RESTORING THE QUALITY OF OUR ENVIRONMENT

Report of The
Environmental Pollution Panel
President's Science Advisory Committee

THE WHITE HOUSE

NOVEMBER 1965

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Ours is a nation of affluence. But the technology that has permitted our affluence spews out vast quantities of wastes and spent products that pollute our air, poison our waters, and even impair our ability to feed ourselves. At the same time, we have crowded together into dense metropolitan areas where concentration of wastes intensifies the problem.

Pollution now is one of the most pervasive problems of our society. With our numbers increasing, and with our increasing urbanization and industrialization, the flow of pollutants to our air, soils and waters is increasing. This increase is so rapid that our present efforts in managing pollution are barely enough to stay even, surely not enough to make the improvements that are needed.

Looking ahead to the increasing challenges of pollution as our population grows and our lives become more urbanized and industrialized, we will need increased basic research in a variety of specific areas, including soil pollution and the effects of air pollutants on man. We must give highest priority of all to increasing the numbers and quality of the scientists and engineers working on problems related to the control and management of pollution.

I am asking the appropriate Departments and Agencies to consider the recommendations and report to me on the ways in which we can move to cope with the problems cited in the Report. Because of its general interest, I am releasing the report for publication.

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Martin Alexander, Associate Professor of Soil Science, New York State College of Agriculture, Cornell University, Ithaca

H. Stanley Bennett, Dean, Division of Biological Sciences, University of Chicago

Nyle C. Brady, Director of Office of Science and Education, U.S. Department of Agriculture (until August 31, 1965), Director of the Cornell University Experiment Station, Director of Research, New York State College of Agriculture, Cornell University, Ithaca

John C. Calhoun, Jr., Science Advisor to the Secretary of the Interior (until February 5, 1965), Vice President for Programs, Texas A & M University System, College Station

John C. Geyer, Chairman, Department of Sanitary Engineering and Water Resources, The Johns Hopkins University, Baltimore

Aarie J. Haagen-Smit, Professor of Biochemistry, California Institute of Technology, Pasadena

Norman Hackerman, Vice Chancellor for Academic Affairs, University of Texas, Austin

James B. Hartgering, Director of Research and Education, American Hospital Association, Chicago

David Pimentel, Head, Department of Entomology and Limnology, New York State College of Agriculture, Cornell University, Ithaca

Roger Revelle, Director, Center for Population Studies, Harvard University

Louis H. Roddis, President, Pennsylvania Electric Company, Johnstown

William H. Stewart, (member until June, 1965) Office of the Secretary, U.S. Department of Health, Education, and Welfare, Washington

James L. Whittenberger, Professor of Public Health, Harvard School of Public Health

John L. Buckley, *Staff,* Technical Assistant, Office of Science and Technology, Washington

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Subpanel Reports

Acknowledgements

The study was conducted under the general supervision of Colin M. MacLeod, Deputy Director, Office of Science and Technology.

The Panel drew on scientists and engineers from within the Federal Government, from state governments, universities and industry to form subpanels of experts, each of which explored a different problem. These busy men put in, on the average, several weeks of their time talking to scientists, studying and evaluating information published and unpublished, and writing reports. The reports are included as the "Y" Appendixes.

The members of the subpanels are listed on the following pages.

SOIL CONTAMINATION

H. Stanley Bennett, *Chairman*
Dean, Division of Biological Sciences
University of Chicago

Martin Alexander
Associate Professor of Soil Science
New York State College of Agriculture
Cornell University, Ithaca

Sterling B. Hendricks
Soil and Water Conservation Research Division
Agricultural Research Service
U.S. Department of Agriculture
Beltsville, Maryland

H. L. Lucas
Professor and Director of Biomathematics Training Program
Institute of Statistics
North Carolina State University, Raleigh

Thomas J. Sheets, *Staff*
Crops Research Division
Agricultural Research Service
U.S. Department of Agriculture
Beltsville, Maryland
(Present address) Associate Professor of Entomology and Crop Science
North Carolina State University, Raleigh

HEALTH EFFECTS OF ENVIRONMENTAL POLLUTION

James L. Whittenberger, *Chairman*
Professor of Public Health
Harvard School of Public Health

Aarie J. Haagen-Smit
Professor of Biochemistry
California Institute of Technology, Pasadena

Lincoln E. Moses
Executive Head
Department of Statistics
Stanford University

William H. Stewart (member until June 1965)
Office of the Secretary
U.S. Department of Health, Education, and Welfare, Washington

John R. Bagby, Jr., *Staff*
Communicable Disease Center
Public Health Service
U.S. Department of Health, Education, and Welfare, Atlanta, Georgia

H. Bruce Dull, *Staff*
Communicable Disease Center
Public Health Service
U.S. Department of Health, Education, and Welfare, Atlanta, Georgia

BENCHMARK SURVEILLANCE

Aarie J. Haagen-Smit, *Chairman*
Professor of Biochemistry
California Institute of Technology
Pasadena

Louis H. Roddis, *Vice Chairman*
President
Pennsylvania Electric Company
Johnstown

Nyle C. Brady
Director of Science and Education
U.S. Department of Agriculture (until August 31, 1965)
Director of the Cornell University Experiment Station
Director of Research
New York State College of Agriculture
Cornell University, Ithaca

Raymond J. Jessen
Professor of Business Statistics
Graduate School of Business Administration
University of California, Los Angeles

James L. Whittenberger
Professor of Public Health
Harvard School of Public Health

W. J. Youden
4821 Upton Street NW.
Washington

John L. Buckley, *Staff*
Technical Assistant
Office of Science and Technology
Washington

ATMOSPHERIC CARBON DIOXIDE

Roger Revelle, *Chairman*
Director, Center for Population Studies
Harvard University

Wallace Broecker
Professor of Geology
Columbia University, New York

Harmon Craig
Professor of Geochemistry
Department of Earth Sciences
University of California, La Jolla

Charles D. Keeling
Scripps Institution of Oceanography
La Jolla, California

J. Smagorinsky
Weather Bureau
Environmental Sciences Services Administration
U.S. Department of Commerce
Suitland, Maryland

SOLID WASTES

John C. Calhoun, Jr., *Chairman*
Science Adviser to the Secretary
U.S. Department of the Interior (until February 5, 1965)
Vice President for Programs
Texas A & M University System
College Station

Patrick Conley
Senior Fellow
Mellon Institute, Pittsburgh

Aarie J. Haagen-Smit
Professor of Biochemistry
California Institute of Technology
Pasadena

Norman Hackerman
Vice Chancellor for Academic Affairs
University of Texas, Austin

Leonhard Katz
President
Astro Dynamics, Inc.
2d Avenue, Northwest Industrial Park
Burlington, Massachusetts

George J. Maslach
Dean, College of Engineering
University of California, Berkeley

Louis H. Roddis
President
Pennsylvania Electric Company
Johnstown

James E. Hill, *Staff*
Bureau of Mines
U.S. Department of the Interior
Washington

COMBINED SEWERS

John C. Geyer, *Chairman*
Chairman
Department of Sanitary Engineering
and Water Resources
The Johns Hopkins University
Baltimore

Leonhard Katz
President
Astro Dynamics, Inc.
2d Avenue, Northwest Industrial Park
Burlington, Massachusetts

EFFECTS OF CHLORINATING WASTES

Martin Alexander, *Chairman*
Associate Professor of Soil Science
New York State College of Agriculture
Cornell University, Ithaca

John C. Geyer
Chairman
Department of Sanitary Engineering and
Water Resources
The Johns Hopkins University, Baltimore

Deric O'Bryan, *Staff*
Geological Survey
U.S. Department of the Interior
Washington

AGRICULTURAL WASTES

Martin Alexander, *Chairman*
Associate Professor of Soil Science
New York State College of Agriculture
Cornell University, Ithaca

Nyle C. Brady
Director of Science and Education
U.S. Department of Agriculture
(until August 31, 1965)
Director of the Cornell University
Experiment Station
Director of Research, New York State
College of Agriculture
Cornell University, Ithaca

Deric O'Bryan, *Staff*
Geological Survey
U.S. Department of the Interior
Washington

AQUATIC BLOOMS

Martin Alexander, *Chairman*
Associate Professor of Soil Science
New York State College of Agriculture
Cornell University, Ithaca

John B. Moyle
Department of Conservation
St. Paul, Minnesota

Ruth Patrick
Academy of Natural Sciences
Philadelphia, Pennsylvania

Leon Weinberger
Division of Water Supply
and Pollution Control
Public Health Service
U.S. Department of Health, Education, and Welfare, Washington

Deric O'Bryan, *Staff*
Geological Survey
U.S. Department of the Interior
Washington

EFFECTS OF POLLUTANTS ON LIVING ORGANISMS OTHER THAN MAN

David Pimentel, *Chairman*
Head, Department of Entomology
and Limnology
New York State College of Agriculture
Cornell University, Ithaca

Don W. Hayne
Professor of Experimental Statistics
Institute of Statistics
North Carolina State University
Raleigh

Louis A. Krumholz
Professor of Biology
University of Louisville

John T. Middleton
Director, Air Pollution Research Center
University of California
Riverside

Lionel A. Walford
Director, Sandy Hook Marine Laboratory
Bureau of Sport Fisheries and Wildlife
U.S. Department of the Interior
Highlands, New Jersey

John L. Buckley, *Staff*
Technical Assistant
Office of Science and Technology
Washington

IMPROVED PEST CONTROL PRACTICES

David Pimentel, *Chairman*
Head, Department of Entomology and Limnology
New York State College of Agriculture
Cornell University, Ithaca

Donald A. Chant
Chairman, Department of Biological Control
University of California, Riverside

Arthur Kelman
Professor of Plant Pathology and Forestry
North Carolina State University, Raleigh
Present Address—
Chairman, Department of Plant Pathology
University of Wisconsin, Madison

Robert L. Metcalf
Vice Chancellor
University of California, Riverside

L. D. Newsom
Head, Department of Entomology
Louisiana State University, Baton Rouge

Carroll N. Smith, *Staff*
Entomology Research Division
Agricultural Research Service
U.S. Department of Agriculture
Gainesville, Florida

Introduction

> Environmental pollution is the unfavorable alteration of our surroundings, wholly or largely as a by-product of man's actions, through direct or indirect effects of changes in energy patterns, radiation levels, chemical and physical constitution and abundances of organisms. These changes may affect man directly, or through his supplies of water and of agricultural and other biological products, his physical objects or possessions, or his opportunities for recreation and appreciation of nature.

The production of pollutants and an increasing need for pollution management are an inevitable concomitant of a technological society with a high standard of living. Pollution problems will increase in importance as our technology and standard of living continue to grow.

Our ancestors settled in a fair and unspoiled land, easily capable of absorbing the wastes of its animal and human populations. Nourished by the resources of this continent, the human inhabitants have multiplied greatly and have grouped themselves to form gigantic urban concentrations, in and around which are vast and productive industrial and agricultural establishments, disposed with little regard for state or municipal boundaries.

Huge quantities of diverse and novel materials are dispersed, from city and farm alike, into our air, into our waters and onto our lands. These pollutants are either unwanted by-products of our activities or spent substances which have served intended purposes. By remaining in the environment they impair our economy and the quality of our life. They can be carried long distances by air or water or on articles of commerce, threatening the health, longevity, livelihood, recreation, cleanliness and happiness of citizens who have no direct stake in their production, but cannot escape their influence.

Pollutants have altered on a global scale the carbon dioxide content of the air and the lead concentrations in ocean waters and human populations. Pollutants have reduced the productivity of some of our finest agricultural soils, and have impaired the quality and the safety of crops raised on others. Pollutants have produced massive mortalities of fishes in rivers, lakes and estuaries and have damaged or destroyed commercial shellfish and shrimp fisheries. Pollutants have reduced valuable populations of pollinating and predatory insects, and have appeared in alarming amounts in migratory birds. Pollutants threaten the estuarine breeding grounds of valuable ocean fish; even Antarctic penguins and Arctic snowy owls carry pesticides in their bodies.

The land, water, air and living things of the United States are a heritage of the whole nation. They need to be protected for the benefit of all Americans, both now and in the future. The continued strength and welfare of our nation depend on the quantity and quality of our resources and on the quality of the environment in which our people live.

The pervasive nature of pollution, its disregard of political boundaries including state lines, the national character of the technical, economic and political problems involved, and the recognized Federal responsibilities for administering vast public lands which can be changed by pollution, for carrying out large enterprises which can produce pollutants, for preserving and improving the nation's natural resources, all make it mandatory that the Federal Government assume leadership and exert its influence in pollution abatement on a national scale.

We attempt here to describe the problem, to distinguish between what is known and what is not, and to recommend steps necessary to assure the lessening of pollution already about us and to prevent unacceptable environmental deterioration in the future.

The Effects of Pollution

HEALTH EFFECTS

Pollution affects human health and comfort in a number of ways. Under some circumstances, fortunately now rare, it brings overt clinical disease or even death. More commonly, however, it produces lesser effects, such as difficulty in breathing and impaired lung function from inhalation of polluted air, irritation of eyes, nose, and throat, unpleasant tastes or odors, psychological or behavioral effects.

Excessive air pollution for short periods (***acute episodes***).—Hazards from atmospheric pollutants have been demonstrated most vividly in episodes of acute exposure. There are many reliable reports of individuals and small groups made ill or even killed by occupational or accidental exposure to toxic fumes, vapors, pesticide aerosols, smoke, or high cencentrations of dust. A few community catastrophes have resulted from combinations of fog, temperature inversion, and air stagnation, coupled with unusually large amounts of ordinary combustion-produced atmospheric pollutants. In these rare but tragic episodes, fatalities occurred predominantly among the elderly and those with pre-existing cardiac or pulmonary disease.

Certain communicable diseases, such as tuberculosis, influenza, and the common cold, are transmitted by airborne microorganisms.

Prolonged exposure to ordinary urban air pollution.—While we all fear, and many believe, that long-continued exposure to low levels of pollution is having unfavorable effects on human health, it is heartening to know that careful study has so far failed to produce evidence that this is so, and that such effects, if present, must be markedly less noticeable than those associated with cigarette smoking. Attempts to identify possible effects of ordinary urban air pollution on longevity or on the incidence of serious disease have been inconclusive. Special attention has been focused on lung cancer, which is known to be closely associated with tobacco smoking, and with the inhalation of radon, other radioactive materials, nickel carbonyl, chromates, asbestos and other chemicals. There are consistent findings of a greater incidence of lung cancer in the cities than in the country, and it is possible that urban air pollution is a contributory factor in this disease. But its role is uncertain except in special situations, such as proximity to industrial plants that handle known carcinogenic materials.

Urban atmospheric pollution can aggravate asthma and some other chronic respiratory illnesses, and can cause transient eye and respiratory tract irritation. Evidence from animal studies suggests that exposure to air pollution may increase susceptibility to pulmonary infections.

Water-borne pollutants and health.—A century ago, our population was ravaged by water-borne diseases, among which typhoid fever, cholera, and dysentery were conspicuous. These tragedies led to today's water treatment methods, which, when applied, control adequately most disease-producing bacteria. Viruses, such as those of hepatitis, remain a problem.

Chemical pollutants in water sometimes threaten human health. Substantial contamination of ground water with nitrates derived from sewage or from fertilized farm fields has been reported in several states. Drinking water with nitrate-nitrogen levels above 8 or 9 ppm, which are occasionally reached, may cause methemoglobinemia in infants.

Pesticides and human health.—The tremendous growth in the variety and use of organic pesticides since World War II has caused concern as to their possible effects on human health. Exposure occurs chiefly from ingestion of foods, from direct skin or respiratory contact during use, and from inhalation of airborne materials near treated areas.

Small numbers of persons perish each year in this country from accidental or occupational misuse of pesticides, and from deliberate ingestion with suicidal intent. It is estimated that about 100 cases of non-fatal poisoning occur for every fatal case. Despite the increasing use and variety of pesticides, there is no evident increase in mortality attributable to their use.

Chlorinated hydrocarbon and phosphate ester pesticides have been detected in many surface and ground waters, in amounts ranging up to a few parts per billion. These small concentrations are not known to be a threat to human health. On rare occasions, higher concentrations of pesticides appear in potable waters, usually as a result of industrial discharges. Human illness traced to pesticides in public water supplies has not been reported, but examples of illness from domestic well contamination may have occurred.

Although deaths and overt illnesses from pesticide poisoning are rare, everyone in the United States has a measurable body burden of some of these substances, accumulated mainly from small contaminating amounts in food and water. Some 20 tons of DDT residue is contained in the bodies of the people of this country; the average amount for each individual is thus about a tenth of a gram. Measurable amounts of dieldrin and other chlorinated hydrocarbon pesticides have also accumulated in our bodies. Clear-cut adverse effects on health of these small accumulations have not been recognized. However, animal experiments have not yet demonstrated safe levels for some of the more dangerous pesticides.

In the bodies of greenhouse workers, spray pilots, and others who have received occupational exposures, the levels of pesticides are higher than in most of our people. These workers sometimes show marginal or definite impairment of an important bodily function as a result of pesticide exposures.

EFFECTS ON OTHER LIVING ORGANISMS

Why do we care?—Man is but one species living in a world with numerous others; he depends on many of these others not only for his comfort and enjoyment but for his life. Plants provide the principal mechanism whereby energy from the sun can serve the earth's inhabitants. In doing so, they maintain the oxygen content of the air and furnish the basic habitat and food of animals and men. Microorganisms—bacteria, algae, fungi, and protozoa—perform a myriad of essential functions including the purification of air, soil, and water, and the recycling of nutrients. Animals serve man as great converters, changing plant-stored energy into forms of food he prefers and supplying him with a wide variety of materials: leather and furs, oils and pharmaceuticals, ivory and pearls, bristles and wool. Many insects are beneficial, some as pollinators; others as predators on harmful forms; some as makers of silk and honey.

As contributors to happiness and the quality of life, plants and animals provide opportunities for enjoyment of natural beauty, for hunting, fishing, gardening, scientific study, entertainment, and the satisfaction of our human curiosity.

In the control of pollution, plants, animals and microorganisms are directly useful in two ways: First, living things, especially microorganisms, have a capacity for absorption and decomposition of pollutants, with resulting purification of air, water and soil. Second, many species of organisms, each with its own particular range of sensitivity to each pollutant, stand as ready-made systems for environmental bioassay and monitoring, and for warnings of danger to man and his environment.

Because living things are interdependent and interacting, they form a complex, dynamic system. Tampering with this system may be desirable and necessary, as in agriculture, which involves artificial manipulation of the balances of nature on a huge scale. But such tampering often produces unexpected results, or side effects, and these are sometimes very damaging. Many of the effects of pollution fall into this category.

Kinds of effects on organisms other than man.—In small amounts, pollution can produce effects so subtle as to escape notice. Small changes in the reproductive rates of birds or fish, for example, can result from pesticide pollution at low levels, yet be very difficult to detect in

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nature. At high levels, damaging effects of pollution become clearly evident, as when fish are killed in large numbers or bees disappear from a locality.

Pollution affects living things in many different ways: In high concentrations, the sulfur dioxide in stack fumes kills trees and crop plants. The mixture of pollutants in urban smog damages spinach, tobacco, and other valuable plants. Domestic sewage and animal wastes can act as fertilizers, stimulating the growth of algae, but creating unfavorable conditions for game fish. Heating of rivers and lakes by return of waters used to cool industrial processes or power plants can favor some living forms and devastate others. Soils and waters can be polluted by radioactive materials derived from weapons testing, from industrial release, or from naturally contaminated fertilizers or spring waters. Once in soils or water, the radioactivity may then become concentrated in organisms. Sediments released into streams or lakes can reduce the supply of light for plants, and smother fish eggs and other useful forms.

The effects of pollution on livestock and crop plants often show up clearly because farmers quickly notice any impairment of health or yield. Effects on wild forms are much less likely to be detected and are harder to measure. Disappearance or catastrophic diminution of a wild population often occurs before the effects of a pollutant are recognized.

The effects of pollutants on living things are usually complicated and seldom well understood. Organisms are subjected to many different pollutants at the same time, pollutants that may enhance one another, partially compensate for one another, or act side by side.

Because different species react differently, and because the living world is so thoroughly interdependent, pollution produces profound indirect effects. A pesticide directed at a certain insect pest may, as a side effect, destroy a population of beneficial predator insects, so that a population of aphids that the predators had kept small suddenly multiplies and becomes highly destructive. A pollutant may fertilize a lake, creating vigorous algal growth near the surface, which shuts off the supply of sunlight from deeper-growing plants. The latter then consume the oxygen dissolved in the water, so that microscopic animals perish, and fish, depending on them for food and on dissolved oxygen for respiration, either starve or suffocate.

