) to 104 to 177 kg $ha^{-1}$ $year^{-1}$ in pasture legumes (symbiotic bacteria). In 1941, Lind and Wilson (*28*) reported that carbon monoxide greatly retards nitrogen fixation by *Rhizobium trifolii* in the roots of red clover at amounts less than 100 parts per million (ppm) in the atmosphere, and inhibits it completely at a concentration of 1000 ppm. At current costs of nitrogen fertilizer (as urea), a pastoralist would have to pay $5.50 per hectare per year (1976 dollars) to replace the lost nitrogen from symbiotic bacteria if atmospheric exposure to carbon monoxide were 50 ppm. In the Los Angeles Basin, including its agricultural regions, the monthly average for the instantaneous maximum concentrations of carbon monoxide ranged from 19 to 56 ppm, with an annual average of monthly 1-hour maximums of 26 ppm during 1975 (*29*).

The Environmental Protection Agency (EPA) recently reported (*30*) that ozone was capable of inhibiting symbiotic nitrogen-fixing bacteria by 40 percent at concentrations of less than 0.08 ppm. In the agricultural region of San Bernardino, at the base of the area earlier discussed in relation to pine needle injury, the ground-level ozone concentration exceeded 0.10 ppm for 1 hour or more on 165 days in 1975 (*31*); for the Los Angeles Basin as a whole, this concentration of ozone was exceeded on 201 days (*29*). The EPA also reported that sulfur dioxide significantly reduced nitrogen fixation when the median concentration exceeded 0.06 ppm (*30*). In the Los Angeles Basin in 1975, the annual average of monthly 1-hour sulfur dioxide maximums was 0.17 ppm (*29*). These concentrations are clearly sufficient to inhibit natural nitrogen fixation in the Los Angeles Basin.

The implications of these findings for ecosystem health (and subsequent values to man) from ecosystem functioning are vast. Virtually all ecosystems are dependent on nitrogen-fixing organisms for this essential element. Global air pollution may be inexorably reducing the primary productivity of the biosphere by reducing the pool of available nitrogen. Subsequent effects on the growth of both terrestrial and aquatic plants and of the animals dependent on them is potentially serious.

At the same time, it is clear that a valuation of the loss of social benefits as a result of inhibiting nitrogen-fixing organisms is severely underestimated by the cost of replacing nitrogen by fertilizer. If lost nitrogen in wildlands is not replaced, as at present it is not, the indirect but interconnected benefits of ecosystem functioning—the gas flux, climatic regulation, wildlife support, and other services provided by a healthy ecosystem—are diminished. The value of those lost services is undoubtedly much larger than the replacement cost for the lost fertilizer. It is in part because of the interconnected nature of the complex systems of nature that valuation of individual services lost is so inevitably misleading.

## Summary and Conclusions

Ecosystem functioning—the flow of materials and energy in biotic communities and the effects of these dynamics on soil and atmosphere—is vital to human welfare. To date, those concerned with quantifying and evaluating benefits of natural ecosystems to man have largely focused on the standing stocks of nature rather than the flows. The quantification of ecosystem functions, here illustrated by absorption of air pollutants, radiation balance, soil binding, and nutrient cycling, is likely to produce evidence on the extent of socially significant damage from pollution. At present, our understanding of ecosystem functioning is limited, but much can be done even now to develop quantitative relationships between pollution levels and damage to ecosystem functions.

Evaluating the contribution of ecosystem functioning to human welfare is a complex task. It is a task of weighing human social values and is the quintessential task of politics. In order for citizens to communicate to their representatives their true desires about the maintenance of the natural environment and the pace of development, it is essential for the public to have a clear idea of the benefits they obtain from nature in its undeveloped state. An enumeration of the relationship between the effects of development and physical damage to ecosystems is a helpful first step. A full range of evaluation techniques, including but not limited to the use of economic measures, then awaits the planner in weighing the social value of benefits and costs (*32*).

