Environment

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The role of science and technology in shaping and solving environmental problems is changing radically in response to shifts in the goals of the environmental movement and in modes of scientific analysis. The emerging perspective on problems of resource management and preservation contrasts with the prevailing approach of the past decade and has much in common, albeit at a more refined level, with the concerns of investigators of the human environment in the 1880's. The new perspective applies sophisticated techniques to questions of the health of people and ecosystems in a fashion that lays less emphasis upon regulation alone and more upon a wide range of remedies, and that examines positive as well as negative effects of anthropogenic alteration. In so doing, it stresses the maintenance of basic life support systems, methods of risk assessment, and the interrelation of environmental factors on local, regional, and global levels.

Summary. In contrast to the approaches to resource management and preservation of the past decade, a new perspective on environmental problems is emerging. Six major trends in scientific thinking are (i) increased efforts to examine environments in holistic frameworks, (ii) greater attention to life support systems, (iii) enlarged canvass of the range of choices in resource management, (iv) refinement in methods of risk assessment, (v) streamlined methods for monitoring environmental change, and (vi) more emphasis on the global framework.

Background

The environmental students of the 1870's and 1880's shared a deep concern for appraising the full impacts of human occupation upon areas as a whole. In Powell's landmark *Report on the Lands of the Arid Region of the United States*, completed in 1878, the potentialities and severe natural limitations inherent in the Great Plains and the Great Basin were examined in a regional context and applied to a proposed new policy for public land management (*1*). Building on the results of field investigations and the pioneering interdisciplinary scientific surveys of possible transcontinental railroad routes (*2*), Powell went beyond the description of economic opportunities to point out those interrelated conditions of climate, water, soil, and vegetation that would restrict the sustained use of the regions. The time was one of massive human conversion of landscape in the western United States and Canada, in Australia, and in parts of Latin America, but also one of critical inquiry into consequences in terms of the interrelationship of people and resources within areas. Monumental efforts were under way to describe the changing face of the earth in its entirety. Ritter and von Humboldt had led the way, and Reclus between 1876 and 1894 completed the great *Nouvelle Géographie Universelle* which synthesized available knowledge about the planet's surface in 13 volumes (*3*). Marsh was deep in his final revised appraisal of the alterations in natural systems induced by past and contemporary civilizations, drawing heavily on the history of soil and forest degradation in Mediterranean countries (*4*).

Although the world and regional perspectives found favor in literary and educational circles, cautions about environmental deterioration had almost no influence on public action for a long time. The principal exceptions were the establishment of the national forests and parks systems in the United States. Embodied in the White House Conference of 1908 was concern over the danger of resource exhaustion and wasteful use (*5*). However, development was the predominant theme for a half a century. Technology for earth moving, dam building, crop growth, forest exploitation, and mineral extraction and refining contributed heavily to the expansion of resource use. National programs for resource development set the tone for science, engineering, and data collection in those fields either in supporting a program or an alternative, as in the case of forests and floods. What Hays calls the "Gospel of Efficiency" was powerful (*6*).

During the 1930's a strong surge of responsibility for stewardship of deteriorating resources left its marks on the governmental shore. A program to conserve soils led to the Soil Conservation Service with its research effort centering on test plots and watersheds treated in the entirety of physical movements of soil and water. This was accompanied by watershed programs in the Forest Service and by the river basin plans of the Corps of Engineers, the Tennessee Valley Authority, and the Bureau of Reclamation (now Water and Power Resources Service). The 1950's and 1960's saw these initiatives continued but with relatively little attention devoted to verifying the consequences of development.

A powerful new aspect of human modification took the form of a massive, steady increase in the volume of chemical compounds released into the environment through waste emissions, pesticides, herbicides, fungicides, and solid waste disposal. In number of products and in volume of production the world chemical industry increased dramatically in the decade beginning with World War II. Bioassays of toxicity of waste accordingly entered a new period in the 1950's. It is variously estimated that the number of different chemicals currently marketed in some volume ranges between 60,000 and 70,000 (*7*), and this may be as low as 40,000. In the United States 105 of these chemicals are manufactured in quantities exceeding 25 million pounds annually; 80 of them exceed 100 million pounds annually. The volume of synthetic organics produced in 1980 will be more than 100 billion pounds, marking an increase from 10 million in the 1940's, as shown in Fig. 1 (*7*). Perhaps as many as 1000 new chemicals are introduced annually.

Also beginning in the late 1940's fundamental questions were raised about the future capacity of the globe to support its rapidly growing population. These were expressed most frequently in popular or semipopular publications sometimes labeled as Malthusian (*8*). They later were stated most dramatically in a systems framework in the Club of

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Rome report in 1972 (*9*), which, while subject to scientific criticism, extended an earlier point of view and provided a broad theme for many investigators concerned with resource degradation and the rising population.