Pollutants tend to reduce the numbers of species, and to make the relationships of those that remain less stable. Large bodies of water, such as Lake Erie, may be depleted of many useful living forms. Pollution typically reduces the variety and abundance of wildlife serving our recreation and enjoyment.

From the economic point of view, pollution may produce serious adverse effects on living things used by man. Useful crops have been damaged by air and soil pollution, valuable commercial fisheries have been destroyed or diminished, as in the Great Lakes, Raritan Bay, and Long Island Sound, and wild populations of game fish and game birds valued for human recreation have been reduced. In a few instances, milk from herds of cattle fed on polluted forage has been so contaminated as to be unmarketable.

IMPAIRMENT OF WATER AND SOIL RESOURCES

Excess fertility in waters.—Many streams, lakes, and estuaries in the United States have received such large quantities of mineral nutrients, originating in sewage or domestic animal wastes, that they have become filled with objectionable growths of algae and other water plants. These commonly result in a deterioration of water quality, making it unsatisfactory for domestic, industrial, and recreational uses, and for fish and wildlife. Hundreds of water bodies, scattered across the nation, are affected to some degree. Only a few outstanding cases—some of the Great Lakes, Lake Washington, the Potomac and the Mississippi—have received much public attention. In rivers, pollution from excessive nutrients is most common below the waste discharge points of large cities.

Nitrates and phosphates derived from human and animal wastes, detergents, and agricultural fertilizers, are the most noticeable causes of overfertilization of waters, though other nutrients may possibly be important.

Soil pollution.—Soil pollution impairs the yield or the quality of farm products, and can contribute to subsequent air or water pollution.

Long-term pollution of soils has resulted from repeated application of copper, arsenic, or lead in insecticides, fungicides or fertilizers: The accumulation of poisonous metals has been so great in some orchard soils as to destroy for a period of many years their capacity to raise any useful crop. The yields of certain cotton soils have decreased because of arsenic accumulations. Since the most serious problems have come from the heavy metal insecticides, whose use has recently been greatly reduced, future losses are unlikely to be nearly as serious.

Chlorinated hydrocarbon insecticides, such as DDT, dieldrin, and endrin, can also accumulate in the soil. In extreme cases, the accumulations may be so great as to reduce yields of useful crops. More often, the contaminants appear in human food in detectable amounts either by absorption or surface adhesion. Such pollutants can impair the flavor of food products. Their concentration can approach or even exceed the levels allowable under Food and Drug regulations, causing losses of alfalfa, potatoes, carrots, and beets. The life of chlorinated hydrocarbons in soil is shorter than that of metals, the more persistent ones probably diminishing to very low levels in a few years or at most in one or two decades.

Herbicides may persist in the soil and injure crops months or even years after application. Since most herbicides have a relatively short life in soil, long-term losses of soil usefulness are not likely.

Radioactive substances derived from uranium in some phosphate ores may survive the manufacturing process and persist in the finished commercial phosphate fertilizer. Where such fertilizer is repeatedly applied, radioactive decay products accumulate and can be picked up by roots and transferred throughout the plant. Polonium and radium apparently reach tobacco leaves in this way.

The concentration of salt in river waters used for irrigation is increased by evaporation from reservoirs, canals, watercourses, ditches, and irrigated fields, and frequently also by the inflow of salty tributaries or groundwaters, often to the point where the water, as it flows downstream, becomes hazardous for irrigation. If the water is high in sodium, this element tends to accumulate in the clay fractions of the soil, causing excess alkalinity and swelling of the clays. The soil then becomes only slightly permeable to water, and useful crops cannot be grown. Even in the absence of excess sodium, irrigation sometimes deposits so much salt in the soil as to impair crop yields, but if an excess of irrigation water can be used, these salts can be flushed away.

POLLUTING EFFECTS OF DETERGENTS

The large scale use of synthetic detergents during the past two decades has caused foaming and overfertilization.

Polyphosphate detergents, after domestic or industrial use, are carried in sewage effluents into rivers, lakes, and estuaries, where the phosphate is readily taken up by algae and other aquatic plants. If present in sufficient quantities, such detergents can give rise to obnoxious algal blooms.

Many detergents survive for long times in surface and ground waters because they contain hydrocarbon chains that are not easily decomposed by aquatic bacteria and other microorganisms. These long-surviving detergents tend to accumulate in rivers, lakes, and estuaries, and to reenter domestic and industrial water supplies. In both situations they may produce troublesome foaming. Effective detergents based on other hydrocarbon chains that are readily decomposed by aquatic organisms can now be manufactured economically. Although these degradable detergents have some toxicity for fish, they disappear fairly rapidly from surface and ground waters. Hence they do not accumulate in such high concentrations as the stable hydrocarbon detergents, and they carry a less durable pollution penalty. Most detergents now marketed in this country are of the degradable type. As the older detergents move through the ground water and down our streams, difficulty with foaming will slowly disappear.

DETERIORATION OF MATERIALS AND URBAN ENVIRONMENTS

Airborne soot deposited on buildings, clothing and automobiles, raises maintenance costs by necessitating frequent cleaning and makes our lives more dingy and depressing. Certain gases, such as hydrogen sulfide, darken paint, while others, such as sulfur oxides, accelerate the weathering of buildings and statues. Coal mine effluents flowing into rivers and harbors are often so acid that they corrode ships' hulls, as well as destroying water life. Other materials, such as phenols, may lend taste or odor to water and require additional treatment steps for municipal water supplies.

The particles of soot and smoke that dirty our cities also lower visibility, obscure attractive views, give gray casts to our days, and make travel more hazardous.

The unpleasant odor of a rendering plant, the noise of a jet airplane or of the the other fellow's transistor radio, disorderly jumbles of auto hulks, unsightly trash in a dump, all are irritating and offensive. All will require increasing attention.

CLIMATIC EFFECTS OF POLLUTION

Carbon dioxide is being added to the earth's atmosphere by the burning of coal, oil and natural gas at the rate of 6 billion tons a year. By the year 2000 there will be about 25% more CO_2 in our atmosphere than at present. This will modify the heat balance of the atmosphere to such an extent that marked changes in climate, not controllable though local or even national efforts, could occur. Possibilities of bringing about countervailing changes by deliberately modifying other processes that affect climate may then be very important.

The Sources of Pollution

Deliberate disposal of wastes is a more or less systematized activity. Most such wastes are not toxic, though some may carry disease. But odors, excess fertility of waters, and offenses against natural beauty are widespread.

MUNICIPAL AND INDUSTRIAL SEWAGE

Two-thirds of the U.S. population, about 125 million people, are served by domestic sewers. Sewage from about one-tenth of these people is discharged raw and that from more than another quarter after only primary treatment. In communities with combined sewers, even if treatment plants are otherwise satisfactory, storm water from heavy rains overwhelms the capacity of treatment plants, and considerable amounts of sewage are discharged raw. Separate sewer systems for storm runoff and for sewage, which lead only sewage to the treatment plant and permit storm runoff to bypass it, avoid this discharge. Few of our older cities have such separate sewers, however, and conversion of old systems will be very costly. Even when separate systems are installed, runoff washes oil, gasoline, accumulated street debris, and surface filth into the untreated outflow. In total, sewage discharges correspond to the raw sewage from almost 50 million people.

Sewage effluents, whether or not treated, carry considerable quantities of phosphorus, nitrogen, and other plant nutrients and are a principal source of the damaging overfertilization of rivers, lakes and estuaries mentioned above. In recent years the phosphate content of these effluents has been rising appreciably, presumably because of use of phosphates in detergents.

ANIMAL WASTES

The excreta of farm animals are a major source of water pollution, entering streams, rivers or lakes either in surface runoff or through underground seepage, and posing hazards to human and animal health from pathogens common to animals and man. In some waters, pollution from farm animal manure has caused fish kills; elsewhere it has resulted in extensive damage to oyster and other commercial shell fisheries.

Odor and fly problems arising from waste accumulations are especially acute in the feedlot finishing of beef cattle and the mass production of poultry, and are made more critical by the encroachment of suburbs into what were farming areas.

URBAN SOLID WASTES

A frequently quoted estimate for the annual output of urban solid wastes, containing such things as paper, grass and brush cuttings, garbage, ashes, metal, and glass, is 1600 pounds per capita. Currently, this means 125 million tons each year, whose collection and disposal costs about 2.5 billion dollars a year.

MINING WASTES

Large quantities of solid wastes result from mining. In the United States during 1963, more than 3.3 billion tons of waste rock and mill tailings were discarded near mine sites. In addition, the refining of ores, the combustion of coal, and the production of metals and nonmetallic materials result in building vast mountains of slag, ash, and other waste material.

CONSUMER GOODS WASTES

A large fraction of all consumer goods ends up as urban solid waste, though significant amounts are salvaged and recycled back to industry.

Scrap iron and steel are generated at a rate of 12 to 15 million tons a year, of which about a third consists of derelict automobiles. The fraction recovered for use has declined substantially. Recovery of other scrap metals in 1963 included at least 974,000 tons of copper, 493,000 tons of lead, and 268,000 tons of zinc.

From 25 to 30 million tons of paper products produced annually, about 10 million tons of waste paper were salvaged in 1964 and used to make new paper. In 1962, about 263,000 long tons of reclaimed rubber were used in the United States, about 15 percent of all rubber. The same year about 10% of the 8 billion pounds of plastics produced was recovered and reconverted.

Each year we must dispose of 48 billion cans (250 per person), 26 billion bottles and jars (135 per person), 65 billion metal and plastic caps and crowns (338 per person), plus more than half a billion dollars worth of miscellaneous packaging material.

Only a small part of our solid wastes is salvaged and processed for reuse, even though the industries engaged in reprocessing waste materials operate at a level of 5 to 7 billion dollars a year. The unsalvaged remainder represents a vast potential for litter and pollution.

UNINTENTIONAL RELEASES

Almost every action of man releases some materials that may spre into the environment and become pollutants. Many of these mater are increasing in abundance, and are causing problems of growing severity, because the capacity of the environment to absorb and neutralize them does not change. Where deliberate disposal is somewhat systematized, accidental release, except in special circumstances, is catch as catch can.

The combustion of coal, oil, and gas in our homes, vehicles, and factories results in the discharge into the air of sulfur dioxide, carbon dioxide, carbon monoxide, oxides of nitrogen, and partially burned hydrocarbons. Some of these gases, together with gasoline and natural gas vapors, undergo chemical change in air and in sunlight, and become the noxious constituents of smog; others, like carbon dioxide, are accumulating in such large quantities that they may eventually produce marked climatic change. Large amounts of lead are dispersed into the atmosphere from motor vehicle exhausts. Indeed, the pollution from internal combustion engines is so serious, and is growing so fast, that an alternative non-polluting means of powering automobiles, buses and trucks is likely to become a national necessity.

Particulate by-products, such as asbestos fibers from brake linings and fly ash from chimneys, are giving rise to increasing concern, because of their possible effects on human health. Pesticide mists and dusts often drift beyond the areas of application. Salts and agricultural chemicals may be dispersed by irrigation or drainage waters.

Many of these pollutants released unintentionally or as a by-product are long-lasting, come from a multitude of sources, and are subject to transportation over great distances in air, water, or living organisms. All three characteristics make them very difficult to control.

In Which Directions Should We Go?

Pollution touches us all. We are at the same time pollutors and sufferers from pollution. Today, we are certain that pollution adversely affects the quality of our lives. In the future, it may affect their duration.

Present levels of pollution of air, water, soils and living organisms are for the most part below the levels that have been demonstrated to cause disease or death in people. At the same time we recognize a number of episodes where air pollution has caused deaths, where disease has been spread by water, where accidental poisonings have occurred from pesticides. The documented cases of pollution-caused injuries to plants, fish, birds and mammals are extensive and the economic loss from these injuries has been considerable. Some waters no longer support any useful fish or invertebrates. Some areas have been rendered unsuitable for useful plants. Many natural waters throughout the country are becoming continually less beautiful and less usable. Air in some of our cities is unpleasant to breathe and obscures our surroundings; our buildings are dirtied and sometimes rapidly weathered. Pollution has denied to some of our farmers the most desirable uses of parts of their lands. Prudence and self interest dictate that we exert ourselves not only to prevent further buildup of pollutants but to reduce present burdens of pollution in our air, our waters, and our land.

Arrangements to deal with pollution have grown on a piece-meal basis, with organizations, programs and legislation created when problems became evident or critical. With this background it is not surprising that current organization is a hodge-podge, with responsibilities widely separated among government agencies, and some unassigned. Some pollutants are dealt with on the basis of the environmental medium in which they occur, for example, pollutants in air and water; others are dealt with on the basis of the kinds of effect they have, for example toxic materials in food; some are dealt with on the basis of their sources, for example artificially radioactive materials.

With some pollutants there is no Federal authority to act until a problem exists. Such is the case with water pollution and air pollution. With some pollutants there is no Federal authority to act at all, as is the case with pesticide residues on tobacco. With some pollution problems existing Federal authorities constrain the type of action that can be taken, as with water pollution problems that can be approached by the Corps of Engineers only through providing excess water storage for low-flow augmentation (usually a costly and inefficient process). With some pollutants such as radionuclides, extreme caution is exercised to assure that unwanted effects in the environment will be prevented; with other materials, such as pesticides, consideration of side effects has been scant in the past.

The situation at the Federal level is more or less duplicated in the states and other jurisdictions.

Careful attention to organization of pollution-related activities in the Federal Government, to the relation of Federal activities and organizations to other political jurisdictions, and to the relations among agencies below the Federal level will be necessary to enable us to cope with pollution in the future.

There are many areas in which ignorance constrains our ability to deal effectively with pollution problems. Examples lie in the deficiencies of our knowledge of the behavior of important carriers of pollution, such as atmospheric gases, surface and ground waters, oceanic currents, and soil particles. Basic research on these topics is necessary in order to clarify our understanding of the movement of pollutants. Some pollutants are carried extensively in living things, moving from one plant or animal to another as food, moving from place to place with the plant or animal. Such movements of pollutants in and through living organisms are important, for example, when we consider means of protecting wildlife, fisheries, and shellfish from pollution. Basic ecological research is necessary if we are to cope effectively with these serious problems.

We now know that the full effects of environmental changes produced by pollution cannot be foreseen before judgments must be made. The responsible judgment, therefore, must be the conservative one. Trends and indications, as soundly based as possible, must provide the guidelines; demonstration of disaster is not required. Abnormal changes in animal populations, however small, at whatever stage in the life history of the individual, or in whatever niche of the species complex, must be considered warnings of potential hazard.

Many kinds of pollution problems could be prevented by the exercise of ecological foresight. Given a reasonable knowledge of persistence, biological effect and expected initial distribution and amount, at least part of the impact on living things can be predicted. In the future, such advance evaluations will be essential.

Disposal of wastes is a requisite for domestic life, for agriculture, and for industry. Traditionally waste disposal was accomplished in the cheapest possible way, usually by dumping in the nearest stream. This tradition is no longer acceptable—we believe industrial and agricultural waste disposal must now be accomplished in such a way that pollution is avoided, and that the higher costs of such disposal should be borne by industry and agriculture, and considered as a part of the cost of operation. The pressure to pollute in the past has been an economic one; the pressure to abate must in the future also be economic.

Much can be done by enforcement of today's regulatory laws, and by modifying the administrative policy under which Federal assistance is provided. For example, pollution from farm animal wastes could be alleviated by vigorous enforcement without technological advances. The same is true of particulate materials in air and sewage effluents in water.

As a basis for pollution abatement, we need to establish environmental quality standards. Such standards imply that the community is willing to bear certain costs or to enforce these costs on others in order to maintain its surroundings at a given level of quality and utility. For each pollutant the elements that must be taken into account are: its effects; technological capabilities for its control; the costs of control; and the desired uses of the resources that pollutants may affect.

These complex problems cannot be handled without a sufficient number of trained technicians, engineers, economists, administrators and scientists, and without the requisite scientific, technical and economic knowledge. The manpower and knowledge now at hand are insufficient for the complete task, though much can be accomplished with present resources. Our government has a clear responsibility to insure that persons of ability and imagination are attracted into this broad field and trained in its intricacies, and that scientists and engineers are enabled to produce the knowledge and technology that will give the people of our country a clean, healthy, and happy environment.

Recommendations

A. PRINCIPLES

We recommend that the following principles be accepted federally, locally, and nationally:

A1. *The public should come to recognize individual rights to quality of living, as expressed by the absence of pollution, as it has come to recognize rights to education, to economic advance, and to public recreation.* Like education and other human rights, improved quality of life from reduced pollution will be costly to individuals and governments.

A2. *The responsibility of each pollutor for all forms of damage caused by his pollution should be effectively recognized and generally accepted. There should be no "right" to pollute.*

A3. *The roles of all governmental authorities, local, state, and Federal, in pollution problems should be complementary and mutually supporting.* While enforcement of pollution control is primarily a regional, state or local responsibility, there is much that the Federal Government can and should do to support and supplement regional, state, and local actions.

A4. *Federal agencies should give special attention, in all operations they conduct, support or control, to avoiding and managing pollution, both to reduce it and as an example to others.* State and local agencies should follow the Federal example as rapidly as possible.

A5. *All agencies and organizations concerned with pollution should strengthen programs that lead to better public understanding of pollution and its problems.* Today there is particular need for better understanding of the nature and extent of soil contamination and of the nature of the values currently damaged by pollution.

A6. *All concerned should recognize the quality of human life and the presence and growth of other living things as the major values currently damaged by pollution.* Many threats to human health have been recognized and largely controlled. While more subtle human effects are possible and should be sought for, demonstrable threats to human health constitute a small part of today's damage from pollution.

A7. *The special importance of the automobile as a source of pollution problems should be clearly recognized.* The automobile is our most rapidly growing cause of many and diverse pollution problems.

A8. *As our pollution problems become steadily more serious, it should be generally recognized that we must consider our balances and choices within successively larger and more complex systems.* Garbage disposal by burning, land fill, or household grinding, for example, sends the resulting pollution to our air, to our soil, or to our waters. In the last analysis, we cannot treat even these three broad classes of pollution separately.

A9. *Each department or agency having responsibility for both enforcement and research in pollution should provide administrative and budgetary separation sufficient to minimize interference between its research and development activities on the one hand, and its investigative and enforcement activities on the other.* While due regard for the advantages of mutual support is essential, smooth functioning of enforcement and control, combined with minimum interference with research, requires adequate separation.

A10. *In making decisions about resource use and community development, including transportation systems, urban renewal, irrigation, drainage, and agricultural practices, information about effects and behavior of pollutants should be an essential consideration.* The effects of pollution, both close at hand and far away, should not only be discussed, but should be part of all comparisons of costs and benefits.

A11. *The filling in of shallow waters essential in life cycles of fishes and shellfish be regarded as an important kind of pollution.*

A12. *The control of pest populations should increasingly depend on an integrated combination of pesticide use with a wide variety of bio-environmental techniques.* The increasingly serious problems of pest control cannot be solved by excessive reliance upon pesticides, biological control, or any single available technique. For success in developing reasonably long-term rather than extremely short-term solutions to these problems, all available techniques must be integrated into a unified approach.

A13. *Unnecessary use of pesticides should be avoided whenever possible.* Pesticide use is necessary under many circumstances, but is almost invariably accompanied by undesirable side effects, and often by hazards. Accordingly, we should always use pesticides no more frequently and in no larger quantities than we must.

B. ACTIONS

B1. *We recommend that careful study be given to tax-like systems in which all polluters would be subject to "effluent charges" in proportion to their contribution to pollution.* Federal and local efforts to reduce pollution of air, soil, and water have traditionally rested upon a mixture of prohibitory regulation and persuasion. The public interest can often be served by reducing pollution below the levels where these means are appropriate and effective. Effluent charges have enhanced effects because individual polluters always have a prospect of financial gain from further reductions in their contribution to pollution.

B2. *We recommend that the U.S. Department of Agriculture require and use, as one of the bases necessary to support registration of a pesticide, information on the persistence and fate of the chemical in all relevant segments of the environment.* Present registration procedures take account of persistence as related to tolerances on food, but have not always done so for non-food uses, or for uses that might result in food residues in years subsequent to the use of the material. (See also Y1.)

B3. *We recommend that the Department of Agriculture require that reregistration proceedings of agricultural pesticides at prescribed intervals be conducted with the same thoroughness and rigor as were used for the initial registration and without prejudice from the approval of registration for the previous term.* Present registration procedures call for reregistration of pesticides at 5-year intervals. Review of data tends, unless specific problems are known to have arisen during the time the preceding registration was in effect, to be less rigorous at the time of reregistration than during initial registration. Special steps are necessary to assure that review of data at reregistration does not become perfunctory.