At the present state in the development of our evaluation methods, it would seem appropriate to seek both expert judgment in the assessment of physical damage and public participation in the assessment of social values. Cost-benefit analysis applied to the development of natural resources will consistently skew estimates of nature's value because of the limited state of our knowledge of ecosystem function and the difficulties in expressing these values in monetary units. Cost-benefit analysis can also be argued to be altogether inappropriate to an assessment of natural values, since there is far from social agreement that monetary units can express the equivalent gains from the loss of nature's services. Although the literature on environmental cost-benefit analysis is becoming increasingly sophisticated, in the eyes of many in our society it has not yet improved upon the poet's summation of nature's worth. This judgment seems to be made both because of the weakness of the assumptions inherent in cost-benefit analysis and because of the inadequacy of our quantitative knowledge of relevant ecological and social factors. It can be expected that as public education on the value of nature's services increases, the estimate of nature's worth on the part of some will increase. Attempts to quantify nature's services have heuristic value in providing perspective on the distance from both present estimates and a full accounting. Yet it is both sobering and important to recognize that, even in the long run, quantitative estimates of the worth of nature to man are likely to remain asymptotic to the value expressed by the poet's phrase.

### References and Notes


1. From "Ode: Intimations of Immortality from Recollections of Early Childhood," in *William Wordsworth. Selected Poetry*, M. van Doren, Ed. (Modern Library, New York, 1950), p. 547.
2. In practice, economists commonly use the so-called Potential Pareto criterion to determine whether a gain in social welfare will occur. By this criterion social welfare is increased when a social change provides sufficient benefits to the gainer that he or she can potentially afford to compensate the loser fully and still experience a net gain in benefits. In the case of developing natural ecosystems, however, the losers include species other than man, which are almost never compensated. The human losers are frequently the public at large, who are often not consulted about whether dollar compensation is acceptable and the adequacy of the amount of compensation; frequently they are not compensated directly at all. For further discussion, see, for example, A. K. Dasgupta and D. W. Pearce [*Cost-Benefit Analysis: Theory and Practice* (Harper & Row, New York, 1972), pp. 54–69].
3. Decision-makers do not always assume that social equity will result from maximizing cost-benefit ratios, but often merely that efficient use of resources will result. I address the issue because social equity is frequently expected of government decisions by the public.
4. For discussion, see, for example, L. White, Jr. [*Science* **155**, 1203 (1967)] and C. D. Stone [*Should Trees Have Standing? Toward Legal Rights for Natural Objects* (Kaufmann, Los Altos, Calif., 1974)].
5. Certain assumptions cannot even in theory be perfectly fulfilled. For example, it is not possible to have perfect knowledge about values assigned to resources by all future generations. Neverthless, criticisms apply to these assumptions even when interpreted more flexibly. For a discussion of the social equity of environmental controls, see M. H. Krieger [in *Environmental Impact Assessment: Guidelines and Commentary*, T. G. Dickert with K. R. Domeny, Eds. (University of California Extension, Berkeley, 1974), p. 55]. For a discussion of shortcomings in the use of dollars for evaluation, see S. O. Anderson [in *ibid.*, p. 89] and D. W. Ehrenfeld (*6*). For a discussion of the strengths and weaknesses of cost-benefit analysis, see J. Adams [*Geogr. J.* **137**, 468 (1971)], D. M. McAllister [*Some Basics of Cost-Benefit Analysis: Theoretical Terra Firma and Terra Not-So-Firma* (School of Architecture and Urban Planning, University of California, Los Angeles, 1974)], and W. E. Westman and W. D. Conn (*7*, pp. 284–362).
6. D. W. Ehrenfeld, *Am. Sci.* **64**, 648 (1976).
7. W. E. Westman and W. D. Conn, *Quantifying Benefits of Pollution Control: Benefits of Controlling Air and Water Pollution from Energy Production and Use* (California State Energy Commission, Sacramento, 1977).
8. However, a number of attempts have been made to evaluate ecosystem functions. Early works include those of C. H. Wharton (*9*); A. E. Lugo, S. C. Snedaker, S. Bayley, and H. T. Odum [*Models for Planning and Research for the South Florida Environmental Study* (Center for Aquatic Sciences, University of Florida, Gainesville, 1971)]; E. P. Odum and H. T. Odum [*Trans. North Am. Wildl. Nat. Res. Conf.* **37**, 178 (1972)]; and J. G. Gosselink, E. P. Odum, and R. M. Pope (*10*).
9. C. H. Wharton, *The Southern River Swamp—A Multiple-Use Environment* (School of Business Administration, Georgia State University, Athens, 1970).
10. J. G. Gosselink, E. P. Odum, R. M. Pope, *The Value of the Tidal Marsh* (Center for Wetlands Research, Louisiana State University, Baton Rouge, 1973).
11. A number of important alternative approaches to the economic evaluation of natural resources have been reviewed (*7*, pp. 284–362). D. W. Ehrenfeld (*6*) elaborates on the inadequacy of cost-benefit analysis applied to natural ecosystems, and details a number of noneconomic arguments for nature conservation. For alternative economic approaches, T. R. Gupta and J. H. Foster [*Am. J. Econ.* **57**, 40 (1975)], M. Clawson [*Methods of Measuring the Demand for and Value of Outdoor Recreation* (Resources for the Future, Washington, D.C., 1959)], and D. R. Helliwell [*Reg. Stud.* **3**, 41 (1969)].
12. For a discussion of the value of wetlands in gas exchange, see E. S. Deevey [*Bull. Ecol. Soc. Am.* **51** (No. 1), 5 (1970)] and R. R. Grant, Jr., and R. Patrick [in *Two Studies of Tinicum Marsh* (Conservation Foundation, Washington, D.C., 1970), p. 102].
13. "Staff report to the National Commission on