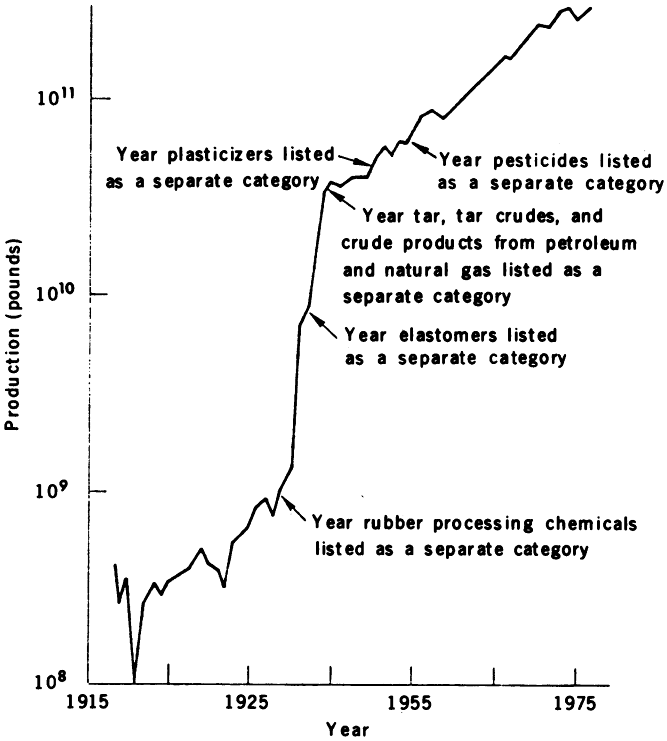

Fig. 1. Production of synthetic organic chemicals. [From (*7*), courtesy of W. H. Freeman and Co.]

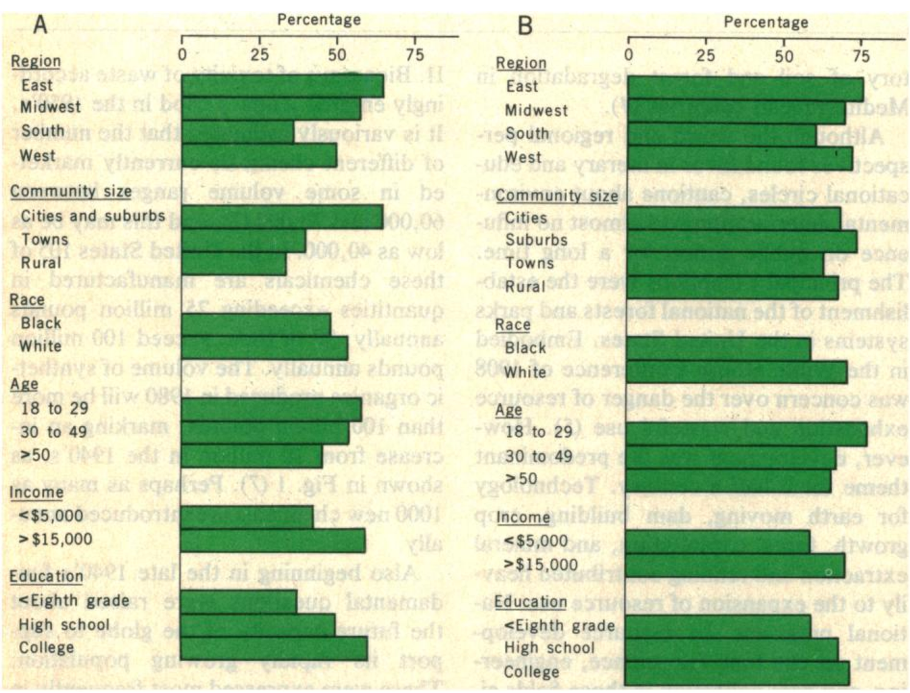

Fig. 2. People feeling that water pollution is very serious as (A) a local problem in 1971 and (B) a national problem in 1978. Source: (A) *Harris Survey Yearbook of Public Opinion, 1971* (Louis Harris and Associates, New York, 1975), p. 260. Question wording: "Do you feel water pollution is a very serious problem around here, somewhat serious, or not a very serious problem?" (B) A Harris survey conducted in May 1978. Question wording: "Here is a list of different kinds of environmental problems. For each would you please tell me if it is a very serious problem, a somewhat serious problem, or only a small problem for this country—pollution of lakes and rivers."

The 1970's

Through a combination of forces, the last years of the 1960's and the decade of the 1970's saw a shift in emphasis to the maintenance of environmental quality. Stress was placed on air and water quality standards, regulations, subsidy of pollution-abatement works, preservation of endangered species, wilderness, and scenic areas, and critical review of the environmental effects of proposed new developments. Earth Day, the National Environmental Policy Act (NEPA), the Council on Environmental Quality, the Environmental Protection Agency, the Endangered Species Act, and clean air and clean water acts were landmarks. The United Nations Conference on the Human Environment, held in Stockholm in 1972, reflected and in turn stimulated similar changes in other countries, principally Western Europe and Japan.