B4. *We recommend that the Department of Agriculture implement fully the principle that—in all proceedings concerning the registration of pesticides for agricultural use, whether the registration be initial, or at the prescribed interval for reregistration, or questioned or reopened because of new evidence—the burden of proof is deemed to fall on the registrant.* Even though the intent of the present law is clear, the finding of new evidence that casts doubt on the validity of the registration and causes registration to be re-examined is, in fact, too frequently taken to require the Department to be able to prove that the registration is not valid, thus effectively shifting the burden of proof.

B5. *We recommend that the Department of Agriculture take all possible steps to encourage modification of present pesticide practices by—*

(a) *Replacement of wasteful "routine-treatment" schedules by "treat-when-necessary" schedules.*

(b) *Recognition that 100% control of most pests is not required to prevent economic losses.*

For example, substantial reduction in insecticide use, in specific cases as much as 50%, can be made by applying our present knowledge of pests and their control. Treat-when-necessary spraying often requires more judgment, but lowered costs for pesticides can often make the provision of specialized advice economically worthwhile. (See also Y11.)

B6. *We recommend that the Federal Aviation Agency condition its issuance of licenses for aerial application upon demonstrated familiarity by the licensee with the precautions necessary for avoiding hazards, that such licenses require use of pesticides in accordance with USDA registered labels, and that they be subject to suspension or revocation for uses not authorized on pesticide labels.* Increasing amounts of pesticides are applied from the air by flyers subject to Federal Aviation Regulations. Nearly 6000 aircraft are now involved. Pesticides sold in interstate commerce must be registered for specific uses and bear approved labels with suitable instructions for use and precautions as to safety. Not all major pesticide misuses occur in aerial applications, but those that do could easily be brought under Federal control.

B7. *We recommend that the principle of requiring registration before use should be extended to the addition to motor fuels of substances which are not eliminated by the combustion process.* Widespread use of automobiles has made motor fuels the single most effective way to expose almost all our people to air pollution from combustion-resistant substances such as metals, and, as well, to escaped gasoline and combustion products. Lead has long been an additive, one whose environmental concentrations before leaded gasoline were never adequately measured; phosphorus and boron have been added for a few years; nickel is now beginning to appear. (See also X6.)

B8. *We recommend that the U.S. Public Health Service intensify its surveillance of body burdens of lead and trends of lead in air, water, food and, in cooperation with the Department of Agriculture, in soil.* The toxic properties of lead have been recognized since ancient times, and lead continues to be one of the major occupational poisons. The average person has a substantial amount in his body from absorption of lead through the lungs and intestinal tract. In persons heavily exposed to automotive exhausts, the body levels approach the concentrations known to have deleterious effects. The steadily increasing use of leaded gasoline calls for continuing assessment of levels in the environment and in human body fluids. (See also B9, Y1, and Y2.)

B9. *We recommend that a pilot survey and studies be made to assess the significant methods of entry and the accumulation of lead from vehicle exhausts in various soils and plants, especially those located close to heavily travelled highways.* The Department of Agriculture, in collaboration with the Public Health Service, should conduct the survey and studies. (See also B8, Y1, and Y2.)

B10. *We recommend that a tax be devised to provide an incentive for eliminating the long-term storage or holding of junk automobiles.* An annual Federal or state license might be imposed on all automobiles except those currently licensed for road use; or a personal property tax might be placed upon junk cars. A tax approach has fewer difficulties than any of the subsidy approaches considered by the Panel. A national eye-sore results from the storage, until such times as the scrap steel market makes it profitable to sell them, of automobile hulks which have already been processed for removal of spare parts. Speeding the processing will reduce the number of hulks in storage and simplify screening of the necessary remnant. (See also Y5.)

B11. *We recommend that an appropriate ad hoc group of Federal, state and local officials be established to determine how best to attack the problems caused by the outmoded combined sewerage systems in the great cities of the United States.* This group should give particular attention to research, development and demonstrations needed to reduce combined sewer problems. They should also consider cost-sharing arrangements for different projects and mechanisms for coordination and review. (See also Y6.)

B12. *We recommend that the Department of Housing and Urban Development direct a substantial proportion of its support for community facilities to assisting cities to use present technology to clean up such obviously critical solid waste practices as open dump burning and unsanitary land fill.* Consideration should be also given to maximum use of these funds to encourage innovation in coping with solid wastes disposal problems. (See also Y5.)

B13. *We recommend that Federal agencies participating in city and regional planning and development insist that minimization of pollution be a required goal.* Planning for cities and regions has achieved increased importance in recent years, but most of the emphasis has been placed on land use, distribution of residences and businesses, parks and greenbelts, transportation and location of industry. Insufficient attention has been paid to waste disposal and to the provision of measures which will minimize air, water and soil pollution. Planning for cities and regions should include effective measures for disposal of wastes without causing unnecessary pollution. (See also X5 and Y5.)

B14. *We recommend that the Federal Government, in its own facilities and in those that it contributes to financially, take such measures as are necessary to insure that provisions for waste disposal are adequate to minimize pollution of air, water, and soil.* The government itself builds a large number of installations such as military bases, hospitals, office buildings, power plants, research laboratories, and the like. Moreover, the Federal Government contributes funds to construction projects undertaken by states, municipalities, universities, school districts, and defense industries. All such facilities should be planned and constructed to minimize the contribution of waste disposal to all forms of pollution.

B15. *We recommend that Federal agencies neither expend funds on or grant financial aid to any construction project or program which does* *not include effective measures for minimizing the production of dust and sediment.* Temporary disturbance from highway and building construction now contributes large amounts of sediment, in some watersheds more than half the total. Much of this can be prevented.

B16. *We recommend that, especially in marshlands and coastal areas, minimizing the impairment of natural drainage patterns should be an important consideration in the building of Federally-supported highways.* These areas are remarkably productive, some producing six times as much organic matter per acre as average wheat land. Nearly 60% of our total harvest of sea foods (which supports 90,000 commercial fishermen) depends on these areas; unnecessary alterations can, through pollution, destroy this food supply and degrade important recreational resources. (See also Y10.)

B17. *We recommend that funds be made available to acquire title, either directly or through the states, to important coastal marshes, lagoons and estuaries which could then serve incidentally, as national and state parks, national monuments, wildlife refuges and public recreational areas.* Critically important protection against pollution can be combined with preservation of some natural areas as well as changes in others to allow intensified recreational and other uses. (See also Y10.)

B18. *We recommend that interstate and Federal-state river basin development compacts and agreements cover related estuaries and marshes.* Many marshes and estuaries lie at the mouths of large river systems or are measurably influenced by the effluents from such systems. Prevention of pollution and other destructive changes in these water bodies should be one of the most important elements in Federal-state river basin development. Although their importance as breeding grounds for fish and shellfish is less obvious, similar considerations apply to the shallow inshore waters of the Great Lakes. (See also Y10.)

B19. *We recommend that the Federal Government, working in cooperation with the states, encourage formation of unified authorities for planning and carrying out the optimum development of waters and marshes that are threatened by destructive encroachment or severe pollution.* San Francisco Bay, the Great Lakes and New York Harbor are examples where planning has been retarded by the existence of multiple local governments along the shores. In many cases state or Federal participation in such authorities is needed to reflect the interests of those who, though they live at a distance, will suffer from the destruction of the area, perhaps through effects on fish and shellfish populations. (See also Y10.)

B20. *We recommend that the Federal Government, working in cooperation with the states, encourage the formation of compacts and unified authorities to deal with air pollution within natural airsheds.* The boundary-crossing nature of water pollution has long been recognized

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through the development of interstate compacts and river-basin authorities. The growing extent of air pollution has now made similar actions important with respect to airsheds. (See also X5.)

B21. *We recommend that the Department of the Interior undertake a new program, which is likely to require the establishment of an appropriate organization, for gathering and making information available about effects of environmental changes on those lands and waters that are peculiarly its responsibility.* Knowledge needed to protect man, domestic animals, and crops seems to be rather adequately circulated, at least within the Federal Government. By contrast, there seems to be no adequate provision for either securing or distributing necessary information relating to most other living organisms, especially those inhabiting our broader and less-populated lands and waters. (See also C4 and Y10.)

B22. *We recommend that Federal agencies concerned with water quality should make detailed studies of the sources of salt coming into our western rivers and should seek ways of isolating these sources from the rivers wherever possible.* (See also Y1.)

B23. *We recommend that water quality as well as water quantity be taken into account in the planning and design of river basin developments in the arid and semi-arid regions of the United States.* Because the value of irrigation water diminishes as its salt and particularly its sodium content increases, greater emphasis should be placed on water quality by Federal and state agencies in the planning and design of river basin developments in the arid and semi-arid regions. In all cost-benefit computations, reductions in downstream salinity should be valued alongside increases in available waters. (See also Y1.)

B24. *We recommend that the amelioration of salinity problems be taken into account in formulating agricultural policies.* Incentives or controls which tend to reduce the number of cultivated acres, and the acreage in crops with a long growing season will, by reducing total consumptive use of water be beneficial in minimizing salinity problems. (See also Y1.)

B25. *We recommend that issuance by the U.S. Army Corps of Engineers of permits for dredging, and decisions concerning the Corps' own operations, be conditioned on the anticipated effects on all resources, not on effects on navigation alone.* Dredging authorized by permits may, and often does, have disadvantageous effects on other resources, both in the areas from which spoil is removed and in those where it is deposited. Other resource agencies, Federal, state and local, should participate effectively in decisions related to issuance of permits for dredging, or to direct operations by the Corps.

B26. *We recommend that efforts be increased to establish the scientific bases upon which standards of environmental quality can be set.* There is at present a great lack of exact information on the impact of environmental factors on people and other living things. A great deal of intensive research will be required to establish the relations between levels of pollution and consequences. This information is essential to the establishment of standards, which provide the intended balance between protection of the community and the economic burden upon those whose easiest course is to pollute. (See also Y2 and Y10.)

B27. *We recommend that the Public Health Service encourage and lead major engineering and scientific organizations and societies to work actively, both on their own account and as advisors to the Federal Government, on problems related to standards of air quality.* The problems of adjusting standards to what is reasonable and possible as well as desirable or necessary involve many diverse technical problems, in which engineers and scientists can contribute much. Moreover, the experience and knowledge gained in such discussions as representatives of professional groups often spreads to those professionally concerned with the actions that must be taken by individual pollutors to abate or control pollution. Professional involvement has been notably less for air pollution than for water pollution. (See also X4.)

B28. *We recommend that the Federal Government encourage the development and adoption of codes governing noise insulation in apartment buildings.* Pollution of apartments by noise from either adjacent tenants or outside sources is a national commonplace. At least two countries have effective codes regulating this problem. Local governments should have access to codes which they can adopt with adequate reliance on both their effectiveness and their reasonableness.

C. COORDINATION AND SYSTEMS STUDIES

Organization for cooperation in identifying both new pollution problems and new aspects of old ones, and for accumulating and distributing information about pollutant effects needs to be strengthened. Broader studies of pollution from waste disposal, combining aspects usually studied separately, are now essential.

C1. *We recommend that the following steps be taken to provide for early identification of broad problems involving pollution and to avoid gaps and imbalances in their study:* (a) *The Federal Council for Science and Technology should establish a Committee on Pollution Problems, composed of its own members.* (b) *The National Academy of Sciences-National Research Council should be asked to establish an Environmental Pollution Board, to be supported by government grant.* (c) *This NAS-NRC Board should meet jointly with the FCST Committee at least once a year to discuss newly recognized broad problems and current changes in the apparent importance of those previously rec-*

ognized. (d) *This Board and Committee should cooperate, through working-level mechanisms such as joint panels, to identify the most pressing broad problems, and the general character of new knoweldge or techniques needed to study or ameliorate them.* (See also X2.)

C2. *We recommend that the Department of Agriculture establish an appropriate unit to assess the pollution status of the Nation's soils, to correlate all research, control, abatement, and monitoring concerned with soil pollution, to make suggestions as to new or additional courses of action, and to report their findings annually to the Congress.* No broad gauge, systematic evaluation of the status of the contamination of soils now exists. Since soil pollutants are subject to absorption by plants which serve as food for man and animals, a knowledge of their distribution and content is essential. (See also Y1.)

C3. *We recommend that there be established a policy-level interagency committee to bring together those facts about Federal programs of financial aid to local governments in connection with waste disposal that are needed to ensure that these programs are consistent in goals, are in technical balance, and are collectively directed toward the problems of greatest national concern.* The Departments of Health, Education, and Welfare, Commerce, Housing and Urban Development, the Interior, and Agriculture should be represented; the Bureau of the Budget might provide a Chairman. Estimates of required expenditures to provide secondary treatment of wastes for 80 percent of our population by 1975 are on the order of $20 billion, of which Federal funds will be a substantial part. Because the Federal financial aid related to pollution abatement is dispensed by so many agencies there are possible overlaps and conflicts.

C4. *We recommend that the Departments of Health, Education, and Welfare, Agriculture, and the Interior establish and improve procedures for making available, through various government and private mechanisms, information needed to protect man, domestic animals, crops, and other living organisms from pollution.* It is especially important to provide this information to those who have the responsibility for making decisions relating to pollution, its control and abatment. (See also B21 and Y10.)

C5. *We recommend that the National Academy of Sciences and the National Academy of Engineering jointly undertake, with Federal support, an intensive study of the broad area of disposal of sewage, trash, and garbage, emphasizing both a systems approach and the types of innovation needed to give stimulus to solid waste technology.* Even a brief examination shows that many interesting possibilities have not been explored to the point where we can balance their advantages and disadvantages in dealing with increasingly serious problems. (See also Y5.)

C6. *We recommend that the NAS–NAE jointly undertake a similar study of sewage treatment and water supply as a single combined system.* We have realized for many years that the water intakes for downstream cities are often largely supplied by the sewage outfalls of upstream cities, yet we have not tried to face the purification of wastes and supply of water as a unified problem.

C7. *We recommend that, after the completion of these two studies, the NAS–NAE jointly undertake an intensive study of the interaction between various disposal systems as they affect the inter-relationship of solid, liquid and gaseous pollution of the environment.* One of the most prominent results of any study of pollution as a whole is the extent to which we must and do choose between polluting the air, or the water, or the land. As soon as somewhat broader foundations are available, an initial study of the combined system can contribute much to our guidance.

D. BASELINE MEASUREMENT PROGRAMS

In addition to continued and expanded monitoring of those portions of the environment where dangers to health, life, and amenities are judged to require particular attention, there are needs for year-by-year information on the average condition of our environment, on atmospheric changes possibly affecting climate, on baseline values for pollutants just entering a period of growth, and on natural populations in relatively unpolluted areas.

D1. *We recommend that—*

(a) *Immediate steps be taken to plan and institute a National Environmental Quality Survey, which would provide benchmark data on the average condition of the environment of the people of the United States as a whole.*

(b) *An agency should be set up to carry out planning, including sample design, and analysis of the National Environmental Quality Survey. This agency should be isolated from all enforcement or action programs and should make the greatest possible use, through transfer of funds, of expertness in carrying out measurements of environmental quality already developed in Federal, state and local governments.*

(c) *Because of clear separation from enforcement and action, and because of long experience with sampling design and analysis, particular consideration should be given to setting up this agency in the Department of Commerce.*

Today no agency or program is concerned with the average condition of our environment, yet we have recognized pollution as a national problem and its abatement and control as national goals. If we are to recognize how fast we are gaining or losing in this struggle we need measurement of both where we stand and where we once stood. (See also Y3.)

D2. *We recommend that the Environmental Sciences Service Administration and its collaborators continue, for at least the next several decades, their series of precise measurements of the CO_2 content of the atmosphere.* Within a few generations we are burning the fossil fuels that were laid down in the earth over 500 million years. About half of the CO_2 (carbon dioxide) produced remains in the atmosphere, where its effects on our climate are likely to be significant. We need to know how fast the atmospheric share increases. (See also Y4.)

D3. *We recommend that temperatures at different heights in the stratosphere be routinely monitored on a world-wide basis.* The influence of CO_2 content on the balance between heat received from the sun and heat radiated to space is important to us because it changes the average temperature of the air near the ground. Average temperatures in the stratosphere will change many times as much. Monitoring stratospheric temperatures offers earlier measures of over-all effect and further insight into its details. (See also Y4.)

D4. *We recommend that the opportunity of measuring baseline values for concentrations of nickel and its compounds in the atmosphere be seized now before the use of this motor fuel additive becomes more extensive.* It is important to establish the present levels of this element in the environment and in the human body, so that we may detect and follow any increases with confidence.

D5. *We recommend that quantitative baseline population densities be established by systematic sampling of certain natural populations in diverse relatively unpolluted habitats to establish a basis for comparison with populations under pollution stress.* Today it is difficult to recognize that a natural population is under severe stress, unless that stress is so severe as to bring it close to regional extinction. Baseline density information is needed if we are to detect stresses with important consequences. (See also B21 and Y10.)

E. DEVELOPMENT AND DEMONSTRATION

There are many opportunities to combat pollution through refinement or further development of existing technology and adoption for use of the improved methods or equipment.

Development of improved equipment and methods for pollution control will only be useful if the developments are applied. Demonstrations and full-scale trials, supported or insured with Federal funds, will be essential in many cases since there will be risks, real or imagined, of unsatisfactory operation. This is particularly true when these developments are for use by municipalities or individuals.

E1. *We recommend that the Federal Government exert every effort to stimulate industry to develop and demonstrate means of powering automobiles and trucks that will not produce noxious effluents.* Less complete steps to reduce pollution from automobile exhausts will certainly play an important role. We must strive for more acceptable mass transportation. We must follow carefully the results of California's imposition of special regulations, and be prepared to extend those that prove effective to other smog-ridden localities. But we must also be prepared, as soon as reasonably may be, to take more drastic action if, as, and when necessary. The development of alternative means of mobile energy conversion, suitable for powering automotive transport of all kinds, is not a matter of one year or a few years. Thus, if fuel cells, or rechargeable batteries, or other devices are to be developed in time to meet the increased threat, we need to begin now. (See also X6.)

E2. *We recommend that the Federal Government stimulate industrial development of more economic processes for exclusion of sulfur compounds from stack effluents.* Oxides of sulfur constitute a major source of air pollution in this country because large quantities of sulfur-containing coal and oil are used for fuel. Removal is becoming a matter of increasing importance; less costly means of removal will contribute to lessening pollution. (See also X6.)

E3. *We recommend demonstration of the feasibility and economy of new developments for abating or controlling pollution through their use at Federal installations.* Opportunities exist, for example, at the coal-burning generating plants of the Tennessee Valley Authority, and at large military installations which have many of the complex waste disposal problems typical of urban places. (See also Y5.)

E4. *We recommend stimulation by the Federal Government for development of container materials which have adequate storage life, but which will degrade rapidly when discarded.* The accumulation of present types of non-reused containers, whether made of metal, glass, or plastic, is a substantial and difficult part of the solid waste problem. The development of containers with adequate storage life which will nevertheless degrade rapidly when discarded is not likely to be an easy task, but the advantages of success are great. (See also Y5.)

E5. *We recommend that the Federal Government, through the Department of Agriculture, the Agricultural Experiment Stations, and private industry accelerate the development of improved equipment and* *methods for applying pesticides more selectively.* Such equipment and techniques will allow for adequate or even improved pest control yet lead to a decrease in total environmental contamination. (See also Y11.)

E6. *We recommend that the Department of Agriculture engage actively in the development and demonstration of new or better equipment and methods for the handling, treatment and use of farm animal wastes.* Disposal of these wastes is a major and ever-growing problem on U.S. farms, and there are yet no methods generally satisfactory for the handling, treatment and disposal of the animal manures originating in many types of livestock or poultry operations. Traditional use as agricultural, garden, or greenhouse fertilizer is no longer adequate because of increasing concentration in the production of manure. (See also Y8.)

E7. *We recommend that the Bureau of Mines increase its studies to speed the recycling of junk auto steel, including means for developing more uniform scrap, and for storing junk auto hulks in excess of current market demands of the iron and steel industry.* Variability of composition of the junk steel currently available makes processing costly and may lower the quality of the final product.. Furthermore, steel is a valuable mineral resource and its conservation through storage for future use is a desirable goal. (See also Y5.)

E8. *We recommend that the Department of Health, Education, and Welfare initiate development and demonstration projects for new and improved systems of collecting and transporting solid wastes to show what can be done to approach the problem from other than traditional methods.* (See also Y5.)

E9. *We recommend that the Federal Government stimulate development and demonstration of new and improved methods of treating solid and liquid wastes, including methods of nutrient removal.* In particular, HEW should be authorized to establish pilot plants followed by construction of prototypes for demonstration, for the purpose of improving existing solid and liquid waste treatment systems. (See also Y5.)