Water Quality" (Government Printing Office, Washington, D.C., 1976).
14. Other recent reviews of the literature on uptake of gaseous pollutants by plants and soils are those of K. H. Rasmussen, M. Taheri, and R. L. Kabel [*Water Air Soil Pollut.* **4**, 33 (1975)] and K. A. Smith, J. M. Bremner, and M. A. Tabatabai [*Soil Sci.* **116**, 313 (1973)].
15. R. E. Inman, R. B. Ingersoll, E. A. Levy, *Science* **172**, 1229 (1971).
16. This figure is the difference between the carbon monoxide absorbed by the pasture (1046 kg $ha^{-1}$ $year^{-1}$) and by the freeway surface (604 kg $ha^{-1}$ $year^{-1}$).
17. R. C. D'Arge, in *Third Conference on Climatic Impact Assessment Program* (Department of Transportation, Washington, D.C., 1974), pp. 568–570; L. M. Thompson, *Science* **188**, 435 (1975); *Impact of Climatic Fluctuation on Major North American Food Crops* (Institute of Ecology, Washington, D.C., 1976).
18. General discussions of the interrelations between biotic gas and energy fluxes and global climate, however, may be found in such works as G. M. Woodwell and E. V. Pecan, Eds., *Carbon and the Biosphere* (National Technical Information Service, Springfield, Va., 1973) and *Inadvertent Climate Modification, Report of the Study of Man's Impact on Climate* (MIT Press, Cambridge, Mass., 1971).
19. Another common example of this class of problems is the relationship between decreases in wetland area and associated declines in aquatic productivity [W. E. Odum and S. S. Skjei, *Coastal Zone Manage. J.* **1**, 151 (1974)].
20. S. L. Wert, P. R. Miller, R. N. Larsh, *J. For.* **68**, 536 (1970).
21. The 8 percent figure was reported for one part of the region by P. R. Miller [*Adv. Chem. Ser.* **122**, 101 (1973)]; the 24 percent was reported for another part of the region by F. W. Cobb, Jr., and R. W. Stark [*J. For.* **68**, 147 (1970)].
22. "Smog and pine trees in Southern California fact sheet" (U.S. Forest Service, Washington D.C., 1972).
23. Experimental conversion of chaparral to grassland was carried out at the San Dimas Experiment Station in the San Gabriel Mountains, 60 km from the San Bernardino Mountains, on similar soils and slopes but at a lower elevation. Soil erosion recorded 5 and 9 years later averaged 200 $m^3$ $ha^{-1}$ [R. M. Rice, E. S. Corbett, R. G. Bailey, *Water Resour. Res.* **5**, 647 (1969); R. M. Rice and G. T. Foggin, *ibid.* **7**, 1485 (1971)]. This erosion figure was used in the calculation of erosion for the San Bernardino forest.
24. Cost of sediment removal from various structures in California is based on the figures of K. H. Ateshian [in *Proceedings of the 3rd Federal Inter-Agency Sedimentation Conference* (Water Resources Council, Denver, 1976), p. 13].
25. R. S. Pierce, C. W. Martin, C. C. Reeves, G. E. Likens, F. H. Bormann, in *National Symposium on Watersheds in Transition* (American Water Resources Association, Minneapolis, 1972), p. 285.
26. An instance in which instantaneous high-dose fertilizer application is not an adequate means to restore fertility to a disturbed site is the rehabilitation of Australian heath vegetation, which is intolerant of high nutrient levels, especially of phosphorus [R. L. Specht, *Search* **6**, 459 (1975)].
27. W. D. P. Stewart, *Nitrogen Fixation in Plants* (Athlone, London, 1966).
28. C. J. Lind and P. W. Wilson, *J. Am. Chem. Soc.* **63**, 3511 (1941).
29. "Air quality and meteorology 1975 annual report" (Southern California Air Pollution Control District, Los Angeles, 1976).
30. Environmental Protection Agency, *Progress in the Prevention and Control of Air Pollution in 1975. Annual Report of the Administrator of the Environmental Protection Agency to the Congress of the United States* (Government Printing Office, Washington, D.C., 1976), p. 46.
31. Southern California Air Pollution Control District, *Metro Zone Publ. 70D088* (1976).
32. A range of evaluation techniques are discussed by Westman and Conn (*7*, pp. 279–412).
33. W. D. Conn and D. M. McAllister contributed important comments throughout the development of this work. I thank research assistants P. Collum, N. J. Leishman, M. Nienberg, D. Pickrell, T. Thomas, and I. Tindimwebwa for collaborating on developing the background to this work (*7*). Supported in part by the Energy Resources Conservation and Development Commission, State of California.