The enthusiasm expressed in the 1970 Earth Day and the Stockholm Conference was not merely a response to the mounting scientific evidence concerning changes in environmental systems or the extent to which many of those changes in air and water involved external effects and the use of common resources. Rather, the environmental movement of the 1970's expressed frustration with the workings of big business, big government, and large universities; it apparently was in part a reaction to the material affluence of the time, to the moral and social impacts of the Vietnam war, and to other stresses in the social fabric that were widely publicized by the media. Whatever the precise climate and conjunction of the forces at work, they defied the observer seeking to explain the new emphasis. It was a reaction to more than the identification of resource destruction and hazards of the type reported in *Silent Spring* (*10*) or in scientific reviews (*11*).

Many a scientist or engineer was alternately confounded and entranced by the speed with which regulations were adopted with incomplete supporting evidence, by the rejection by some public interest groups of what previously had been hailed as beneficial measures—like the Echo Park dam or the Alaskan pipeline—and by radically different values placed on various risks, such as nuclear power, automobile fatalities, and pesticides (*12*). In scores of cases public concern was voiced over the alleged miscarriage of well-intentioned technological projects (*13*). Anxiety grew over carcinogens and radiation hazard. Citizen groups became sensitive to hazards carried involuntarily by individuals.

The experience of the 1970's is significant for the future because it reminded the scientific community that, if it is to help the bodies politic deal intelligently with environmental problems, it must understand the factors that affect how different publics value nature, and the complexities of local community response to scientific evidence and to perceived difficulties in manipulating natural systems (*14*). It also must understand that social response may be sluggish by comparison with technological change.

It is notable that although the programs of the 1970's provoked improvement in some sectors of the environment and critical opposition by some interest groups, they commanded larger expressions of public support in the United States in 1978 than in 1971. As shown in Fig. 2, this strengthening of concern was reported in all regional, ethnic, income, and educational groups in the face of economic challenge.

Events generated by the 1973 oil embargo had a profound effect on the U.S. definition of resource needs and of appropriate scientific research to help meet them. Within a few years the first approximation of a national energy program was under way, and this encompassed new inquiry into the environmental health effects of energy technology, the management of public lands, energy conservation, and alternative sources. This set of efforts has just begun to be reflected in scientific and technological advances, but the mounting perception of the severity of possible energy shortages lends urgency to appraisal of environmental policies.

Ten years after NEPA, measures to improve environmental quality are subject to attack from several quarters. It is claimed that impact assessment and pollution regulations hold back innovation, and that they are cumbersome, unduly costly to society by impeding economic growth, and in some instances, like the clean air standards, are based upon unsound or inadequate scientific evidence. Environmental activists are branded as hypocrites not prepared to sacrifice the comforts of modern society (*15*). Each of these arguments is in debate and surely will be debated for a long time to come because the environment is regarded as important. Fundamental to them is the question of whether or not in each sector in which regulations and new control technologies have operated the quality of the environment has, in fact, improved. One direct result of these controversies has been to stimulate more searching examination of the full range of consequences of the various remedial measures as well as of other social forces affecting the environment.

Thus far, the analytical tools available for that purpose are at best modest, and in many instances the data required for adequate appraisal are deficient. Many environmental impact statements are written without a sound basis for estimating the impact. This was given sharp emphasis by the interaction of scientists and environmental lawyers in the litigation made possible by NEPA (*16*). Much of the controversy between industrial and environmental groups hinges on effects that are either unverified or speculative. For example, the assertion that clean water regulations retard manufacturing growth and reduce profits is heard frequently, but there is little solid information on which to assess it (*17*).

To deal effectively with the whole range of environmental problems that are evident or emerging would call, ideally, for perfect knowledge of the natural systems to be affected. The knowledge would be so nearly complete that for any proposed intervention in the environment it would be possible with a high degree of confidence to estimate the expected effects on people and ecosystems, and to specify the full costs and benefits of any measures that might be devised to enhance resource use. As illustrated by the program for reducing air pollution, this ideal never will be reached. At best, new technologies will present new solutions and new complications, and further investigations will reveal processes and conditions previously unsuspected, as in the recognition of the role of small particulates. Yet, the effort to estimate impacts will be pursued. The sobering prospect is that most of the major public decisions about resource use and environmental management will be made in the face of large uncertainty deriving from ignorance of physical and biological systems and from evolving techniques and social values.