E10. *We recommend that HEW utilize its contracts and grants in the sewage treatment field to emphasize involvement of biochemists and biologists in the development of improvements and innovations in the technology of sewage treatment.* The existing systems of sewage treatment are relatively primitive and have developed without many insights that can be contributed by modern biologists and chemists. Imaginative scientists should be able to devise new approaches to problems of sewage treatment. (See also Y5.)

E11. *We recommend that the Federal Government draw more heavily on the experience and technological skills of private industry in developing instruments and devices for measurement of pollution.* A variety of incentives, different in different cases, may be necessary to provide necessary stimulus. Such incentives might include contracts for the development of specific hardware or systems; deliberate actions to make consumers want the product developed (such as legislation requiring the device or establishing tolerances that could be met only with the device); underwriting of demonstrations to prove the utility of the device; or waiving of the government patent rights in specific instances where vesting such rights in the government would remove the incentive to develop or market the device (as might be the case with small volume, low cost devices).

E12. *We recommend that the Federal Government ensure increased attention by manufacturers to satisfactory "fool-proof" automation of recording instruments for measuring pollution.* The high cost of supervising and maintaining the proper functioning of (supposedly) automatic recording instruments is to a large extent responsible for the inadequate coverage of many areas that need to be guarded. Through establishing adequate standards and purchasing from adequate specifications, among other actions, the Federal Government can do much to improve instrument quality.

E13. *We recommend that the Federal Government encourage the development of atmospheric instrumentation needed for warning systems.* In our growing metropolitan areas it becomes increasingly more important to be able to predict strengths and locations of intense pollution, caused either by adverse meteorological conditions or acute releases of poisonous chemicals.

E14. *We recommend that the Federal Government stimulate development of a method for assigning a numerical index of chemical pollution to water samples.* The method should be sensitive to most chemical pollutants, and its results should be roughly proportional to the unfavorable effects of the pollution on man or aquatic life. Such an index will allow us to follow many important changes in general water quality in a way similar to that in which the coliform count has enabled us to follow changes in pollution by untreated sewage. (See also X3.)

F. RESEARCH

MUCH RESEARCH IS ALREADY BEING CONDUCTED AND PLANNED THAT WILL CONTRIBUTE TO OUR UNDERSTANDING OF POLLUTION PROCESSES AND PROBLEMS AND TO OUR ABILITY TO ABATE AND CONTROL POLLUTION. IN ALMOST EVERY INSTANCE, THIS RESEARCH IS WORTHWHILE AND NEEDS TO BE CONTINUED. We have not identified any exceptions of a magnitude worthy of notice here, and anticipate that the normal processes of program review and internal competition for funds will be sufficient to keep these research programs in good order. We have, however, been able to identify a number of areas in which increased research effort will be both important and worthwhile. We do not believe that our list is complete, rather we anticipate the appearance of other clear needs as our national attack on pollution strengthens and broadens.

WE RECOMMEND THAT THE FEDERAL GOVERNMENT EXPAND SUBSTANTIALLY ITS INHOUSE AND SPONSORED RESEARCH IN THE FOLLOWING BROAD AREAS:

F1. *On the acute biological effects of common air pollutants.* Our knowledge of the effects, on either human beings or experimental animals, of realistic concentrations of gases or gas-particulate combinations is very limited, particularly under conditions, such as the presence of disease, which might enhance toxic effects or increase susceptibility. Much needed data can be obtained from human volunteers and from appropriately selected samples of industrially-exposed and non-industrially-exposed populations. (See also Y2 and Y10.)

F2. *On the effects on man and animals, particularly as revealed by epidemiological studies, of chronic low-level pollution, with special emphasis on lead, asbestos, oxides of nitrogen, carbon monoxide, and sulfur compounds.* Increased support should be made available for epidemiologic studies of possible health effects of chronic low-level pollution. Because of the importance of competing factors in morbidity and mortality (as when the effects of cigarette smoking appear to overwhelm possible effects of community air pollution) emphasis should be placed on refinement of methods, and on study of populations most seriously exposed to the pollutant. If studies of long-term exposure of animals are to be effective, high standards of environmental maintenance and animal care must be met. (See also Y2 and Y10.)

F3. *On the effects on wildlife and fisheries, directly and through their habitats.* A reasonable amount of information is available for the direct effects of a few compounds on a few species of animals. In most instances when judgments of allowable amounts of pollution have to be made, the necessary basic information is lacking. (See also Y10.)

F4. *On the effects of common pollutants on beneficial insects, crops, forests, domestic animals and birds and agricultural lands.* While much has been done, information is inadequate on immediate and long-term effects of many pollutants for many species. There is even less information available on their effects on soils and their fate in different kinds of soils. (See also Y1 and Y10.)

F5. *On bioenvironmental pest control.* Greater emphasis should be placed on reseach aimed at methods of reducing pest populations to the low density levels which are required for men's health, welfare, and crop protection by manipulation of the pest's environment or ecology, by altering the pest's physiology, genetics, or behavior and especially by employing various combinations of these. (See also Y11.)

F6. *On the metabolism, flow in the environment, natural degradation, and long-term deposition of pollutants, especially pesticides.* (At least HEW, USDA, and Interior should be involved in a coordinated study.) Little is known of the metabolism and natural degradation of a wide variety of pesticides and other pollutants. Similarly, with few exceptions, the flow and fate of organic pollutants in many habitats and the long-term deposition of these substances are largely or totally unclear. (See also Y1 and Y10.)

F7. *On research that may contribute to the development of new pesticides, that have high specificity and rapid degradability.* Damage to non-target organisms and hazard to humans could be minimized or eliminated by use of chemicals with greater specificity, perhaps approached through different mechanisms of toxicity. The use of pesticides which are more rapidly converted into innocuous products than those currently employed for many purposes will avoid or minimize environmental contamination. (See also Y11.)

F8. *On investigations of the role our coastal lowlands (estuaries, marshes, and lagoons) play in the life histories of many important fishes and shellfish and how they are affected by accumulated river pollution and related man-made alterations.* Greater knowledge is needed of our coastal lowlands because many of our most valued commercial and game species, such as prawns, menhaden, bluefish, weakfish, croaker, mullet, and channel bass, spend their juvenile stages in the estuarine zone, while oysters, clams, crabs and terrapins are all permanent residents of the estuaries. (See also Y10.)

F9. *On the development of more objective techniques to measure the tolerance levels of different organisms to pollutants and to identify and assess the changes in abundance and distribution of organisms making up biological communities under pollution stress.* Information on the tolerance limits of various organisms is urgently needed to interpret and understand changes in biological communities caused by pollutants. (See also Y10.)

F10. *On the chemical and physical nature of the pollutants produced by reactions in the atmosphere, and their biological action.* The prominence of automobile pollution in recent years has led to the recognition of the great importance of chemical change after emission into the atmosphere in the production of irritating and otherwise objectionable materials. A better knowledge of these reactions will be of decided benefit in the intelligent control of this source.

F11. *On intensified studies of the species composition of plant and animal communities, aquatic and terrestial, and the interactions among species and between organisms which make up plant and animal communities, including the influence on these communities of physical, chemical and biological factors, singly and in the aggregate.* At present little is understood concerning the structure and function of plant and animal communities. Our vital living environment must be satisfactorily understood to adequately protect it from various physical, chemical, and biological pollutants. (See also B21 and Y10.)

F12. *On the mechanisms controlling sizes of pest populations.* The success of pest control by pesticides or bioenvironmental methods, separately or as an integrated whole, depends upon our understanding of the fundamentals of pest-population dynamics. Development and testing of population models should be undertaken for representative types of organisms. Information developed from such studies should lead eventually to the ability to predict population trends accurately. The diversity of the information required for an understanding of population processes will make cooperation of ecologists, physiologists, biomathematicians, microclimatologists, geneticists, microbiologists, biochemists, chemists, morphologists, and taxonomists necessary. (See also Y11.)

F13. *On the development of techniques which will enable more accurate sampling of organisms in the natural environment.* Limited ability in detecting the effects of relatively low levels of pollution is a major technical deficiency in the field study of the effects of pollution. Relatively small changes in numbers of individuals of a species would often be the natural indicator, but present methods are adequate to measure such changes for only a few species. (See also Y10.)

F14. *On the biology and chemistry of the aquatic environment, the relative contribution of various sources of nutrient elements, and potential means for the effective control of the aquatic plants that flourish in enriched waters and of over-enrichment itself.* Objectionable growths of algae and larger aquatic plants are appearing in many bodies of water that now receive increased amounts of nutrient elements, especially nitrogen and phosphorus, because of man's activities. The behavior and sources of these nutrients, their relationship to algal blooms and possibly even their identities are frequently uncertain. (See also Y9.)

F15. *On the behavior of farm animal wastes in storage, in soil, and in water, and on the physical, chemical and biological properties of such wastes.* The properties of animal manures produced today are either totally unknown, or, because of different farm feeding practices, differ substantially from those studied years ago. In order to devise efficient disposal practices, the characteristics of the wastes and their behavior in environments into which they are deposited or through which they pass must be understood. (See also Y8.)

F16. *On research directed toward the development of techniques for predicting local air movements, with special reference to urban areas and concentrated pollution sources.* We do not yet know enough about the movements of smaller bodies of air to predict the consequences of releasing pollution into the air from smokestacks or pollution-generating disasters. This knowledge is needed both in setting tolerances for routine releases that depend appropriately on meteorological conditions and in managing evacuations necessary because of pollution-generating disasters. (See also X1.)

F17. *On conserving and increasing water supplies in semi-arid parts of the United States as a means of ameliorating salinity problems.* Special efforts should be made to increase water-use efficiency by crop plants, to increase runoff and underground flow from watersheds, and to decrease evaporation and seepage losses from reservoirs, canals, fields and unwanted plants. (See also Y1.)

F18. *On studies of the oceanic and biological processes by which CO_2 is removed from or returned to the atmosphere.* Use by land plants and absorption in the ocean restrains the increase of atmospheric CO_2, which may have significant effects on world-wide climate, to only half the amount we release. If we are to understand the consequences of the releases that we will make in the future, it will be essential to understand, in some detail, the mechanisms which so greatly reduce these consequences. (See also Y4.)

F19. *On taxonomic investigations basic to studies of the biological environment. The identification and reference services now provided by the Smithsonian Institution's Oceanographic Sorting Center should be expanded to cover a much wider variety of organisms and habitats.* At present many investigations of plant and animal communities are limited by inadequate knowledge of classification for certain types of organisms and a severe shortage of systematists who can provide identification and reference services. (See also Y 10.)

G. MANPOWER

Men and women of widely differing abilities, education and interests are needed to solve the problems of pollution and to protect our human environment.

IN THE LONG RUN, IMPROVING BOTH NUMBERS AND QUALITY OF HIGHLY TRAINED MANPOWER ENGAGED IN KEY ACTIONS, FROM RESEARCH TO ENFORCEMENT, WILL DO THE MOST FOR US, AND MERITS THE HIGHEST PRIORITY.

Besides the general improvement of education, especially in science and technology, the following specific policies, authorizations and actions should be implemented. (See also X1.)

G1. *We recommend that every opportunity be seized to acquaint young people with careers in fields related to environmental pollution.* Students in elementary schools, high schools, and colleges should be exposed to the problems of environmental investigation and the related opportunities for stimulating intellectual adventures which might alter their career choices. The dissemination of knowledge of the less well-known scientific disciplines and effective presentation of the personal satisfactions to be found in them are important tasks for university and government scientists.

G2. *We recommend adoption of a policy by Federal agencies that a consideration in the awarding of research grants related to environmental research should be the intention of the grantee to stress the training of students through involvement in such research.* Although training grants are an invaluable mechanism in the production of future research workers, they are not as generally available as research grants and are usually less flexible for securing the part time involvement of students. Employment of students in research projects not only assists the student financially but acquaints him with a field about which he might not otherwise learn. While in some cases the work might be, in the short run, more efficiently performed by skilled technicians, the contribution to recruitment of future scientists from graduate and undergraduate student assistants is, in the long run, far more significant.

G3. *We recommend that the Departments of Agriculture and the Interior be authorized to award, on a competitive basis, extramural contracts and grants to universities and other qualified institutions for research and research training in scientific and engineering fields supporting their missions.* These contracts and grants should be used at least in part to support the education and training of graduate students in fields concerned with environmental pollution in which there are critical shortages of professional manpower. Disciplines which contribute to our knowledge of biological control of pests and of interspecies relationships should be given high priority.

G4. *We recommend that the Departments of Health, Education, and Welfare, of Agriculture, and of the Interior be authorized to provide grants covering up to 100% of costs to universities, or other non-profit institutions for the construction, remodeling and equipping of facilities needed for projects, institutes, or centers to be devoted to research and research training in environmental health, environmental science and environmental engineering.* Present patterns of Federal support of universities are for the most part confined to research and training, on the assumption that adequate facilities are already available at universities. Where facilities are not available, the university is expected to provide them as its share of the endeavor. However, the universities are now confronted with educational responsibilities which greatly overtax their capacity to support them by conventional means. Few universities are in a position to contribute significantly to the large and complex efforts needed in the environmental pollution field, without an exceptional degree of support from the Federal Government.

G5. *We recommend that the Department of Health, Education, and Welfare increase its program of grants and contracts with universities, including schools of medicine, public health, engineering, public administration and agriculture. This program should support educational programs involving combinations of in-service experience, formal education and participation in basic and applied research. As soon as the Departments of Agriculture and the Interior have legislative authority for such grants and contracts, they should establish similar programs.* In particular, a variety of training grants should be provided to schools of medicine and schools of public health to support expanded programs in the teaching of preventive medicine and its constituent disciplines: Practical field training in epidemiology should be supported through residencies in certain of the larger well-staffed city-county health departments and in certain state health departments. Support to schools of public health and medicine should be continued for specialization in epidemiology, and residency field training should also become a part of this training. Grants should be provided to schools of medicine or public health for the support of summer field training programs in preventive medicine and public health, particularly epidemiology, in order that medical students may acquire practical field experience and, it is hoped, an interest in preventive medicine as a career.

G6. *We recommend that contract and grant support be provided to selected, progressive colleges of agriculture to enlarge and intensify their research and teaching to cover all aspects of the biological basis of human life in a world of many species.* These broadened programs would encompass, but not be restricted to, agricultural as well as biological problems relating to environmental pollution and natural populations.

G7. *We recommend that the Department of Health, Education, and Welfare and the National Science Foundation increase their support for traineeships and fellowships for graduate students in the pure and applied environmental sciences, and in those areas of behavioral sciences and engineering relevant to pollution problems. As soon as Agriculture and Interior have legislative authority for such support, they should establish similar programs.* Modest support is already available in some of these areas. Broader support is necessary to bring in promising students from a wider variety of fields and to give them the depth of training needed for research and teaching in the environmental sciences related to pollution.

G8. *We recommend that the Department of Health, Education, and Welfare provide long-term support to between five and ten universities to establish interdepartmental research centers for environmental studies, which would devote the greater part of their effort to research directly or ultimately related to pollution problems.* In the support of these centers, funds should be made available for research by graduate students, postdoctoral research workers and faculty members as well as for equipment, facilities, technicians, and administrative services. To allow adequate planning and recruiting, grants to a single center should overlap, lasting as long as seven years. The centers should be encouraged to conduct faculty and graduate seminars and to recruit visiting investigators. They should be sufficiently large to contain a critical mass of scientists and engineers, able to form and reform cooperative teams to attack problems of their choice. The scope of these centers should be broader than that of the environmental health science institutes now planned or funded by the Public Health Service. This kind of effort is needed because of the broad scope of environmental pollution problems and the range of disciplines which must interact and contribute in the solution of these problems.

G9. *We recommend that the Department of Health, Education, and Welfare provide research and training grant support for greatly broadened studies pertinent to the solid waste field.* Studies in systems engineering, public administration, environmental sciences and similar areas should be supported. This effort should be directed toward the involvement of academic faculties and graduate students as a means of spreading interest in this field across the entire educational community. (See also Y5.)

G10. *We recommend that the Federal Government establish a policy which encourages Federal research workers in the field of environmental pollution to make use of training and retraining opportunities.* A system similar in intent and operation to the sabbatical leave program of universities should be initiated. Provision should be made for reimbursement to the host institutions for expenses incidental to the leave program. (See also Y11.)

G11. *We recommend that each Federal agency concerned in its program with pollution, plan and budget specifically for the support of activities which contribute directly to maintenance and improvements in competence and skills of its scientists and engineers.* Items such as travel and subsistence in connection with scientific meetings and to and from training assignments should be included. Once established, the budgets for these activities should not be diverted to fund on-going operational programs.

G12. *We recommend that the National Science Foundation and the Public Health Service examine the adequacy of their present programs to provide for one-year fellowships allowing state and university research workers and teaching personnel to develop new skills and competence in pollution and related fields.* The rapid pace of technologic advance and the emergence of new problem areas in environmental pollution make it essential to provide means for research workers and teachers to acquire sound additional training through fellowships at institutions with active research and training programs in pollution-related fields.

G13. *Periodic refresher courses on new developments in all methods of pest control should be given for all extension personnel, commercial field men, and others who assist farmers with their pest problems.* No matter how effective techniques of pest control may be, if they are to be adopted and used successfully by growers it will be necessary to educate extension specialists and county agents in their use. Effective use of integrated control will require almost all extension personnel to change from relatively simple single concepts to a broader approach based on principles of applied ecology. This change is necessary if the farmer is to receive adequate guidance in pest population management. (See also Y11.)

G14. *We recommend that the Public Health Service increase its support to the Communicable Disease Center.* Epidemiologists are in very short supply. The Communicable Disease Center is by far the leading training center for epidemiologists in this country, probably the world. This increase should allow its Epidemic Intelligence Service to expand its training of epidemiologists at the maximum possible rate, and at least at a rate that will permit doubling of output in 5 years. (See also Y2.)

G15. *We recommend that the National Science Foundation and the Public Health Service establish summer institutes in the environmental sciences for high school and college students and teachers.* A summer program is one of the most effective ways to acquaint students and teachers with the environmental sciences, and to stimulate a lasting interest in this field.

G16. *We recommend that the National Science Foundation direct more of its support for undergraduates to programs that will enable them to work in environmental science laboratories both during the academic year and during the summer.* In an effort to draw promising young men and women into the field of environmental sciences, it is of great importance to stimulate the interest of the students at an early date before their direction of study and career choices have been satisfied.

G17. *We recommend that the National Science Foundation and the agencies with missions in environmental pollution (HEW, Agriculture*

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and Interior) support programs to develop a very much broader recognition of the opportunities for intellectual adventure in the environmental sciences related to pollution. This recognition should extend to students, teachers and guidance counsellors at all levels from elementary school to college. Visiting lecturer programs, special segments of conventional courses, teaching aids and educational publications can all contribute to this end. It is essential to enlarge the community of awareness.

G18. *We recommend that interaction among scientists working in basic and applied areas related to pollution be fostered through regional, national and international conferences designed specifically for this purpose.* A genuine attempt to forge communication between scientists working in the basic areas and those who are concerned with applied problems should distinguish these gatherings. Careful planning, structuring of the formal program and provision of abundant opportunities for informal discussion, will be needed. The selection of participants is crucial. Diversity of approach and active participation can help to generate many new perspectives. The Gordon Research Conferences are a highly successful model for intensive though informal exploration of scientific problems.

H. INCOMPLETENESS OF RECOMMENDATIONS

The recommendations we have made, many though they be, are not an exhaustive list. Even with the aid of some 11 subpanels, whose reports follow as appendices Y1 to Y11, one group cannot hope to cover the diverse field of pollution exhaustively. Moreover, it is essential, we believe, to focus attention on recommendations of greater importance and urgency. Accordingly, it has been necessary to set aside many recommendations which we think are valuable and significant, including many findings set out in individual subpanel reports, with which the Panel is in general agreement.

As examples, consider findings that the possibilities of deliberately compensating for the effects on climate of the increase in atmospheric CO_2 should be thoroughly explored (see Y4), and that comprehensive plans for diverse uses of shore lines and coastal water bodies should underlie modifications made by Federal agencies (see Y10).

APPENDIX X1

Challenging Tasks for the Men and Women Who Can Improve the Quality of Our Environment

Men and women with a full spectrum of abilities, education and interests are needed to solve the problems of pollution and to protect our human environment. Finding them, training them, and directing their efforts toward these problems will be a major task. Fundamental to all else in the long run, however, will be the natural and behavioral scientists and engineers who have the imagination, the dedication, and the skill to gain the understandings of unknown processes and obscure relationships that we must have if our complex civilization is to continue to exist in harmony with its earthly environment.