**NEWS AND COMMENT**

# Seafarer: Project Still Homeless as Milliken Says No to Navy

For the better part of a decade the Department of Defense (DOD) has been trying to meet the Navy's need to be able to communicate with its nuclear submarines while they are cruising fast and deep, and to do so without forcing the submarines to drag a possibly tell-tale antenna on or near the surface. This need could be satisfied by taking advantage of the unique properties of extremely low frequency (ELF) radio, whose extraordinarily long wavelength can penetrate seawater to a depth of several hundred feet before the signal becomes too attenuated for effective reception. But the Pentagon's dogged efforts to have an operational ELF system continues to be frustrated by severe political problems which are in no small part self-inflicted.

On 12 August Governor William G. Milliken of Michigan wrote President Carter to reemphasize that Seafarer, the current name for the ELF system the Pentagon wants to build, is still unwelcome in his state even though defense officials have been talking vaguely (and inconsistently) about drastically cutting the size of the antenna grid and, hence, reducing the amount of land affected. And he again called on the President and Pentagon to live up to past promises that Seafarer would not be imposed on Michigan over strong public opposition. Many citizens have objected to the project's large scale and have feared that ELF radiation might harm people and wildlife.

As first proposed, Seafarer was to involve building five transmitters and imposing a grid of antennas on an area of up to several thousand square miles, with the antenna cables buried to a depth of 4 to 6 feet and positioned 5 miles apart. Up to 2000 miles or more of cable were to be laid altogether. An individual antenna line might be anywhere from 30 to 90 miles in length and would carry about 100 amperes of current (an electric toaster requires about 10 amps). The current would pass from one ground terminal through the crust of the earth to a depth of a few miles then back to the opposite terminal. The entire circuit thus formed serves effectively as the antenna for transmitting the ELF signal into the atmosphere where it is trapped in the ionosphere and travels around the earth.

Milliken's rejection of Pentagon efforts to find a home for an ELF system is only the most recent in a long series of rebuffs. Sanguine, the first and by far the most ambitious ELF system to be proposed, ran into so much opposition in Wisconsin that in early 1973 Melvin R. Laird, the Wisconsin congressman whom President Nixon appointed as his first Secretary of Defense, directed that his state no longer be considered as a site for the project. Later, a plan to build Sanguine in Texas was greeted by hill country ranchers in about the same way they would receive a truck load of cattle infected with hoof and mouth disease. As for Seafarer, which the Navy began promoting in 1975, it has run into trouble in New Mexico and Nevada (where sites have also been evaluated) as well as in Michigan.

Thus far, Seafarer has continued to find support in Congress, at least to the extent that R & D money is still being provided. But this year the project ran into serious problems there too. The House would have cut off all support for Seafarer (though some money would have been allowed for a small ELF experimental facility at Clam Lake, Wisconsin), and it was only at the Senate's insistence that another $20 million in R & D funds was approved.

If Seafarer can be rescued from its present distress, it will take a determined effort on the part of the President. He must persuade Governor Milliken and key members of the House armed services and appropriations committees that the Pentagon has now come up with an environmentally and politically acceptable plan for the project—and one that it will stick with.

Despite the sharpness of Governor Milliken's rejection of Seafarer as it has been presented up until now, his letter to the President seemed to leave open the possibility that a small ELF project might not be unacceptable if ironclad as-