While emphasis during the 1970's was on reducing pollution and preserving wilderness, some of the earlier development programs received new, critical attention. Water resources projects were reevaluated in the light of sterner efficiency criteria and their impacts on natural systems. Concepts of multiple-purpose management in forests embracing use of clear-cutting techniques were reexamined. Fire was recognized as playing a possibly constructive role in ecosystem maintenance when all impacts, including those on air quality, are taken into account. It was ironic, however, that while much effort was expended on wilderness preservation virtually no attention was paid to establishing scientific grounds for managing the huge proportion of the land surface remaining in the public domain and for the basic ecological survey to assist that belated program.

When one seeks to peer ahead, some of the prospective interactions of science and technology with environmental policy can be projected by extrapolating recent trends. Others may constitute sharper breaks with the past. In the environmental field over the years, however, there have been relatively few shifts in the course of events as rapid or dramatic as those of 1933 to 1938 or 1969 to 1972. Perhaps the only three technological changes bringing about sharp discontinuities in development during recent decades were the invention of nuclear power generation, the refinement of techniques for measuring very small quantities of substances in air, water, soil, food, and organic tissue before and after waste discharge, and the provision of computing capacity to handle very large models of natural systems and the data from extensive sampling.

Now appearing prominent on the scene are at least six trends in scientific thinking and action. Others might be identified, but these seem to point to significant problems and opportunities. (i) More serious efforts are made to examine environments in a holistic framework. (ii) Greater attention is given to studying processes within the basic life support systems. (iii) There is expanded emphasis on canvassing the theoretical range of alternatives in resource management. (iv) Numerous efforts are under way to refine methods for the assessment of risk. (v) Techniques for monitoring changes in environmental systems are being streamlined. And (vi), increasingly, all this is happening within a global framework. Each of these advances in perspective and method cuts across the traditional divisions of environmental problems according to natural media of air, water, soil, vegetation, and animals. Each also calls for unconventional collaboration across disciplinary lines.

Environment in a Holistic Framework

Much of the activity devoted to enhancement of environmental quality faces a task of integration. The most conspicuous move in that direction was achieved over the past half-century by investigators and planners involved in water management, but only in part. Notwithstanding pious affirmations of the unity of drainage basins and the social efficiency of multiple-purpose management through mixes of single and multiobjective measures, it took a long time to organize genuinely integrated investigations in which diverse but clearly related topics such as sediment flow, floodplain use, aquatic ecosystems, upstream urbanization, and irrigation water application patterns could be attacked in unified fashion. The performance still falls short of aspiration, but the conceptual groundwork and the administrative machinery have begun to emerge (*18*). Genuinely national, interdisciplinary programs of research on surface and groundwaters took shape in the 1960's, and although they were laid aside in the 1970's, they will undoubtedly receive fresh and relatively coherent attention in the future under the stimulus of questions as to supplies of water for synthetic fuel and increased crop production.

Not so with the array of studies and regulations initiated during the 1970's. Although the Environmental Protection Agency provides an administrative umbrella for programs on clean air, clean water, solid waste disposal, and control of toxic substances, the programs remain disparate activities by virtue of independent congressional authorization. To take only two sectors, the studies on water supply and waste treatment under Section 208 of the Federal Water Pollution Control Act of 1972 are independent of studies to determine air quality standards and emission limitations under the Clean Air Act as amended in 1977. It may be argued that the two groups of pollutants are essentially different and that in most respects they operate with little effect on each other. However, the populations and manufacturing activities involved are the same, locational decisions on highways and land use are similar for both, and nonpoint sources are major contributors to water pollution. Genuine pollution control has the potentiality of what Reilly designates as a "quiet revolution" in land use (*19*). It, further, is abundantly evident that the interchange of particulates and pollutants such as sulfur dioxide and nitrogen oxides and organic compounds is significant. It will in time be necessary to examine regularly the interrelationship of flows of all polluting materials in any given area, and the theoretical framework for doing so is taking shape (*20*). The EPA has moved toward coordination of the investigations it supports, and has begun to establish centers for anticipatory research, but the demands of justifying and monitoring regulatory procedures tend to take precedence over holistic approaches, and the contracts and grants follow suit. Lawyers operating within statutory compartments and scientists with circumscribed expertise still tend to dictate the immediate study agenda.

No aspect of environmental management in the United States is more neglected for political reasons than land use and its planning. The term "land use planning" with its connotation of encroachment on private property rights became anathema to powerful sectors of the electorate, with the result that its direct support at the federal level is muted. Indirectly, many of the federal programs have changed the mix of property rights and social mechanisms affecting land use. National encouragement of planning is still given chiefly for coastal zones and urbanized areas, and in those instances it is frequently almost obliterated by the generous use of exceptions. Yet most decisions influencing the location and character of industries generating waste, or the quality of wild areas and open space, or the transportation of toxic substances are made at the level of determining how particular pieces of land will be used. Wise action requires intimate knowledge of local conditions. As long as the process of making those decisions remains essentially in the hands of private landowners and local governments, and the federal government treats them with cautious detachment, the stimulation of research to supply necessary data will remain weak.