Creative men and women are always in short supply and the demands and rewards for their talents continually increase. How can we ensure that a sufficient number of them will devote themselves to environmental problems? We believe this can be done only if the challenges of the environmental sciences can be made manifest. First-rate people seldom devote themselves to second-rate problems.

Great scientific excitement is usually associated with the exploration of great mysteries. One of these is the mystery of life and of living things.

Homo sapiens is but a single species among an almost numberless variety on earth. He is related to and affected or rewarded in subtle ways by almost all the others. He senses that when a species disappears something wonderful has been lost; that when the balance among living things is perturbed, the quality of his life is changed.

The delicate interrelationships between living creatures on and beneath the land and in the rivers, lakes and oceans, are dimly appreciated and little understood. Yet few things are as satisfying as study, understanding and appreciation of what goes on in the world of living things.

Excitement must be in discovery, immediate reward in understanding. Wiser control of the environment can then follow almost automatically.

But these generalizations are not enough to recruit first-rate minds. We must be able to point out, as we try to do in the following pages, specific examples of exciting problems and promising pathways to fundamental understanding.

Pesticides as tools in cell biology.—The biological actions of pesticides after uptake by both susceptible and resistant organisms present profound problems in biochemistry, genetics, molecular biology, and evolution. Just as elucidation of the mode of action of some antibiotics has led to extensive use of antibiotics as tools to shed light on biochemical mechanisms, so further knowledge of pesticide action may give us new means to explore fundamental chemical reactions in living cells.

The mode of action of the organic-phosphate-ester insecticides which serve as acetylcholine esterase inhibitors and thus interfere with nervous function, has been studied in some detail. Much has been learned of the linkages between pesticide molecule and enzyme which interfere with the activity of the enzyme. The metabolic pathways of degradation of some of the pesticides have been partially mapped. But there remain deep questions to be answered. When an enzyme engages a substrate molecule at an active site, how is the electronic structure of the substrate distorted so that a chemical reaction occurs, with exchange of atoms between one molecule and another? The molecules of organic-phosphate ester must be engaged by the enzyme in a different way, one which results in no further reaction, but blocks access of normal substrate to the active site. Detailed interactions between enzyme, substrate and inhibitor are poorly understood. The elucidation of these intricate and important chemical phenomena offers a challenge to the biochemist and the molecular biologist. Adequate understanding can be achieved only in terms of quantum chemistry.

The mechanism of action of the chlorinated hydrocarbon insecticides, which also tend to produce disorders of nervous function is more mysterious. In structure and solubility properties, these insecticides resemble many of the fatty constituents of cell membranes. The surface membranes of nerve and muscle cells have essential roles in transmitting signals along and across these cells. It is tempting to suggest that the chlorinated hydrocarbons may interfere with nerve function by mingling with the fatty constituents of nerve cell membranes, thus impairing the conduction or transmission of nerve impulses. Cells also have many internal membranes, associated with many internal structures and intimately involved in such cell functions as secretion, excretion, uptake, internal transport, synthesis, segregation, and oxidative phosphorylation. Chlorinated hydrocarbons may also find their way into these internal membranes and there influence many of these functions. Careful study of the ways in which chlorinated hydrocarbon insecticides affect cell activity and regulation might thus give up keys to the structure and function of both external and internal cell membranes, opening up new understandings of certain aspects of cell biology.

New directions in microbiology.—Pollution problems open many doors to the microbiologist seeking new areas to conquer or looking for new tools to cope with long-standing problems of his discipline. Some of the chemical pollutants are common substances found in the environment in low concentrations; others are unique, exotic molecules whose reactions and transformations cannot be predicted from what we know today. The pathways of oxidation, reduction or decomposition of these novel classes of molecules are largely unknown, and as such they are attractive subjects of concern to biochemists and other specialists in metabolic biology.

Many of the pollutants are metabolized by organisms, rare or abundant, present where the pollutants are deposited or pass by. Some of the resulting chemical changes in pollutant molecules may lead to environmental decontamination, while others increase the unwanted effects arising from pollution. The nature and details of the reactions that take place are still very poorly understood.

On the other hand, an important feature of many pollutants is their persistence in nature. The resistance of certain organic pesticides to biodegradation was most unexpected. It had long been held that the microorganisms in water or soil could degrade essentially all carbon compounds. Little is known as to why certain types of chemicals resist biological or enzymatic attack under natural conditions or why certain readily biodegradable molecules are not destroyed in some environments. Research opportunities exist for microbiologists, biochemists, and water and soil chemists, to establish the environmental, physiological and metabolic bases for the resistance of pollutional chemicals to inactivation or enzymatic destruction, and the reasons why some chemical structures are not suspectible to degradation by the natural inhabitants of our soils and waters.

Research in population dynamics and the interaction of species.—In the "Origin of Species" Darwin stated that man does not know how the numbers of a single species are controlled in nature. A century later his statement needs little modification. The population biologist or ecologist interested in pest population control has an opportunity to contribute to basic knowlege in population dynamics. Many of the concepts and principles of population behavior and interspecific interaction arose from attempts to control some insect pest. Conversely, scientific study of behavior and interaction will contribute to applied problems of pest control.

The growth of pest populations in the field has rarely been studied quantitatively. Careful study would add fundamental knowledge and, at the same time, help us predict population outbreaks. Such studies will require development of better sampling techniques to provide reliable and efficient estimates of population size and distribution. Biologists with broad training in both ecology and statistics are needed.

Mathematical models of the dynamics of pest populations have received little attention. The possibilities of employing systems analysis to describe population events for a particular ecological system await evaluation and use.

The mechanisms responsible for cycles in populations still remain a biological mystery. Similarly, the factors determining the natural dispersal and migration of organisms, including pests are little understood. We are almost equally ignorant of the genetic and evolutionary mechanisms operating in the adaptatation of pests to their habitat.

Parasites, predators, and pathogens have been used successfully against several pests but the mechanisms of parasite-host, predator-prey, and pathogen-host population interactions remain vague.

Contributions might be made to the principles of epidemiology through these studies.

Human manipulations of the environment in cultivated areas provide opportunities for experimental study of the behavior of field populations. For example, it is possible to investigate the influence of the distribution of host plants in space and time upon the growth and development of animal populations; to measure the effects of plant productivity per unit area upon animal population productivity; and to study the relation of species diversity to population outbreaks.

All of these studies would contribute to the field of environmental biology, and in the long run would help in translating the results of laboratory work in molecular and cell biology into understanding of how the organism survives in the natural environment.

Opportunities in the behavioral sciences.—Pollution in all its aspects is related to human beings. It would not exist except for man's activities, and it concerns almost the entire range of interactions between human beings and their environment. Although all living creatures are affected by pollution, only man has the ability to control or eliminate it. The sciences that deal with man,—with his behavior and his institutions—are thus of central importance in finding improved solutions to pollution problems. These problems present challenges for research in the political sciences, and in sociology, economics, urban and regional planning, and communications.

Environmental pollutants do not recognize conventional political demarcations. Air and water pollution move across city and county lines, and often ignore state boundaries. New types of governmental entities based on river drainage basins, "airsheds", or on the limits of bays and estuaries, need to be invented and tested. At the same time, existing agencies at different levels of government must cooperate effectively, often in new ways, in the management and control of pollution. Many kinds of pollution cannot be handled by governments alone. Corrective measures must also be taken by individuals and private corporations. Both incentives for right actions and legal sanctions against wrong actions— carrots and sticks—must be devised and ways for applying them must be found. These problems of governmental organization, intragovernmental cooperation, and public-private interaction, all present fields for research in political science, public administration, and law.

For the sociologist there are opportunities to study the changing patterns of public attitudes toward pollution and its control, as these are related to levels of information, education, and income, and to changing levels of pollution and other stresses. The sociologist, the psychologist, the anthropologist, and the biostatistician, together with the epidemiologist, and the physiologist have roles to play in appraising the effects, both biological and behavioral, of long continued exposure to polluting substances in air, water and food. These effects need to be determined as functions of age, sex, occupation, location, and susceptibility; both average values and statistical variabilities must be found. The subtlety and complexity of the problems and their quantitative nature can challenge behavioral science to sharpen its techniques of measurement and analysis.

Pollution problems also present opportunities for economists. We need to find ways of analyzing esthetic, recreational, and other aspects of the "quality" of human life in economic terms. How much will people pay, and how much should they pay, for these intangibles? The apparent and real costs of pollution abatement and the proper allocation of these costs among different elements of society need to be studied. Many pollution problems can best be approached through modern methods of systems analysis; here the economist can play a part in providing the formal objectives for linear programming and simulation analyses.

Air pollution is a sickness of cities; in cities problems of liquid and solid wastes are most critical and most varied. Urban and regional planners must deal with these problems in all aspects of their work, as must specialists in land use. They can find opportunities here for interactions in research and development with natural scientists and engineers, as well as with economists, sociologists, and political scientists.

Specialists in public communication will find opportunities for development of their science in the need to arouse public concern and impel reasoned action, to inform, yet not needlessly alarm, their fellow human beings about the growing intensity and diversity of the problems of pollution.

In general, the sciences of human behavior have dealt with attempts to analyze equilibrium or slowly varying situations. In their growing magnitude and intensity, pollution problems represent rapidly changing situations, which challenge the behavioral sciences with opportunities to develop new approaches and new methodologies.

Opportunities for engineering research and education.—The increasing pollutional threat to health and well-being in the United States, and the increasing public awareness of this threat, offer unusual opportunities for broadly trained and oriented engineers. To be able to make their full potential contribution, civil and sanitary engineers need, as do engineers in other specialties, to be educated in ways that combine knowledge in the medical, biological and physical sciences with insights into economics, sociology, and public administration.

Environmental pollution leads to numerous problems, many related to health, recreation, comfort, and general well-being, others affecting economics and industry. When these problems are examined in detail they usually turn out to be complex and to require for their solution a combination of the skills of many disciplines that differs from one problem to another. Some may demand those of the chemist and the microbiologist, others those of the mathematician and the toxicologist. Engineers with exceptionally broad but practical training can be especially effective in judging what skills are needed in the solution of a particular problem. In most areas the engineer will not himself be competent to delve deeply into the fundamental areas of research, but he must be able to team up effectively with a colleague who has the necessary competence.

We could cite many problems demanding basic and applied research in which the imaginative engineer could play an important role. A few examples will suffice to illustrate some of the opportunities to combine scientific excitement with the performance of important public service.

Water pollution and shortage of water for its manifold human uses is emerging as one of the most critical issues facing the country. Present treatment plants for those municipal and industrial wastes that are committed to water do not adequately remove viruses, pesticides, or many of the chemicals now being used in industry. New processes and new designs for treatment plants, and new principles for collection systems, are urgently needed. Design of water storage and distribution systems must be modernized to reduce evaporation and seepage losses and salt contamination. New techniques of systems analysis must be applied to conservation, use, and reuse of water supplies.

These new methods of analysis may also be applicable to the increasingly serious problem of how to handle refuse, demolition materials, and other solid wastes. Incineration of these materials commonly leads both to air and water pollution. How the details of combustion affect its products is inadequately understood. New approaches to the engineering of disposal systems are badly needed.

Other fruitful research would be the study of new and better methods of removing products of combustion from stack gases and vehicle exhausts. Equally important would be redesign of the processes that cause pollution or substitution of others with less pollution potential.

In industry the engineer has responsibility for protecting the worker from many environmental hazards—radiation, noise, toxic chemicals, and accidents, to mention a few. While the record of health protection in industry is generally good in this country, there is room for improvement with respect to old hazards, and every year brings new problems that no one had visualized before (as when many physicists and engineers were seriously exposed to beryllium dust before its extreme toxicity was recognized) that require first research and then changes of practices.

Research in atmospheric problems.—The problems of air pollution call for much research. Little is known, for example, of what happens to our most common pollutant, SO_2, once it has been discharged into the atmosphere.

We suspect the particles in the air are as important as gases in causing the effects of air pollution. In general, we are concerned with the entire spectrum of particle sizes, the physical and chemical behavior of the particles, their catalytic actions, their capture, and their physiological action alone or in combination with other materials. Most of the literature on atmospheric particles deals with larger particles, greater than 4 millionths of an inch in diameter, for which fairly satisfactory techniques of collection and description are available. Very little has been done on sampling and characterizing submicronic particles. These particles are very pervasive, remain in the air for much longer times than the larger particles and are growing in relative amounts. While their weight may not be impressive, their consequences may be.

We know little about the very small particles as condensation nuclei. Condensation processes can produce high concentrations of various chemicals, orientation on surfaces, and unexpected chemical reactions. We can perhaps use some of these processes in directing the course of atmospheric chemical reactions in polluted air. The physiological actions of the small particles are equally interesting—do they affect us like a gas or like an aerosol? In the group of small-particle suspensions belong certain smokes (tobacco smoke and some metallurgical fumes), viruses, and proteins, and a whole array of various sized molecules suspended either as single molecules or as aggregates.

Some molecular aerosols may have been formed by mechanical means, friction, or wave splashing. Chemical processes are another source. What we see in smog formation is the end result. There is a whole spectrum of sizes before the particles become visible.

Understanding the motion of our atmosphere has long been a challenge to man. Today, especially with the aid of modern computers we are learning more and more about the behavior of the atmosphere as a whole, or in large pieces. We can often forecast "showers" correctly, but not where and when individual showers will occur. We have learned much about the behavior of "atmospheric turbulence" at safe distances from the grass, trees, or tall buildings that help make it, but we are equally at a loss to describe what happens in the streets of New York, in the glades of the forest or among the blades of grass in the pasture. And moving up just clear of those obstructions helps us not at all. The middle ground of mesometeorology is difficult by its very nature; hard to observe effectively; hard to provide with useful concepts; hard to study and comprehend.

Yet many crucial issues of pollution depend on just the questions mesometeorology still finds it hard to answer. An explosion has released a ton of noxious material at 63rd Street and 14th Avenue. If this is the weather map, which areas should be warned or evacuated? A growing industry wishes to triple its combustion of coal. What effect will this have on this hill, in that valley? Air pollution is unusually bad in these two districts. What sources are most likely to be implicated?

All that the mesometeorologist can learn about the flow of air under complex conditions will be helpful. What can the student of pollution offer in return? How far can natural sources of pollution help in studying the motions of the atmosphere? Careful work has made it possible to detect and measure very small amounts of certain chemicals and organisms. When can we learn most about the air motions by using these sensitive detectors to follow the air flow from some point where we have made a deliberate release? What are the questions and situations where tracer experiments might lead us to new insights and new concepts?

As these examples illustrate, pollution offers a broad range of challenges for research—research that can lead both to new levels of scientific understanding and to new capabilities for action. But these challenges will lie fallow unless they can be made widely known. They must also be translated into research opportunities which can be seized upon by sufficient numbers of imaginative, dedicated, and skillful scientists and engineers.

Funds and facilities are needed to provide these opportunities, but more important will be research environments which will attract and inspire outstanding young people. Over the next few decades, several thousand new research workers will be needed, from a wide variety of specialties in the natural and social sciences and engineering.

In most pollution problems, we are dealing with complex and subtle systems of interactions among human beings, other living creatures, and the physical environment. To attack the problems of these systems, there must be continuing interaction not only between researchers working on fundamental problems and those concerned with application, but among biologists and biolochemists, hydrologists and meteorologists, engineers and systems analysts, political scientists and sociologists, and workers from many other disciplines.

Within the existing scientific and engineering establishment of the United States, the tasks of finding and educating outstanding young people, and of providing broadly diversified research environments characterized by both freedom and interaction, can best be undertaken by the graduate and professional schools of our universities, acting in partnership with the Federal Government.

APPENDIX X2

Organizational Questions

Understanding and control of environmental pollution may be divided into four categories:

(a) Problem identification

(b) Management and regulation—relatively straightforward though often highly technical

(c) Improvement—often involving new knowledge

(d) Gathering of detailed knowledge basic to actions in management and regulation, or to improvement.

Problem identification mechanisms.—In its considerations, this Panel has learned of a number of pollution problems which were not widely recognized. Some of these problems had been noted by certain government agencies and not by others; some had been recognized by individuals outside of government. We are convinced that these examples are not unique, that there is a real need for mechanisms designed to aid in the recognition of both new problem areas and new specific problems involving pollution.

It is often most difficult to recognize the existence of such broad problem areas as (i) the influence of pollution on the balance between various forms of transportation (and various forms of power production), (ii) the slow effect on the geophysics and climate of the earth from CO_2 from our fuels, (iii) the possible effects of water vapor left in the stratosphere by supersonic transports, or (iv) the slow accumulation of lead from motor vehicle exhausts in the ocean. These tend to be everyone's problems but no one's problems. Once they have been adequately recognized and related to the broad outlines of available knowledge, the natural assignment of responsibility to an agency or group of agencies of the Federal Government may be clear enough. There is, however, a real need for a better mechanism for their identification and preliminary technical evaluation.

Any such broadly defined problem must now be broken down into major portions: What effects would increased CO_2 have, through changes in acidity, upon the transport of ground water? What would be the effects on mean annual temperature and rainfall of such an increase? How fast is atmospheric CO_2 increasing? Can we adequately explain the difference between the rate of formation of CO_2 by combustion of fuels and its rate of accumulation in the atmosphere? In this example, we meet problems involving the solid earth, the atmosphere, the oceans, and the plants of the world. Clearly no one agency of government is competent to deal with, or even to identify all these major portions of the problem. There is need for—

(1) An adequate focus of responsibility and technical competence for identifying major portions of pollution problems.

(2) Mechanisms for keeping in general balance the work conducted on these various portions, with special care to avoid critical gaps.

(3) Mechanisms to promote adequate exchange of understanding and facts at the working level.

Of these the last is the most easily attainable, but only provided its existence and importance is adequately recognized across agencies and sub-agency groups.

In order to provide for (i) identification of broad problems involving pollution, and (ii) adequate identification of major portions of such problems, (iii) avoidance of gaps and unbalances in the study of such major portions, it would be desirable that—

(1) The Federal Council for Science and Technology establish a Committee on Pollution Problems, composed of its own members, with the responsibility for ensuring adequate attention to each of (i), (ii), and (iii).

(2) The National Academy of Sciences-National Research Council establish an Environmental Pollution Board, to be supported by government grants, with the responsibility of aiding the Federal Government in connection with each of (i), (ii), and (iii).

(3) This Committee and this Board meet together at least once a year to discuss both the existence and importance of newly recognized broad problems and current changes in the apparent importance of those previously recognized.

(4) This Committee and this Board cooperate, through working level mechanisms such as joint panels, to identify the most pressing broad problems, and the general character of new knowledge or techniques needed to study or ameliorate them.

(5) This Committee act to ensure adequate coordination—whether by interagency committee, delegation of responsibility as executive agent, or otherwise—of Federal activity directed toward each recognized broad problem.

(6) The principle of frequent and adequate interagency (and intergroup within agency) contact, at the working level, among those concerned with different aspects of the same pollution problem be broadly recognized and effectively implemented.

Management and regulation.—The general steps involved in management of air, water, soils, food and other resources, including the regulation of pollutants in these resources include monitoring, surveys and investigations, standards development, enforcement and discouragement.

Monitoring provides measurements of what is happening; it generally answers the question of how much of what is where; continued in time it provides information on rates of change. Obviously such information is essential to permit judgments as to whether or not action is necessary.

Surveys and investigations are necessary to provide information on what is causing the conditions detected by monitoring and to suggest appropriate actions to rectify the conditions if necessary.

Standards development is based on criteria that will permit use of the resource without undue detriment to some prescribed resource(s) or use(s). Thus the setting of standards depends on the detailed knowledge of the effects of the various pollutants on man directly, his possessions, or the plant and animal life that he values; moreover, the standards are tempered by man's ability to control the release of specific pollutants, and by the value that society places on the activity that creates the pollutant. In a sense, standards are a numerical consequence of the benefit-risk equation, determining the losses that are acceptable in return for the costs that are avoided.

From the foregoing discussion it is clear that "standards" are in most cases guides subject to variation with places and times.

Enforcement is the final step in the process of regulation. Using the information obtained by monitoring, surveys and investigations, and interpreted in the light of current standards, actions are taken to reduce the concentration of pollutant. The appropriate actions vary with the pollutant, the resource polluted, and the sources of the pollutant. Generally speaking, enforcement aims at control at the source.

Discouragement is an alternative final step in control. It, too, operates at the source. Taxes, effluent fees, publicity, and even private persuasion can all be effective in reducing pollution below the levels at which regulation can be reasonable or effective.

Improvement.—In the broad sense used here, improvement implies actions to prevent or reduce pollution and the gaining of knowledge that may prove relevant to such actions. Its end products can include such diverse steps as devising new methods of pest control that do not pollute the environment, development of an economical device for removing SO_2 from stack gases, or devising new energy conversion mechanisms that give off less (or no) pollutants. The knowledge-gaining involved will range the whole gamut from basic research through applied research, and on to exploratory development. In our view the basic research will prosper best when it is discipline oriented; the applied research and exploratory development when project oriented.

Gathering of detailed knowledge.—Without understanding the biological effects of the various pollutants, singly or in combination, and whatever their location in the environment, we are unable to know what action, if any, is necessary. Without understanding the mechanisms by which these pollutants are transported, in air, water, or in living organisms, we are unable to decide where our action should be taken. Some of the understandings will require research of the most basic sort; others require meticulous data gathering and empirical experimentation. Most is yet to be done.

Governmental organization.—We suggest there is merit in separating the function of enforcement and research.

As presently constituted, several government agencies have responsibilities both for research in a given area involving pollution problems, and for enforcement of pollution regulation within that area, e.g., combined responsibility for research and enforcement are carried by the Bureau of State Services of the U.S. Public Health Service, by the Food and Drug Administration, and by the Agriculture Research Service, Department of Agriculture.

Responsibilities for enforcement in highly technical areas such as pollution control require a large amount of monitoring, measurement, survey and investigation of possible violations. Emergency pollution problems suddenly developing from accidents or other unexpected events can require extra efforts not provided for under normal allocations of dollars and manpower. Under such circumstances, agencies with both research and regulatory responsibilities have often diverted research scientists into regulatory or enforcement tasks. As a consequence, both functions have suffered. The primary and greater casualty is the research function, as it loses essential continuity, with spoilage of experiments and delays in completion of important projects. The enforcement and regulatory functions suffer likewise, in part because of the lesser experience of research people in enforcement work, but more gravely because delays in research completion deprive the enforcement people of knowledge which would facilitate their work and, in addition, deny to sources of pollution the knowledge and techniques which could be useful in reducing the magnitude of the pollution in the first place.

Successful research requires highly specialized, trained and imaginative scientists, a favorable research environment, and continuity of effort without interruption. In contrast, enforcement and regulation require persons of different training and capabilities.

A suitable solution to the over-all problem must include clearer separation, organizationally and budgetarily, of the regulatory and enforcement functions from the research and development functions. This can be done with sufficient residue of overlap so as to maintain continually up-to-date approaches to the problem by those involved in the field operation.

Within the research function we recognize that some division in attitude and location is possible and desirable.

The research effort of our country requires competence and achievement in both basic and applied areas. The distinction between basic and applied research is not always sharp, and there is often an overlap between the two. Broadly speaking, basic research is directed towards achieving a better understanding of the phenomena of nature, whereas applied research is directed towards the development of methodology and instrumentation which might achieve some desired goal. If the results of basic research are to contribute effectively to the benefit of mankind, applied research is necessary. In its turn, applied research must draw on the results of basic research, and cannot progress very far or very fast in the absence of a strong and successful basic research effort.

There are many areas in which lack of enough basic knowledge constrains our ability to deal effectively with pollution problems. Examples lie in deficiencies in knowledge of the behavior of important carriers of pollution, such as atmospheric gases, surface and ground water, oceanic currents, soils, and other particulate carriers. Basic research on these topics is necessary in order to clarify our understanding of the movement of pollutants. Some pollutants are carried extensively in living things, moving from one plant or animal to another through food chains, and moving from place to place as plants drift in water or as animals move about. Such movements of pollutants are important, for example, to our wildlife, fisheries, shrimp and shellfish beds and bald eagle populations. Basic research in ecological fields is necessary if we are to cope effectively with these serious problems.

Turning to applied research, we cite examples that illustrate the value of research in directly reducing the amount of pollution.

A highly fatal virus disease of the cabbage looper moth is known, and the virus can be recovered readily in large amounts from caterpillars dying of this disease. A very dilute suspension of the virus sprayed at the proper time over an infested cabbage field provides very effective control of the pest. It leaves no harmful residue and does not interfere with beneficial insects or wildlife. Although basic research permits one to anticipate a successful method of control of the cabbage looper based on use of the virus, applied research has not yet developed practical methods which permit safe and effective use of this virus in truck gardens raising vegetables commercially. When this method of control is developed, a source of pesticide contamination and unnecessary slaughter of beneficial insects, birds and other wildlife will have been eliminated and contamination of human food by dangerous pesticides will have been reduced.

Our nation's cotton crop is subject to heavy depredation by the boll weevil and the pink boll worm. In order to combat these pests, cotton fields are sprayed many times each season by wide-spectrum pesticides. This spraying is very expensive to the farmer, but accomplishes control of the pests. The widespread and frequent spraying of these potent poisons may be devastating to beneficial insects, birds, wildfowl, and aquatic life, and threatens neighboring food crops. Research has revealed many discoveries which might be developed by applied research to achieve the necessary aim without undesirable side effects. Some genetic strains of plants are immune to predation by specific insect pests. Powerful sex attractants for some insects have been collected and identified. Sterile mating has has been found to occur when fertile females mate with males sterilized by suitable means. Basic research has taught us of the existence of virus diseases specifically devastating for a single species of insects. Yet none of these basic research findings has yet been sufficiently developed through effective, persistent applied research to solve in a practical way the principal insect pest problems of cotton. We remain committed to a costly and pollution-producing program of frequent spraying of our vast cotton acreage.

Recognizing thus the need for both applied and basic research in adequate strength, we emphasize the necessity of formal administrative frameworks to assure the sufficiency of both. Our nation's medical schools have faced this problem for some decades, and have evolved the device of separate organizational units for accomplishing each objective. In medical schools, basic science departments have primary responsibility for basic research, whereas the clinical departments undertake main responsibility for developing basic biological concepts for the benefit of the patient. Enough overlap is provided to insure satisfactory flow of ideas and information, and to fortify the applied and basic departments respectively with knowledge of the needs and achievements of the others.

We consider desirable a similar division of responsibility in the pollution area, again with effective functional overlaps of interest, reflecting the absence of any sharp boundary between basic and applied research. In each important area relating to pollution, we recommend separate but coupled responsibility for basic and applied research. These responsibilities should be separated in problems of air pollution, water pollution, pesticides, silting of reservoirs, thermal pollution of streams, ground water pollution; soil pollution; environmental transport of pollutants, control of pests resulting in pollution, and in other important areas of pollution. This principle should be placed in effect by all Federal agencies charged

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with responsibilities related to pollution, and should be implemented vigorously in extramural and intramural programs alike.

Intramural and extramural research.—There is much we do not yet understand which is of vital importance to the management, and amelioration of environmental pollution. We need more basic research upon which to build both understanding and techniques of amelioration. We need more applied research to take advantage of basic knowledge in the discovery and shaping of such techniques in broad outline. We need exploratory development to bring new techniques to actual trial. And we need final development to produce techniques in a form suitable for general use. We dare neglect none of these: the problems of today are serious enough to demand development; those of the future will be so much more serious that we must do much research now.

The nation can look to industry for the accomplishment of some of this research and development. By choosing its own policies wisely the nation can somewhat increase industrial effort. Private, local, and state support of work at colleges and universities can and will help. But the main responsibility, both for planning and dollar support, must come through the Federal Government's actions.

In doing this, the Federal Government can utilize four methods:

(1) support of research within universities and other non-profit institutions,

(2) establishment of government or contract laboratories related to universities,

(3) establishment of large government research centers,

(4) establishment of separate small laboratories with responsibilities for specific problems.

The government's best distribution of effort differs considerably between research and development, and between the basic environmental sciences and the disciplines of environmental health and environmental engineering. The usual broad guidelines are appropriate here, although they require the usual detailed adjustments.

Directing the attention of new workers of high ability into fields of more direct importance to pollution is one of the most effective means of conducting basic research (as well as certain kinds of applied research), but it is not likely, by itself, to provide either a large enough stream of work or adequate interactions between workers in different disciplines. There are real needs for research institutes in which workers concerned with a variety of related problems, often involving varied disciplines, can be brought together for mutual stimulation and support. So long as these institutes are concerned with basic research (they may be also concerned with certain limited aspects of applied research), there are great advantages to be had from the closest possible relationship of the institute with an individual university whose faculty has broad competence in related areas.

Location on campus is good. When combined with effective arrangements for students to work in the institute and for institute staff to not only direct these but to spend a small part of their time teaching, campus location is even better. Transfer of the whole operation to university management, in addition to these steps, is usually still better. So long as we deal with basic research, the closest possible relationships to universities, as communities of scholars and as communities of young men whose training teaches the teachers, is desirable and should be sought.

Except through the time-tested mechanism of the agricultural experiment stations, and through isolated examples of other special mechanisms, the conduct of development and of some forms of applied research in conjunction with universities and colleges has not proved satisfactory and efficient. Since the Federal Government has major needs for expanded applied research and development related to pollution problems, it must then plan to expand its program of large research centers and isolated individual laboratories.

However it may choose to divide its efforts, the success of each unit will be determined by:

(1) the quality of the scientific, engineering and medical personnel who are working on specific problems,

(2) the quality of insight and resourcefulness of the management of the unit,

(3) the quality and vigor of technical leadership,

(4) the quality and extent of stimulation received, from those engaged in basic research, by those working on applied research and development,

(5) the adequacy of supporting facilities.

Together with the reasonableness and attractiveness of living in the neighborhood, items (2) through (5) will, in the long run, be the major determiners of the quality of personnel. They contribute both directly and indirectly to the success of the unit, and thus gain extra importance. Of these, the last is a matter of dollars. If high quality stimulation is to continue to come from basic research workers within the unit, both management and technical leadership must reach at least an equivalent level of quality.

Thus management and technical leadership quality is the most crucial *sine qua non*. This is particularly true in dealing with pollution problems, where engineers, biologists, chemists, and physicians must often work together, without undue jealousy and with clear opportunities for those from any discipline to rise as fast and far as their abilities permit.

Adequate management and scientific leadership requires appreciation of basic science, ability to keep application from dominating basic work (without inhibiting the flow of ideas and knowledge from the basic to the applied), ability to direct engineering or health programs (or, in many instances, both). The persons who can do all these things are hard to find.

In many aspects of applied research and development in connection with pollution, a large number of the men qualified to provide such management and leadership work in industry. For this reason, the possible gains following from private operation under contract need always to be considered in connection with any substantial research and development center.

Although wide scattering of small laboratories inevitably lowers the quality of leadership and management, almost the worst choice of all is the inadequately led and managed large center which can easily be as poor as or even poorer than the scattered laboratories. The large well-led-and-managed center is at the opposite extreme.

Whereas it is evident that organization of large-scale Federally supported laboratories and field research is urgently needed in the environmental health area, it is not yet clear what portion of this should be in centers built and operated by Federal Government and how much should be Federally supported but managed by universities or industry. The scale of the effort required is large, being comparable in magnitude to the scientific work necessary to underwrite the peaceful developments of atomic energy. In that case, three large Federally supported laboratories—Oak Ridge, Argonne, and Brookhaven—have been operated by universities or by industries, with very effective service to the public interest. The success of these efforts prompts an examination of a similar mechanism for the nation's environmental health needs. The shortages of scientific, engineering, and management manpower in the environmental health fields caution against too rapid expansion of Federal effort in spite of urgent national need.

APPENDIX X3

A "General" Index of Chemical Pollution

The control of water pollution due to human and animal excretions has used the coliform count as one of its main tools. By measuring the density of these harmless bacteria, which tend to occur in much greater numbers, it has been possible to control pollution by rarer disease-producing bacteria. While there is no necessary connection between coliform counts and the presence of disease-producing bacteria, increases in coliform counts have proved to be effective warnings of possible increased contamination. There is a need for a similar indicator which will measure, in a rather general way, the contamination of water by chemicals of all sorts.

There is increasing concern about the contamination of water (and air and other parts of the environment) by a wide variety of exotic chemical substances. Much valuable work has been done on analytical procedures for detecting specific chemicals. Much more of this is needed and will be done. But the existence of satisfactory but separate analytical methods for a few hundred individual chemicals will never meet all the needs for rapid routine monitoring of water quality, both because of the likely importance of chemicals for which such methods have not yet been developed and because of the impracticality of routinely making separate tests for a wide variety of chemicals.

No direct analog of the coliform count is to be expected, since we are dealing with contamination which comes from very different sources. Measurement of total dissolved solids is of little use, since the tolerable concentrations of different pollutants are so different (e.g., sodium chloride and sodium cyanide). If a simple overall measurement is to be made, it will almost certainly have to involve a biological reaction, in which small fish, fresh-water shrimps, or some other water-living organism of modest size is used as an indicator.

We require a measure of amount, not just an indication of presence or absence. Were we testing a poison we would test it at successive dilutions, in order to find the dilution at which an effect is noticeable but not complete. Since we are testing water which, though somewhat polluted, is likely of satisfactory quality, we must concentrate, rather than dilute, in order to reach a situation of noticeable but not complete effect.

To bring such a general index of "chemical" water pollution to the point where it could be used as a routine measure of water quality, it would be necessary to select, on the basis of moderately extensive tests—

(1) the species to be used,

(2) their ages or sizes,

(3) the way in which effect is to be noticed (inactivity, death, etc.),

(4) the method or methods to be used to concentrate the water sample,

(5) the spacings of concentration to be used in routine testing.

It is of course possible that work directed toward an index of this sort might lead to the development of a more satisfactory index of a somewhat different character. If so, well and good. The need is for a reasonably effective and conveniently usable technique which is sensitive to most, though perhaps not all, chemical pollutants at concentrations roughly proportional to those that have unfavorable effects on man, or on water life.

It might be possible to go further, combining the abilities of such processes as chromatography to separate and array constituents with the ability of diffusion into a growth medium to give directly perceivable indications of concentrations of unfavorable materials (as in the routine assay of penicillin). Such a combination of techniques might allow visual comparisons of "spectra" to give semi-specific warning of major changes in any of a wide variety of contaminants, thus calling for special specific analyses when needed.

In using either technique, it would be important to keep two things in mind: The finding that toxicity to the test species is very low does not *necessarily* indicate the absence or low level of substances with chronic or acute effects on man. The assay organisms will differ from man both in their feeding habits and in their responses to toxic agents. Alternatively, evidence of a high concentration of chemicals lethal to the test species does not necessarily indicate a potential hazard to man. Nevertheless, such measurements of lethality would indicate changes in the amount of biologically active substances, and would serve as a semi-specific warning of major changes in any of a wide variety of contaminants, thus calling for specific analyses when needed.

APPENDIX X4

Standards Development

For the purposes of this discussion, the term standard means a definite concentration of pollutant adopted locally or generally by any agency of government as a maximum with the intent of requiring compliance pursuant to its legal authority.

Broadly, the need for standards arises from concerns about our health, effects on the living environment, or pollution damage to objects which is clearly unacceptable.

Thus, the establishment of legal standards is based on the effects of the pollutants on humans, animals, plants and materials. Standards may vary because of factors such as duration of exposure and economic considerations. In order to balance the advantages of a control effort against possible economic disadvantages one should know the whole spectrum of effects of a pollutant. At low enough concentrations we find only nuisance effects and slight but reversible changes; at high concentrations there may be irreversible damage; at intermediate concentrations, where effects are less clearly expressed, there is often considerable debate.

Even when considering human health, because of the large variation in sensitivity within a population, there is no single level at which a particular pollutant becomes objectionable to every person. In communities one deals with a range of concentrations at which a certain percentage of the population becomes adversely affected. While the legal levels or standards should in most instances be established by local authorities, we must all look towards the Federal Government to supply basic information on the effects of pollutants. This information may be based on laboratory and field studies on plants, animals and materials, as well as on epidemiological investigations.

The development of numbers to describe conditions of exposure considered safe for a wide variety of hazardous chemical and physical agents has been a slow and laborious process. Most progress has been made in the field of occupational health, where we are often dealing with a single substance, with an exposure relatively easily characterized, qualitatively and quantitatively, and with an exposed population which is in good physical health. Some 300 threshold-limit values have now been accepted and are being applied in industry. Of these, probably no more than ten are known to be rigorous enough to ensure a safe and healthful environment over a full working lifetime.

One approach to the development of standards makes maximum use of existing governmental and engineering and technical society groups. The imposition of standards of government regulation at whatever level involved will meet with opposition unless the technical people concerned with the administration and effectuation of the necessary changes have come to understand the problems present. Such understanding is most rapidly gained and spread by involvement in development of these standards. Present efforts at standards development do not adequately involve the engineering and scientific communities. The German VDI (association of engineering societies) has set an example of such a procedure which could be considered. The Engineers' Joint Council, the American Standards Association, and the Founder Societies should all be more fully involved in standards problems.

Given the necessary standards, one turns to the necessity of controlling the sources and distribution of pollution so that the public interest is protected. Proper control depends on adequate methods for measuring pollutants in a medium. Standards set arbitrarily without proper prescription of measuring instrumentation and technique accomplish very little. In the case of standards for air, the guidelines should be influenced by pollutant concentrations as measured at ground level, as well as on the amounts and concentrations discharged by various emitters. In the case of standards for waters, the concentrations reached after dispersal in the diluent, as well as amounts, concentrations and rates of pollutants discharged at sources, should be included in formulating the bases for standards. In the case of soils, the standards should deal with the concentrations of pollutants in the soil and with the amounts and frequency of application of the chemical. In the case of all three, the tolerance standards can be set at different levels in different places in accordance with what the air, soil or water is to be used for, and what dangers to health, agriculture, economy, recreation and welfare are relevant.

In the case of limits of pollutants in food, standards should be set in accordance with national chemical and toxicological standards.

In all cases, the techniques, instruments and methods of measurement should be specified in setting guidelines for standards.

The setting of standards is highly technical; there must be provision for appropriate revision of standards from time to time as new scientific knowledge and improved methods of measurement become available. These necessary judgements are best exercised by highly knowledgeable scientists and engineers. Difficulties and inequities would be avoided if Federal responsibility for setting these guidelines for standards resided in the Department of Health, Education, and Welfare. It would be desirable if the legislative branch of the government refrained from setting standards or tolerance limits directly by law.

APPENDIX X5

Metropolitan Problems

An increasing fraction of the Nation's population lives in urban places, with two-thirds of our people residing on 9 percent of our land in 212 standard metropolitan statistical areas. If recent trends continue for 40 years, 300 million people will be living where only 40 percent of that number now live.

PennJerDel, an example.—The nature of the problems faced in these metropolitan areas can be illustrated by the PennJerDel area at the lower end of the Delaware River Basin. This area contains 377 municipalities in 11 counties in 3 states; the 1960 population was 5.0 million, and the 1985 projection is approximately 8.0 million. The area contains about 100 major industrial plants.

For PennJerDel 3.5 billion gallons of water per day are available and 2.9 billion gallons per day are already used. The forecast is for a threefold increase in use in the next 30–40 years. Water pollution in terms of BOD (biological oxygen demand) discharged totals 225 million lbs/year and a 50 percent increase is estimated by 1975.

In 1959 in Philadelphia, daily releases amounted to 830 tons of SO_2, 300 tons of NO_2, 1350 tons of hydrocarbons and 470 tons of particulates. The city has some degree of inversion 200 days a year and severe conditions 100 days a year. Within a 15 mile radius particulate fallout is 7000 tons per month. In southern New Jersey, 36 different species of plants were shown to be injured by pollutants from the Philadelphia area.

About 2,000,000 tons of solid waste have to be disposed of annually; this figure is to increase by a factor of 4 by the year 2000. Philadelphia will be exhausting its available land for land fill by 1990.

Two points are illustrated from the foregoing: first—the rates of pollution are increasing more rapidly than the population. We must run harder even to maintain present quality levels. Second—air pollution, control of solid wastes and water pollution can probably only be handled in such areas by such forms of interstate cooperation as airshed and river-basin compacts.

Air pollution.—In many areas the effects of emission of pollutants into the air is aggravated by geographic and meteorological conditions. Severe inversion conditions are far more frequent than is generally appreciated. For most of the country, inversion conditions occur about two-thirds of the year. Under these conditions pollution is held close to the ground and at high concentrations. In open country many industrial stack emissions can be properly dispersed by the use of high stacks, but air traffic rigidly limits stack heights in metropolitan areas. Available control techniques can limit the emissions but are generally not used because of cost.

An even more difficult problem has arisen with the evolution of our transportation system, which is dominated by the automobile. Almost every major metropolitan area now has the "smog" symptoms originally observed in Los Angeles. Incomplete combustion in the automobile engine and losses caused by venting of the crankcase and evaporation of gasoline from carburetor and tank result in the emission of unburned gasoline and its partially oxidized irritating products, as well as large quantities of carbon monoxide, oxides of nitrogen and hydrocarbons.