A more comprehensive view of environmental interactions is developing in the field of toxicology. Much of the earlier, fundamental research on effects of exposure to toxic materials, such as arsenic and lead, came from studies in the human workplace. Observations, chiefly clinical and epidemiological, demonstrated pathological effects of various dosages on people producing or using substances containing the suspected materials. For some of them permissible levels of exposure were established for purposes of occupational health and safety.

During the past three decades two technological changes and two shifts in scientific orientation have altered the situation in a fashion that profoundly affects public policy. On the technological side, the commercial production of chemical compounds grew rapidly for 25 years, as noted above, while the capacity to detect and measure minute quantities of many potentially hazardous substances increased by several orders of magnitude. On the scientific side, the concept of threshhold limits of toxicity was severely challenged, and the view of humans as the major targets for toxic materials was enlarged to include other constituent organisms in ecosystems.

During the period of growth in chemical production the means of identifying toxic chemicals in air, water, soil, food, and tissues were advanced by the refinement, chiefly after 1950, of mass spectrometry, neutron activation analysis, electrochemical techniques, atomic spectroscopy, and gas and liquid chromatography (*21*, p. 128). Whereas in 1950 polychlorinated biphenyls, dioxin, and nitrosamines—to name only a few—could not be measured in trace amounts, in the 1970's they could be detected routinely in amounts of parts per million (*22*). The sensitivity of analysis in some cases, as for chromium, increased to parts per billion in a few years and dioxin to parts per trillion (*23*). Chloroform was not known to be present in minute quantities in drinking water as recently as 1960, but its presence at the part per million level became a target of public concern within a few years after it was recognized as a carcinogen (*24*). Some aspects of analytical chemistry, previously considered routine, were suddenly on the forefront of environmental study.

The implications of these advances in testing and associated problem-solving are widespread. Producers as well as regulators of known or suspected toxic substances find the task of dealing with environmental effects facilitated by rapid and accurate determinations. At the same time the task is complicated by detecting new ramifications and subtleties of relationships; numerous elements, for example, are found to be essential to the functioning of organisms in very small amounts although they are toxic at higher levels. Further refinements are certain to heighten the complications, and the limit on precision of sensitivity will be set by the capacity to remove residual impurities in reagents and solvents (*21*, p. 130). Thus it is argued that isotope dilution mass spectrometry makes it possible, combined with ultra clean analytical methods, to identify concentrations of lead and other materials from anthropogenic sources previously regarded as natural background (*25*).

The subject of toxicity becomes more intricate when the focus shifts from human targets to other organisms in an ecosystem. We are moving into a period when ecotoxicology will claim increasing attention and will address itself to such questions as the synergistic effects of substances, the health of nonhuman species, and the consequences of altering the reproduction or nutrition of selected populations (*26*).

Basic Life Support Systems

The health of the land and its associated plants and animals is basic to preservation of the resource base, yet it is rarely investigated in a fashion that permits recognition of the interactions that affect its net ability to support life. Reductionist research prevails and is encouraged by the organization of most universities. We know a great deal about such matters as crop yields per acre and rates of soil loss in test plots and about the effects of specified pesticides on a few insect and bird populations, but we have no fully adequate means of estimating the capacity of land areas as units to permanently sustain a diverse population of species under prevailing techniques. Such appraisal becomes increasingly vital as the number and variety of technological innovations multiply—fertilizers, pesticides, herbicides, fungicides, tillage techniques, narrow genetic strains, urbanization—so that a short-term gain in return from one source may mask long-term deterioration of the producing base. For the world as a whole the volume of production of nitrogen in commercial fertilizer will soon equal the volume made available by biological fixation (*27*). With alterations of this magnitude under way in the face of the continuing growth in world population, the time is ripe for a searching examination of what is happening to the fundamental resources.

Only recently has the investigation of drainage areas reached a point at which it is possible, in addition to analyzing stream flow, to trace the flows of nutrients into and out of a small forested area, as at Hubbard Brook, New Hampshire, to measure the effects of different management practices, and to estimate the consequences for stream flora and fauna (*28*). The comprehensive view of lakes as unified systems reflecting the interaction of many biological, physical, and social factors has exemplified a long-term goal (*29*). This is but a beginning in what promises to be more extensive and penetrating research into the vital processes by which the land is maintained and changed.

Theoretical Range of Management Choice

As reflected in the experience with water management in the United States and many other countries, the trend in handling resource problems is slowly moving away from single-purpose to multiple-purpose programs. Of greater significance, the tendency is to rely less on a single technological fix and more on a multiple mix of various adjustments suited to the unique characteristics of each physical, biological, and social configuration (*30*). An earlier example was that of management choices in dealing with floods (*31*). These choices have come to encompass upstream and floodplain land use measures, techniques to reduce vulnerability of structures, and insurance. Similarly, greater attention is being paid to a wider range of choice and to the balance of gains and losses in coping with pests, waste disposal, and air pollution (*32*).

The implications of these management policies for research and technological development are immense. Flood control research expands from corrective works to include modifications in building design, the niceties of zoning ordinances, human response to warnings, and restraints on use of hydrologic data by lending institutions in writing mortgages. When water pollution abatement, instead of concentrating on one type of measure such as municipal waste treatment, reaches out to alternative measures such as irrigation, land disposal, self-contained water and waste recycling, and revisions in industrial processing technology, it makes a diversified set of claims on research and development, and suggests improved procedures for setting research priorities.

Refining the Assessment of Risk

As more attention turns to studying complete natural systems and to alternative methods and strategies for managing them, and as the number and effects of environmental alterations expand, the way of presenting the risks and gains to the public prior to decision calls for greater sophistication. Decisions as to standards setting deserve careful refinement of the method of estimating the likely effects of interventions, but they also demand better understanding of how different publics perceive and are helped to evaluate the consequences (*33*).

Much public evaluation of environmental measures today ranges between two positions. The conventional benefit-cost analysis embodied in justifications for public works projects attempts to tally up and compare, for a specified time horizon and discount rate, the future flows of gains and losses. Few fields of research developed more rapidly during the 1950's and 1960's than the economic analysis of resources management measures (*34*). The early emphasis on the economic efficiency of firm or nation has expanded to include impacts on environment and regional welfare. This has tended to become routinized and has been subject to criticism on numerous grounds, among them that estimates have been manipulated, that long-term costs are underestimated, and that the full impacts on ecosystems and quality of human life are neglected (*35*). At the other extreme certain of the major efforts to preserve environmental quality have been based on broad assumptions that it is in the public interest to achieve a specified standard, with little explicit analysis leading to its setting. The water pollution abatement goal of making all streams swimmable and fishable is one such. The air quality standards for auto emissions specify thresholds in terms of health effects but with limited data to support the precise figure used. Whatever the methods used, the public decision is likely to consider factors broader than those figuring in the risk assessment.

Two recent reports by National Research Council units—those on saccharin and nitrates—illustrate the complications (*36*). They explicate uncertainties attaching to effects of the substances in question, present much of their evidence in probabilistic terms, and venture estimates of constructive as well as deleterious consequences of using the material.

It has become dramatically apparent that values attached to these probable flows of gains and losses by expert groups of engineers and scientists may not coincide with the values assigned by various publics concerned (*37*). The divergence is nowhere more extreme than in the realm of energy options where the estimated risks of using coal, solar, or nuclear energy not only divide the experts but provoke strong responses from different publics. Nuclear power is seen by certain citizen groups as carrying threats to life ten times those of other environmental hazards, while a National Research Council committee places the risks to health from nuclear power far lower than coal (*38*).

The steps under way in the National Research Council and the Royal Society and in various other groups to improve methods of risk assessment and of interpreting the results fairly to interested publics may be expected to be followed by further, wider ranging investigations that will sharpen the choices and clarify the essential part played by value judgments (*39*).

Streamlining Monitoring Techniques

Judgment about what is happening in natural systems depends in considerable measure on the accuracy and scope of monitoring observations. To appraise the effectiveness of regulatory measures for air pollution control as well as to support them, extensive networks have been organized to observe air quality. Accompanying them, but rarely in an integrated fashion, are statistics on human morbidity and mortality. These measures provide a point of departure for inferences as to the effects of air quality on health, but the strength of assertions about those relationships has not grown conspicuously (*40*).

An integral component of monitoring is the measurement of the perception and valuation by different publics of environmental parameters. The methods have advanced notably in recent decades.

Increasingly it is recognized that there is no static natural system, let alone one which is fully understood, and that management interventions, as with pest control or dam construction, are likely to provoke unexpected results and to require dynamic alteration (*41*). It is not a matter of simply taking action after a one-time environmental impact statement: monitoring is needed to provide a ground for revising policy and techniques, perhaps repeatedly. The grand design is flexible and sensitive to new knowledge and technology.

Monitoring of substance or effect or perception of effect may be fruitless or ineffective unless the basic processes are understood or hypothesized and unless the data collection is accompanied by continuing critical assessment of the monitoring strategy and the accuracy of the data set.

As illustrated by the United Nations surveillance of atomic radiation, the greater the precision of comprehension of the diffusion and transport processes involved, the smaller the number of observations required. Accurate and reliable models based on understanding of the underlying processes permit broad description from a small set of established points. But this is not yet true for many environmental parameters, and the task of monitoring rests partly on improving basic knowledge of the system, as in the case of water (*42*), partly on improved instrumentation, and partly on innovative methods of using small bits of data to describe large systems. Major advances in electronic and integrated systems for data processing now permit simultaneous determinations of many components in a substance.