Engineering efforts are being made to reduce these emissions and considerable progress has been made. In 1966, the automobile industry plans to install corrective devices which will be partially effective in meeting performance standards set by the State of California. However, the presently contemplated reduction in emission is not sufficient to compensate for the steady increase in the numbers of vehicles for more than about two decades.

One of the difficulties inherent in controlling a very decentralized source such as the automobile is non-expert handling of the engineering phases of maintenance. The education and licensing of mechanics may need to be considered, since inspection of the automobile for proper functioning is an essential part of control in a metropolitan area. Indirect approaches, including improved flow of traffic, more efficient modes of transportation and general planning of urban growth for minimum air pollution will also have to be vigorously undertaken.

Water pollution.—The most intense water pollution is in or near great metropolitan areas and the industrial complexes associated with them. Sewerage systems and waste disposal practices were developed in early years as means for reducing the severe health and nuisance problems resulting from individual responsibility for waste disposal. Sanitary sewerage systems are undoubtedly the most significant of all the sanitation measures of modern society. Unfortunately sewers impose the burden of disposal on nearby waterways. For a variety of reasons waste treatment has not completely solved the problems associated with municipal sewage disposal. The unsolved problem of fertilization of receiving waters is discussed in Appendix Y9.

Even if treatment could remove all undesirable constituents from sanitary and industrial sewage, a great deal of pollution would reach streams in metropolitan areas. Most of the older cities have combined sewerage systems which not only carry sewage but also drain off storm waters. Since the runoff during storms can be 100 or more times as great as domestic sewage flows, storm waters are almost always discharged through overflow or relief sewers into the most convenient drainage way. Only the dry weather sanitary sewage flow is carried away for treatment. During heavy rains most sewage goes untreated and enters the rivers with the storm water. (See also Y6.)

Planning.—When planning the future growth and redevelopment of metropolitan areas, careful attention should be given to how various arrangements and activities might increase or decrease the severity of environmental pollution. There are many opportunities for reducing the amount or the effect of air and water contaminants. The type and location of industries can be controlled to suit the capacity of the environment to accept waste discharges. Sources of water and places of waste treatment and discharge can be arranged to afford maximum protection both of the public and of other water users. Use of acceptable electric powered public transportation would reduce air pollution. However, the ways our cities are growing do not make public transportation problems easier to handle. Satisfactory schemes for financing newly conceived and constructed mass transportation systems are needed.

Planning and action to alleviate environmental pollution by the methods mentioned above is particularly difficult because almost all large metropolitan areas spread across many jurisdictional boundaries. For example, the Washington Metropolitan area lies across three states, eight counties, two incorporated communities and one Federal city. Areas of this kind are desperately in need of acceptable bases for coordinated planning of area-wide facilities like transportation, water supply, and solid and liquid waste disposal. In the past, zoning measures were used, which aimed at the shift of pollution away from built-up areas. In Los Angeles and other confined airsheds, the increased magnitude of the problem now makes this type of solution unrealistic, although it is still useful in more open areas.

The political structure of our municipalities is evidently not able to cope with this problem in a satisfactory manner. This situation is unlikely to improve much in the coming years when problems of urban living will become even more difficult. Those who determine the course of expansion of the community rarely have a background that enables them to take full advantage of the experience with pollution gained in other areas. It is timely to consider setting up an organization of experts in the field of city planning and its many aspects, transportation, housing, power and water supplies and the preservation of clean air. Such a group could assemble and digest available information and indicate how local communities could cope with their expansion in the most practical, economical manner while preserving a healthful environment. But local communities also need organizations which cross jurisdictional boundaries. At this time one can see the desirability of airsheds for pollution control and abatement extending from San Diego to Santa Barbara, from Richmond to Boston, and from Madison, Wisconsin, to northern Indiana. Compacts involving these areas, covering air and, desirably, water and solid wastes as well, with Federal participation as well as State and local, would seem to be a useful mechanism to solve the intricate jurisdictional problems that now exist. There are also international problems, as in the Detroit-Windsor area.

APPENDIX X6

Air Problems

The striking increases in illness and death that occur in acute air pollution incidents show clearly that specific types of pollution above a certain level may seriously affect health. At lower levels of exposure we find marked irritation of eyes, nose, and throat; and damage to vegetation. In addition, depending on the type of pollutants, corrosion of metals, damage to wooden structures and streaking of paint are common. Dirt and grime deposited by airborne particulates are everywhere.

In order to balance the advantages of control measures against economic disadvantages the effects of the pollutants must be understood. In principle, the dispersing of non-toxic products into the air is acceptable but limits have to be defined.

At present our knowledge regarding toxicity of air pollutants is not adequate to allow us to know how to safeguard the health of the variety of people making up a community.

The most important air pollutants, which need a more systematic investigation of their effects on humans, animals, plants and material are:

Highest priority: sulfur dioxide, carbon monoxide, carbon dioxide, fluoride, ozone, sulfuric acid droplets, oxides of nitrogen, carcinogens (various types), peracyl nitrates, gasoline additives including lead and asbestos particles.

High priority: benzene and homologues, alkyl nitrates, alkyl nitrites, aldehydes, ethylene, pesticides, auto exhaust (raw), amines, mercaptans, hydrogen sulfide, and beryllium particles.

In addition the effects of the simultaneous presence of aerosols and gases have to be studied. The particulate matter may be of inorganic or organic nature. Special attention should be given to the effluents of combustion, which always carry particulate matter even when control equipment is installed. The present tendency to increase the fraction of particulates and condensation nuclei smaller than 0.1 of a micron in diameter needs evaluation.

There are a number of pollutants which are of local interest, such as the release of chemicals from a particular industry or from agricultural operations.

Pesticides are often considered only as agricultural hazards. With the encroachment of urban development on agricultural areas, communities will be exposed with increasing frequency to the action of various pesticides. This is a distinct area of interest and active investigation by the Department of Health, Education, and Welfare and the Department of Agriculture.

Toxicological studies, especially the study of pretoxic phenomena of agricultural and home poisons, need expansion. It is disturbing to see chemicals used in the home with a total disregard of possible adverse effects. Acute and long range study of small concentrations is needed for: cleaning solvents and other household chemicals (volatile or sprays), specific chemical effluents from industry, household chemicals, lacquers, etc.

The products of imperfect combustion are a major cause of motor vehicle air pollution problems in every metropolitan area.

The major emissions from the automobile are: carbon dioxide, carbon monoxide, gasoline, oxides of nitrogen, aldehydes and acids, nitrogen-containing organics, phenols, particulate matter, and lead salts.

There are four main emission points; tailpipe exhaust, crankcase vent, carburetor, and gasoline tank.

Hydrocarbon emissions, expressed in percentages of gasoline used, amount to—

	Percent
Tailpipe exhaust	5.4
Crankcase vent	2.1
Carburetor	0.5
Tank and filling loss	0.2
Total	8.2

In addition, three pounds of poisonous carbon monoxide and two ounces of oxides of nitrogen are formed for every gallon of fuel burned. The average amount of gasoline used per day per average driver and car is 2 gallons.

The energy loss through incomplete combustion is about 15% of the fuel heat value and is equivalent to one million gallons of gasoline daily for Los Angeles. For the nation this amounts to a loss of energy corresponding to 10 billion gallons of gasoline per year. Not only air pollution control but also conservation and wise use of our natural resources demand careful attention to the reduction of this detrimental waste.

The hydrocarbon emissions from the crankcase, about 30% of the total, will in the foreseeable future be nearly 100% controlled. However, considering the difficulty of enforcement and effective inspection, we may not reach more than a 50% reduction of the other emissions.

It is predicted that the increase in automobile population will continue with the same rate for many years. Gasoline consumption in the U.S.A. rose from 40 billion gallons per year in 1950 to an estimated 70 billion in 1964. By 1980 the use of gasoline in the Los Angeles area will have increased by a factor of four since smog was first noticed around 1945. Parallel with the increase of fuel is the emission of pollutants. The partial control of emission predicted for the coming years cannot keep up with this increase.

Research and development directed towards improvement in combustion and greatly reduced emissions should be promoted at universities and government laboratories. These studies should include radical changes in engine design and the development of, for example, the fuel cell for practical use.

Other aspects of this pollution problem which need study are analytical problems, control of oxides of nitrogen, and control of the use of lead and other additives in gasoline.

Biological research needs.—There are two main approaches to the further study of pollutants: epidemiological and experimental.

Epidemiology: Substantial evidence on the health effects from air pollutants may be accumulated from epidemiological studies, even though in many cases the complexity of the air pollution defies accurate specification of the particular agent responsible for the observed effect. Nevertheless this method of approach has the advantage that it deals with man.

Experimental toxicology and physiology: Due to the inherent limitation of epidemiological studies, direct experiments on plants, animals and man are necessary.

At present we have too few data on too few species of animals for too few pollutants. Lacking are also data relating effect to concentration and duration of exposure. Much of the available information deals with concentrations which are to be found in occupational situations. The lower concentrations of special interest in community health problems are far more difficult to study experimentally. Studies of single pollutants do not necessarily apply to combinations of pollutants, which may show adverse effects at lower exposures.

Since a population is made up of individuals with a whole spectrum of sensitivities, the absence of toxic or adverse symptoms in a single group of healthy subjects does not establish safety for the whole community. Accordingly we must also measure the typical extent of individual differences, whether these be due to transient states of ill heath or to continuing differences in physiology. When more is known about the range of variation, communitywide effects can be more accurately predicted.

Such studies cannot be confined to toxic or adverse symptoms alone, since measurable changes in normal physiological behavior often occur at lower concentrations and can provide useful indications of population exposure if enough is known about corresponding differences in sensitivity.

Animal experimentation: Inherent in such toxicological research is the need for long term animal experimentation. Especially when studying the effects of low concentrations, this work requires care, insight, and intelligence, both in proper execution of exposure and in observation of symptoms. Some of these symptoms may have been foreseen at desk level; others will be discovered by keen observers while experimenting. Many experimenters entering this field face for the first time a situation where the concentration of the gases arising from the natural emissions of the animal may easily equal or exceed those of the pollutants whose actions are to be studied.

It is essential that the personnel conducting such experiments, including those responsible for feeding and proper maintenance of animals, meet higher standards than are often thought adequate. Often too many aspects of this important work are delegated to animal keepers who do not have the knowledge necessary for the proper execution of the experiments. Adequate supervision can help but cannot be a substitute for properly qualified workers.

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APPENDIX X7

Water Quality

Our concern with the quality of water differs from place to place and in time. Our earliest preoccupation was to have water for drinking free of bacterial contamination; most of our present treatment of wastes and water is to assure this level of purity. A second concern has been to correct nuisances resulting from odors, soils, trash and visible pollutants; here again some success has been achieved. We are now beginning to be more concerned about the esthetic quality of natural waters, about the suitability of these waters for municipal, agricultural, industrial and recreational uses, and about potentially harmful substances present in extremely small amounts. We are also concerned with both immediate and long-term changes in our lakes, streams, and estuaries caused by increasing and even excessive fertility and with the rise in dissolved minerals as water is more extensively reused.

The relative importance of the various water quality problems depends on the uses to which the water is put and upon the priorities assigned these uses. It is unlikely to be desirable to attempt to maintain a busy industrial harbor in the same degree of cleanliness as a municipal water supply reservoir. All streams cannot be trout streams. Some deterioration or changes must accompany the growth of municipalities, the development of industry, and the exploitation of agricultural and mineral resources.

Priorities are largely a matter of local and regional concern, influenced by historical, economic and political factors. In the eastern United States the major uses of water have been for municipal and industrial water supply, water power, irrigation and recreation. In the arid west irrigation has dominated all other uses. At first irrigation projects were developed with private capital, but as the need grew for storing more water for longer periods of time and for transporting it greater distances, public funds were made available through the Reclamation Act, and the Bureau of Reclamation became the great Federal irrigation development agency.

As a result of these differences between east and west, pollution effects and quality requirements are not the same in the two regions. The principles of water law are entirely different, as is also the manner and degree in which the Federal agencies are involved in producing and dealing with quality problems.

A sampling of current problems includes (1) fertility; (2) water-borne viruses; (3) dispersal of waste heat; (4) increase in salinity; and (5) chemical pollutants.

Algae and rooted plants are appearing in many bodies of water in various areas of the country because of the increasing load of fertilizing elements which can be traced, directly or indirectly, to man's activities. These plant blooms create not only an esthetic problem but they also diminish the value of the water for domestic, industrial and recreational pursuits. Fish mortality may also occur as oxygen is consumed during the periods of plant respiration and decay. (See also Y9.)

Water pollution and human disease.—The potential of public water supplies to spread massive epidemics is a matter of public record. Even in the early years of this century typhoid fever and other enteric diseases were major causes of death, with many epidemics traced to water. Since about 1920, however, these enteric diseases have contributed little to total sickness and death in the United States. This remarkably good and continually improving record is a tribute to the stringent control measures developed and practiced by the sanitary engineering profession. Water-borne outbreaks still occur from time to time but are usually the result of accidents and commonly involve small or private water supplies.

As typhoid fever and dysenteries have become less prevalent in this country, concern about water-borne spreading of the viruses of infectious hepatitis has grown, although water transmission is thought to cause only a very small fraction of the cases of this disease. While there have been very few water-borne outbreaks in this country, a large epidemic did occur in New Delhi, India, in 1955 under circumstances suggesting that the treatment given the highly polluted water controlled bacteria without inactivating hepatitis virus. This virus, in the presence of organic material, appears to be unusually resistant to water treatment procedures.

Disposal of waste heat.—Even with today's most efficient steam-electric generating stations, about 50% of the heat value in the fuel burned must be dissipated in the condenser circulating water. With the trend toward larger generating stations, disposal of this heat in our rivers is becoming increasingly burdensome. Thus, in those areas where large rivers are not available for absorption of this heat release, the trend is toward use of large cooling towers.

Although use of large cooling towers to dissipate the entire heat release eliminates the thermal pollution problem and the subsequent damage to aquatic life, it may not be the optimum answer for a given stream. In the use of cooling towers, all of the heat is dissipated by evaporative cooling. Make-up water to the cooling tower for this evaporative cooling is taken from the stream, eliminating subsequent use of this water by those downstream.

If the heat is absorbed by water returned to the river, only one-quarter to two-thirds of the heat released is dissipated by evaporative cooling, depending on ambient conditions. The balance of the heat is removed by radiation and convection to the atmosphere, by conduction to the stream bed and by other factors. Thus, although the river temperature has been increased to downstream users, they have more water available than they would have if 100% evaporative cooling were used.

By the way of illustration, a 1,000,000-kw unit rejects about 4,500 Btu/kwh to the condenser circulating water. Assuming that a 15° F. rise, say from 78° F. to 93° F., in average summer river temperature is permissible, a condenser flow of 1,300 cubic feet a second would be required. Few rivers in America have a minimum summer flow of this magnitude. On the average, one-half of the heat rejected to the river is dissipated downstream to the atmosphere by evaporative cooling so that about 10 cubic feet a second (2¼ million lb/hr) of water would evaporate. If cooling towers were used instead, 100% evaporative cooling would remove 20 cubic feet a second from the river.

Since the consumptive use of water by the utility industry would be relatively small even if all power plants were evaporatively cooled, this choice is only important in special local cases. The decision as to whether the cost of cooling towers is warranted in any local case must rest on determination of the consequences of direct disposal into waterways. Reliable predictions of the consequences of direct disposal will require much better knowledge than now exists with regard to physical mixing and cooling phenomena, and biological effects.

Increases in salinity.—Salinity of water refers to its total content of dissolved mineral constituents of all kinds. Rain and melting snow are relatively free of minerals. When these waters come in contact with the earth the process of mineralization begins. Mineral quality changes continually and is determined by the type and time of exposure to soluble salts, by the uses to which water is put, and by the disposal of wastes.

The sources of troublesome amounts of mineral salts are both natural and man-made. Natural sources include saline spring and ground water coming through rock formations which contain soluble salts. Evaporation from water bodies and extraction of water by plants also tend to increase natural salinity. Man-made sources of salinity include domestic and industrial wastes, mine drainage, oil well brines, residual water from evaporative cooling and saline water conversion, and drainage water from irrigation water from irrigation projects. Each reuse adds it burden of salts.

Small amounts of dissolved salts are acceptable for many users, but in every case there are levels above which it is undesirable to go. Hardness above one hundred or so parts per million places economic burdens on domestic users. Amounts of some salts in excess of a few hundred parts per million cause tastes and physiological reactions. Larger amounts could conceivably have long-term renal or cardiac effects, but little is known about these possibilities.

Perhaps the most difficult salinity problem arises in connection with irrigation in the Western United States. Each storage, transmission and use of water increases its salinity. As salinity rises, increasing amounts of water must be spread on the fields to assure that salt concentration in the soils are held below acceptable levels. Such flushing further increases the dissolved salts and reduces the efficiency of water use. Since the production of irrigated soil declines when flushing is reduced or when the salinity of the applied water rises, a very delicate balance is involved in obtaining maximum efficiency of irrigation water use throughout a large river basin.

There is at present no feasible way to remove minerals from water used for irrigation and other purposes where low cost water is an economic necessity. Holding down the mineral content must depend on management of the sources to reduce the input of salts. The problem and its solution or management needs more attention at both the planning and operating stages.

Chemical pollutants.—The tremendous growth in the production of synthetic chemicals for all kinds of uses is producing an entirely new type of pollution problem. Wastes from the manufacture and use of these chemicals are reaching natural waters in significant amounts. Their effects on plants and animals are poorly understood, and many do not undergo decomposition as readily as do most biologically produced materials.

Synthetic chemical pollutants are known to create taste and odor problems that are difficult and expensive to solve. Some of these chemicals, particularly the pesticides, are toxic to various forms of aquatic life. Others are suspected of interfering with aquatic food chains. Questions about the possible carcinogenicity of some of these materials remain unanswered. In fact, the identities of many of the organic pollutants or products formed in nature from the original chemicals have not been established. Although the kinds of chemicals and their effects remain largely unknown, it is known that, on a gross basis, many, if not most, of them pass through the usual water treatment processes and reach the consumer in his drinking water.

Far more research is required on the identity, fate and biological and non-biological transformation of these chemical pollutants. Means should be developed to minimize such pollution by new or improved manufacturing techniques, by new methods of waste treatment, and by the substitution of more readily degradable or less objectionable chemicals.

SUBPANEL REPORTS

APPENDIX Y1

Soil Contamination

H. STANLEY BENNETT, *Chairman*
MARTIN ALEXANDER
H. L. LUCAS
STERLING B. HENDRICKS
THOMAS J. SHEETS, *Staff*

Contents

INTRODUCTION

The soils of the United States are one of this nation's most valuable natural resources. Our agricultural productivity and economic wealth result in large part from the vast areas of fertile land which provide the food and fiber so important to the high standard of living that is enjoyed by our citizens. However, coinciding with the rapid changes in agricultural management and practices and changes in other aspects of man's use of land resources, some undesirable modifications or unwanted additions have been made; and these often have altered the characteristics, properties, or productivity of the land. Such soils have become polluted.

Soils are being polluted with a variety of substances, both inorganic and organic. Although problems arising from contamination have been recognized for some time, neither the severity nor the magnitude of the broad issues of soil pollution has been widely appreciated. Considerable attention has, from time to time, been focused upon one or another type of pollutant, but the impact of the problem has been dissipated by the lack of a sustained, integrated effort to examine and evaluate the severity of the many forms of contamination.

It is not yet possible, except for certain substances, to assess the severity and extent of soil pollution. Nevertheless, it is clear that ever-increasing amounts of pollutants have been entering the soil in recent years. Radioactive fallout, organic pesticides, radionuclides in fertilizers, heavy metals, salts from irrigation water, industrial and household wastes, salts used on roads for the purposes of de-icing, lead from fuel combustion, pathogenic microorganisms, growth-regulating chemicals and mulching materials represent some of the more readily apparent soil contaminants; others may be recognized.

Focussing attention upon soil pollution is unpopular in many circles, but the issue has now become a matter of national concern. The land resources available to us are too precious and too limited to permit delay in undertaking a major effort directed at the prevention, abatement, and control of the contamination of the soils of the United States.

POLYETHYLENE AND PETROLEUM MULCHES

Polyethylene sheets, tar-paper, and asphalt sprays are used to a limited extent in crop production as mulches to control soil moisture, soil temperature, and weeds. Data on acreages involved are not available.

Polyethylene is not decomposed in the soil; and if not physically removed, this material could accumulate to the point of causing tillage problems. Otherwise it is not harmful. Asphalt sprays apparently are decomposed in the soil at a rate which prevents any substantial accumulation through continued use. These mulches are not used enough at present to be of any national concern as soil contaminants.