At the regional level, a stock taking is under way in those countries in the Organization for Economic Cooperation and Development (*43*). On a global scale, the United Nations Environment Programme has begun to lay the groundwork for detecting changes in major environmental parameters, but a genuine world strategy is just beginning to take shape and faces the difficulty of sifting out the background fluctuations (*44*). It will require new approaches like the "mussel watch" which measures changes in coastal water quality through analysis of selected accumulator organisms appropriate to the conditions under surveillance (*45*).

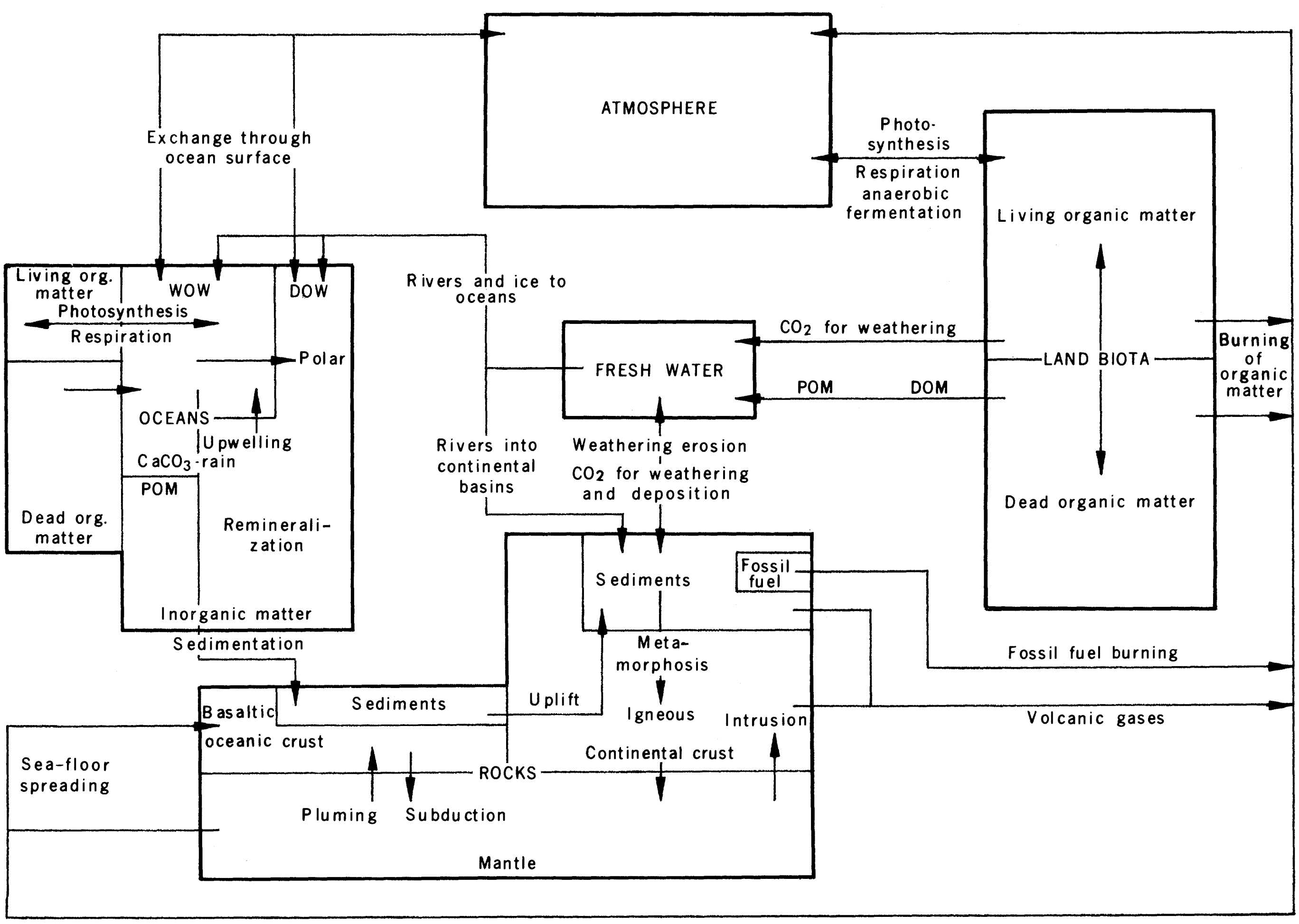

Fig. 3. Principal reservoirs and fluxes in the carbon cycle. Abbreviations: *WOW*, warm ocean water; *COW*, cold ocean water; *POM*, particulate organic matter; *DOM*, dissolved organic matter. [From Bolin *et al.* (*54*), courtesy of John Wiley and Sons]

Global Perspective

Approaches to investigation of environmental problems at the local or national level gain in strength from the global perspective. A great variety of problems have international implications in that they are common to many countries, or in that what happens in one country affects one or more other countries through physical or economic linkages (*46*). There is a good deal of experience with international river basins and a growing disposition to cope with transnational pollution, as in the case of acid rain in North America and Western Europe.

The global perspective is gaining rapidly in scientific work in at least two environmental sectors. One is the accelerated networking of experience in coping with common questions of environmental deterioration or enhancement. Through the United Nations Environment Programme, the Organization for Economic Cooperation and Development, the United Nations Educational, Scientific, and Cultural Organization, bilateral collaboration, and scientific unions a more concerted effort is being made to exchange and bring to bear the available knowledge and to stimulate new research on such questions as desertification and waste disposal. The threat to the resource base from soil depletion in some areas is well established (*47*), yet concerted means for coping with it are still feeble.

A second, momentous development during the past decade has been the recognition that a few environmental alterations have attained a magnitude that promises or may already have brought about change in global systems. The convention for the protection of endangered species on a world scale was executed in 1977 with a view to preserving unique genetic resources. Intergovernmental action was taken to control ocean dumping in 1972.

At an international conference in 1977, the prospect of depletion of the ozone layer was first confronted (*48*). The World Climate Conference in 1979 saw serious discussion of the probability, as yet unspecified, that mounting concentrations of carbon dioxide in the atmosphere would trigger climatic change (*49*). The pace of action is accelerating, and other, perhaps more significant, alterations may be in the wings. But for the first time the world scientific and political communities are systematically contemplating globally significant transformations (*50*).

An Illustrative Case: Carbon Dioxide and Biogeochemical Cycles

To a remarkable degree the developments described above are merged in the current attacks on our ignorance concerning the great global biogeochemical cycles. The prevailing efforts stem from two sources. Of long duration is the series of attempts to describe the cycles. The first such investigation was undertaken by Vernadsky (*51*); one of the most recent was sponsored by the Scientific Committee on Problems of the Environment (SCOPE) (*27*). Of shorter duration are the growing expressions of concern over ozone depletion, acid rain, and the mounting levels of CO_2. Interest in reduction in the ozone layer in the stratosphere with its consequent effects on the incidence of skin cancer as a result of augmented ultraviolet radiation stems from discovery of a few of the photochemical processes induced by releases of fluorocarbons (*52*). The acid rain problem, which first came into public view in the train of observations of decreases in fish populations in Scandinavian lakes and of increasing acidity in surface waters and precipitation, has broader linkages in the sulfur, nitrogen, and phosphorus cycles (*53*).

The CO_2 concern stems from speculation about global warming accompanied by observations at Mauna Loa and the Antarctic of an increase of approximately 5 percent in atmospheric CO_2 since 1957 and of 13 percent since before 1850 (*54*). As noted by Revelle (*55*), the augmentation, while linked with fossil fuel generation, may also be affected by rates of vegetation burning, forest destruction, and other interventions in the carbon cycle, as outlined in Fig. 3. It is symptomatic of the stance commonly taken by government agencies that they focus on what appear to be immediate issues of policy. Thus, the CO_2 investigations received strong impetus from debates over plans for increased use of coal and synthetic fuels in relation to nuclear sources.

The alternative approach, which is slowly taking shape, examines the problem in the context of the interactions among the cycles of carbon, nitrogen, phosphorus, and sulfur as affected by other elements, including trace metals. This alternative promises greater returns in the long run by attempting to understand the cycles themselves instead of trying to solve the CO_2 problem, a goal impossible to reach without making large gains in the former direction. The holistic framework therefore is essential to finding solutions. In considering ways of coping with the hazards and opportunities involved in cycle changes—assuming that reasonably accurate models can be devised to predict direction, magnitude, and spatial pattern of climatic change—it will be important to look carefully at all theoretical avenues of action, including readjustments in land use, changes in industrial and agricultural techniques, and the like. Choices among the various possibilities will require far more sophisticated methods of assessing the risks of alternative responses for each of the human populations and habitats affected. These methods will have to take account of the intricacies of physical, biological, and social systems. They will need to be supplemented by discriminating deployment of new monitoring observations, particularly in the oceans. All this must take place in an international context if the full assets of the world scientific community are to be brought to bear. Collaboration at that scale also will be required if consensus as to process and consequences is to be reached as a necessary condition for determining whatever intergovernmental action, if any, may be suitable. Different areas and populations probably will be affected quite differently, and there will be pressure to make policy choices about energy generation and vegetation management while neither the basic cycles nor the likely impacts of changing them is well understood. Policy decisions should await the advance of basic research.

The net effect of a widespread effort of the sort shared by many individual investigators and teams dealing with biogeochemical cycles would be the achievement in roughest form of something approaching what Bolin likes to call a "global ecology" (*56*). Similar undertakings must be expected in other sectors. Nothing less will do in meeting the human family's ultimate need to preserve and use sanely its only base of support.

References and Notes

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