PESTICIDES, GROWTH REGULATORS, AND HARVEST AIDS

Although less than 5 percent of the total land area in the 48 contiguous states receives insecticides during an average year, many of our most productive soils are treated. Such figures, however, do not delineate problem areas that are related to the type of pesticide, its rate of degradation and inactivation in soils, acreages sprayed with a particular pesticide, the rate, frequency and methods of application, type of soil, and the prevailing environment.

Of all pesticides presently being used in agriculture, the chlorinated hydrocarbons as a group pose the greatest dangers from persistence and accumulation in soils. Although specific instances can be cited of persistence of certain organophosphates and carbamates for several weeks to several months, these pesticides do not appear to cause any significant, long-term, soil residue problems, even with continuous use.

The most persistent chlorinated hydrocarbons that have been widely used in agriculture are aldrin, dieldrin, heptachlor, endrin, DDT, and chlordane. In the early days of insect control, persistence of these insecticides was considered a virtue because residual activity controlled insects for extended periods after application. For some uses, persistence is still a virtue.

There are large variations among the persistences of aldrin, dieldrin, heptachlor, endrin, chlordane, DDT, methoxychlor, and toxaphene. Soil type and other characteristics of the environment influence rates of loss. Insecticides applied as dusts or sprays to the aerial parts of plants do not accumulate in soils as rapidly as those that are applied directly to the soil. In several cases problems arising from excessive persistence in soils of these insecticides have developed.

Heptachlor and dieldrin have been widely used to control alfalfa weevil in the humid eastern United States. After sensitive electron capture detectors were developed for gas-liquid chromatography, residues of heptachlor, heptachlor epoxide, and dieldrin, which hitherto went undetected, were found in milk. A recent study indicated that alfalfa plants can be contaminated with heptachlor and its epoxide by absorption of the chemicals from the soil into the roots (and possibly the crown) and subsequent transport to the shoots.

From about 1958 through 1963, an estimated 840,000 acres of alfalfa were sprayed with heptachlor and dieldrin each year in New York, Pennsylvania, and Maryland. This acreage comprises about 80 percent of the alfalfa grown in these three states. Some adjoining states also treated sizeable acreages. The best estimates of soil residue levels and known disappearance rates indicate that residues of these two pesticides in alfalfa soils should be dissipated to negligible levels within 2 or 3 years after use was discontinued in 1964.

Residues, especially dieldrin, were found in potatoes and in certain other crops, notably such root crops as carrots, when these were grown on land previously treated with aldrin and dieldrin to control wireworm in potatoes. Root crops such as carrots and beets usually become contaminated with pesticides at lower soil residue levels than other types of crops. Because of the problems encountered, recommendations and registration of aldrin and dieldrin for wireworm control in potatoes have been dropped by the U. S. Department of Agriculture.

During the last 25 years many different pesticides, including several chlorinated hydrocarbons, have been used in the production of cotton. In Arkansas in 1964, for example, 60 percent of the total harvested acreage of 1.2 million acres was sprayed with insecticides with an average of 4.3 applications per acre. Although DDT, BHC, toxaphene, and endrin are still used, cotton acreages sprayed with these compounds have declined greatly during the last several years. Preliminary data from the U. S. Department of Agriculture monitoring program, now in its second year, indicate that pesticide residues are not present at high concentrations in soils with high pesticide-use history. This result is partly attributable to changes in usage from the more persistent chlorinated hydrocarbons such as DDT, BHC, toxaphene, and endrin to less persistent chlorinated hydrocarbons, organophosphates, and carbamates.

In the past orchards have been sprayed with DDT at rates ranging up to about 40 to 50 pounds per acre per year. A recent survey of 35 orchards in southern Indiana showed DDT residues greater than 100 pounds per acre in several orchards, with a few values approaching and perhaps exceeding 400 pounds per acre. At known rates of disappearance, many years will often be required for residues of this magnitude to dissipate to negligible levels. In most states, trends are away from chlorinated hydrocarbons in orchards, but large amounts are still used throughout the United States.

Although insecticides still are, in terms of pounds of chemicals sold, the major type of agricultural pesticide used in the United States, the market for herbicides continues to grow rapidly, and the production and use of herbicides may eventually exceed the manufacture and use of insecticides. Thus, in the years 1962, 1963, and 1964 the annual sales of organic insecticides, fumigants, rodenticides and soil conditioners was essentially constant at 440 million pounds per annum, while the annual sales of herbicides and plant hormones in these years was 95, 123, and 152 million pounds.

Among the dominant pesticides are DDT (124 million pounds was the estimated U.S. production in 1964), the aldrin-toxaphene group (105 million pounds) 2,4–D and its esters and salts (108 million pounds), sodium chlorate (35 million pounds), 2,4,5–T esters and salts (24 million pounds), copper sulphate (42 million pounds) and pentachlorophenol (37 million pounds).

Inactivation and dissipation rates of herbicides in soils vary widely. Cereals planted in the fall after crops that have received summer applications of diuron, atrazine, simazine, diphenamid, and some related herbicides have been injured by residues. Injury to soybeans, sugar beets, oats, and forage grasses and legumes has been encountered in a few instances 10 to 12 months after application of atrazine to corn. Tobacco, cotton, peanuts, and soybeans have been injured by fenac residues 1 or 2 years after application at rates used for selective weed control in corn.

Although low levels of phytotoxic residues of diphenamid and of the substituted urea and *s*-triazine herbicides have persisted from one season to the next, data from many sources indicate that accumulation of excessive levels is extremely unlikely. Inherent phytotoxicity provides a natural indicator for residues and a defense against accumulation of herbicides used for selective weed control in crops.

Certain benzoic, phenylacetic, and picolinic acid herbicides persist in soils for several years. These same chemicals, especially the benzoic and phenylacetic acids, move downward through soils in percolating water; and phytotoxic residues of benzoic and phenylacetic acids have been detected at depths of 6 to 8 feet in soils. These herbicides are being used to control deep-rooted perennial weeds. The rate of application for this purpose varies from 5 to 30 pounds per acre; however applications are generally not repeated. Nevertheless, certain of these herbicides are not readily degraded in soils and hence pose a potential problem if use should become extensive. The present scale of use and frequency of application do not cause major long-term accumulation problems.

Of all the fungicides in use, the organic mercury compounds are generally the most hazardous to man. Total sales of these fungicides in 1962 were estimated to be 1.77 to 1.87 million pounds. These compounds are widely used as seed treatments, but the amounts used per acre are relatively small compared to most other pesticides. Soil pollution does not appear to be significant.

An estimated 100 million pounds of nematocides were used in the United States in 1961 principally on tobacco, pineapple, and vegetable soils. Nematocides are presently applied to about 1 million acres.

In the past, the effective nematocides have been volatile fumigants, and losses from soil are rapid. Chloride residues from decomposition of chlorinated nematocides sometimes cause short-term problems. Some plants growing in soil previously fumigated absorbed several times as much chloride as those growing on unfumigated soil. Although water soluble residues such as chlorides may cause some problem, the halogen can be leached out of the soil. Chloride residues are not a long-term problem.

Many years ago copper and lead from fungicide and insecticide applications accumulated in orchard soils to five to ten times the level of these metals found in untreated soils. The increasing use of organic pesticides has been accompanied by a marked reduction in use of copper- and lead-containing chemicals.

In orchards sprayed for many years with lead arsenate for control of codling moth, arsenic residues accumulated in many orchards to levels which severely injured cover crops. Mature fruit trees were unaffected, but young trees transplanted into old orchards were often injured. Many of these soils remain unproductive, although lead arsenate sprays are no longer used extensively in orchards.

Lead arsenate has also been used for insect control in tobacco. A recent survey in North Carolina indicated that arsenic levels in tobacco soils varied from 1 to 5 ppm and averaged 2.8 ppm. Arsenic levels of this magnitude may be found in virgin soils.

Calcium arsenate was used for many years to control insects in cotton. Most cotton producing states report no known instances of significant effects of soil residues of arsenic on plants. However, several years ago in South Carolina, phytotoxicity from arsenic was observed on cotton, oats, and cowpeas growing in old cotton soils. In a few soils in South Carolina, arsenic apparently still causes some damage. This problem is understood, and contaminated lands eventually, although very slowly, can be brought back into production.

Because rates of application are low, because acreages treated are not extensive, and because dissipation rates are relatively rapid, the widely employed growth regulators do not pose significant soil contamination problems. Most defoliants and desiccants probably behave similarly in soil. One possible concern is arsenic acid which is used on about 1 million acres of cotton in Texas and probably is employed extensively in other states. These inorganic arsenicals and certain organic arsenicals presently being developed as defoliants and desiccants potentially add to arsenic residues already present in many cotton soils. The rate of application is such, however, that further accumulation probably will not occur.

Research in progress in the U.S. Department of Agriculture, other Federal agencies, State Experiment Stations, and industrial laboratories is aimed toward development of more selective, less residual pesticides. More research is needed on the movement of pesticides in soils under different climatic and growing conditions and on decomposition rates at different soil depths. Fundamental research on pesticide-soil interactions should be expanded. Studies should be conducted to determine the sources of pesticides, industrial wastes, and other pollutants that cause damage to wildlife.

SOIL-BORNE PATHOGENS

Soils harbor a large number of disease-producing organisms. These organisms may bring about a variety of diseases in man, farm animals, wildlife, and cultivated and non-cultivated plants. Considerable effort has been, and still is, being directed at the control and elimination of these harmful microorganisms; but further research in these directions is warranted because many of the problems are still of national concern.

Investigations on the control of animal and plant diseases caused by soil-borne microorganisms and studies on the behavior of these harmful species in the soil environment are underway in many federal, state and private agencies. These studies have resulted in many practical, effective measures for crop and animal disease control and for the control of maladies affecting non-agriculturally important plants and animals as well.

In addition to continuing these lines of investigation, further work is required on the development of non-pollutional methods for the control of soil-borne plant pathogens as well as other soil-borne pests. A modest amount of research is being conducted at various locations in the country, but the effort needs to be increased.

Soil also serves as a reservoir for a number of human pathogenic microorganisms. Of chief concern are the fungi, notably species of *Histoplasma, Coccidioides, Blastomyces, Cryptococcus* and *Sporotrichum*.

Histoplasma capsulatum, a soil fungus responsible for histoplasmosis in humans, is widely distributed in certain soils of the United States, but statistical data on the incidence and prevalence of acute and systemic histoplasmosis are not available. The distribution of this microorganism is associated with habitats of chickens, other birds, and bats. The fungus apparently has been transported from infested to uninfested areas in soil moved by man, and the development of farm lands and wooded tracts are known to be responsible for acute histoplasmosis in persons exposed to dust raised in these operations. There seems to be no alarming increase in histoplasmosis infections at the present time, yet in the absence of suitable control measures, the problem is not decreasing in severity.

Activities that result in the disturbance of soils contaminated with *Coccidioides immitis* may lead to the release of spore clouds which are responsible for coccidioidomycosis infections in susceptible individuals inhaling the spores. However, serious infections with this fungus are comparatively rare.

There is thus reason for concern about the contamination of soils with human pathogens, and continuing vigilance is essential. The issue, however, is not of primary concern.

RADIONUCLIDE FALLOUT

One of the primary concerns of the contamination of soil by radioactive fallout is the eventual incorporation of some radionuclides in foods. About 200 isotopes of 35 elements have been identified from nuclear explosions and fallout. Many of these are not important as internal radiation hazards to man because (1) small amounts are involved, (2) half-lives are extremely short, or (3) they are not incorporated into the food chain.

The most important radionuclides in fallout are strontium-89 (halflife 53 days), strontium-90 (halflife 28 years), barium-140 (halflife 13 days), cesium-137 (halflife 27 years), iodine-131 (halflife 8 days), and iodine-133 (halflife 22 hours). Strontium-89, strontium-90, and barium-140 behave similarly to calcium in soils, plants, and animals; of the three barium-140 is least hazardous because of the short halflife and because the human body absorbs less barium-140 than strontium. Strontium-90, with a 28-year halflife, could pose a long range hazard. Cesium-317 behaves like potassium and, if ingested, would be found primarily in muscle.

Because of its occurrence in milk and its deposition in bone tissue, strontium-90 has received more attention than other fall-out nuclides. The U.S. Department of Agriculture in cooperation with the Atomic Energy Commission has conducted a soil monitoring program to determine world-wide distribution and total strontium-90 deposition from nuclear testing. The two most important factors that affect distribution are latitude and rainfall. Generally, the higher the rainfall in a given area, the greater the strontium-90 deposition. Strontium-90 injected into the atmosphere of the northern hemisphere has remained largely in the northern hemisphere.

Strontium-90 is relatively immobile in soil as are strontium-89, cesium-137, and several other radionuclides. Strontium-90 has been in the upper soil layers for many years, and many more years would be required for it to reach ground water. And during this time, the concentration would be reduced by a factor of ½ each 28 years.

According to a recent report by the U.S. Department of Commerce, fallout during 1965 will be about half that in 1964. If atmospheric testing of nuclear weapons is not resumed, the rate of deposition will continue to decrease; and after 1966 the rate of decay of strontium-90 will exceed deposition so that the total quantity in the soil will decrease. If fallout continues to decrease as predicted, the total in all years after 1965 will be less than that observed in 1964.

The present monitoring program of the Department of Agriculture appears to be adequate for following deposition of strontium-90 in soils. There is need for additional research on uptake by crop plants of radionuclides from soils.

Scientists in the Department of Agriculture are studying soil decontamination for the purpose of developing cultural practices and farming methods that could be used to produce edible crops in case of heavy nuclear fallout. This research should be continued at about the present level.

SOIL POLLUTION FROM FERTILIZER USE

A number of elements other than nitrogen, phosphorus and potassium are used as fertilizers. These substances are applied in agricultural practice to correct plant deficiencies arising from the low available levels in the soil of these micronutrients. Iron, copper, manganese, and molybdenum, for example, are, or have been, used in this way in a number of regions. Where the treatment is made properly and the appropriate rates of application are employed, there are no undesirable effects on plants. Occasionally, however, excessive quantities of these fertilizing elements have been applied to soil; abnormal and stunted plants have resulted; and crop yields and quality have been reduced. A notable example of this type of soil contamination is the accumulation of copper in citrus soils. This problem does not seem to be of major concern and is probably of little consequence when proper agricultural practices are employed.

Superphosphate fertilizers often contain traces of many substances. The concentration of potentially harmful elements such as arsenic, boron, fluorine, and uranium is generally so low as not to pose a significant problem of chemical contamination in agricultural soils. Most superphosphates have a uranium content equivalent to that of the original rock, estimated to average about 0.01% U_3O_8, but the uranium content may range from less than 0.001% to about 1%. Uranium is not readily absorbed by plants, but the radioactive decay of uranium-238 gives, among other products, radium-226, lead-210, and polonium-210.

The properties of radium-226 are very similar to those of calcium and strontium. Being similar to calcium, radium-226 is readily absorbed by plant roots and transported to leaves.

The level of radium-226 in soil is determined by the rate of decay of uranium-238. The concentration of radium-226 is inversely proportional to the halflife of the two elements; therefore, the amount of radium-226 in soil is a very small fraction of the quantity of uranium-238 present (1 part radium-226 per 3 x 10^6 parts uranium-238). By making several assumptions, it is possible to calculate the average amount of uranium-238 being applied in fertilizers. Assuming that the phosphate has a total uranium content of 0.01% and assuming an application rate of 1000 lb. phosphate/acre/year to the same soil for 100 years, 10 pounds of uranium-238 would be deposited in the soil with fertilizer. The calculated level of radium-226 in the soil is then 3.55 x 10^{-6} pounds per acre, equivalent to the addition of 1.6 milligrams or 1.6 millicuries of radium per acre. This amounts to about 1020 millicuries per square mile over the 100-year period. The natural abundance of radium-226 in soil is about 1000 millicuries per square mile although a great part of this is entrapped within minerals and rocks where it is unavailable for plant uptake.

Recent work by USDA and AEC has shown that the levels of radium-226 and polonium-210 in tobacco leaf vary with soils on which the plants were grown and that the radium-226 content of tobacco grown in 1950–1963 was three to six times as great as that grown in 1938. This comparison is made, however, on tobacco differing in type, in culture and curing methods, and in the soil on which the tobacco was grown. The amounts of radium-226 and polonium-210 in soils are known to vary. Moreover, the amount of certain radionuclides absorbed by plant roots appears to vary considerably. Polonium-210 could be of some concern in this regard since it is volatile at the combustion temperature of tobacco. The significance of the levels of polonium-210 now present in tobacco is apparently open to speculation.

Lead-210 may also be absorbed by plants and, hence, is also a potential radioactive contaminant of foods.

SALINITY PROBLEMS ASSOCIATED WITH IRRIGATION AND DE-ICING HIGHWAYS

In Hawaii and the 17 States west of the Mississippi, there are about 47 million acres of arable land, most of which are irrigable. Of these acreages about 28 percent were estimated in 1960 to be saline or alkali in character. For Oregon, the figure was only 7 percent, for Hawaii and Nevada about 40 percent, and for South Dakota about 70 percent. The level for the remaining States ran below that of Hawaii and Nevada.

Salinity is a problem in the interior valleys of California, the Great Basin, the Colorado and Rio Grande River drainage areas, parts of the Columbia River Basin, and localized areas in the Great Plains. An unknown large proportion of these lands is naturally saline or alkali, but 3 or 4 decades ago, salt accumulation in some of the more heavily irrigated areas was recognized as an actual or potential threat to agriculture. Whether a saline or alkali soil is natural or has been created by man, the problems it poses are the same. In 1937, the U.S. Salinity Laboratory was established at Riverside, California, and since that time much has been learned about the management of saline and alkali soils.

The change in soil salinity depends upon the balance between the salt input and outgo of soluble salts. Principal input media are irrigation water, capillary rise from a shallow water table (as under poor drainage conditions), weathering of soil materials, and, to a limited extent in coastal regions, rain water. Principal outgo occurs by leaching into drainage water. Salts can accumulate when the salt content of irrigation water is too high, when there is insufficient water for proper leaching, and/or when there is poor drainage. Under many irrigational situations, however, salt content of the soil stabilizes at a level not deleterious to crop production.

Studies on salt balance in the Imperial Valley were started in 1942. For a period of 5 years thereafter, salt accumulated at a rate of 0.4 to 1.0 ton per acre per year. However, this trend reversed, and from 1948 though 1963 salt levels decreased at the rate of 0.3 to 1.6 tons per acre per year. There were 7 tons of salt per acre less in 1963 than in 1942. Similar studies were made from 1948 through 1963 along three successive reaches of the Rio Grande Basin. In the first 2 years the salt balance was favorable at all locations. However, in 1951 the trend reversed. At the up-river location the salt level fluctuated but was usually favorable until 1956; it then took a permanent favorable turn, and by 1963 there were 11 tons of salt per acre less than in 1948. The unfavorable salt balance at the two down-river locations continued until 1963 when the studies were terminated. At that time, the salt content per acre at the two locations was 15 and 12 tons more than in 1948.

Salt accumulation in irrigated lands can usually be prevented by increasing the volume of irrigated water above that required for evapotranspiration; and draining off dissolved salt with the excess water. However, salty irrigation water which contains a high proportion of sodium, relative to calcium and magnesium, may so reduce the soil permeability that applied water will not flow through it. Soils with severe sodium damage become useless for agriculture, and because of their low permeability they are very difficult to reclaim. Damage is particularly likely if the soil contains large quantities of clays of the montmorillonite type. The clay particles swell when hydrated sodium ions enter their lattice structures. To avoid soil damage, high-sodium waters must not be used without dilution on clayey montmorillonite soils. Accurate knowledge of both water quality and soil type is thus essential for successful irrigation agriculture.

For the United States west of the 100th meridian, the annual rain- and snowfall are less than the potential evapotranspiration. In these arid and semi-arid regions, intensive agriculture can be sustained only by gathering the water that falls over a large watershed area and using it for irrigation in a relatively small cultivated area. In these processes the water inevitably acquires a burden of dissolved salt.

Upstream return of used irrigation water increases the salinity of the river water for the downstream users. Evaporation losses in reservoirs and conveyance channels also increase the salinity of the water. Such losses may be particularly serious when, as in the case of the Colorado river, water is stored and re-stored in a series of reservoirs along the course of the stream.

In the river basin developments of the arid and semi-arid regions of the United States, as much attention needs to be paid to water quality as to water quantity. Planning and design must insure that the downstream users receive water they can use.

Salinity and sodium problems become intensified as a higher and higher percentage of the total water supply is "consumptively used" by evapotranspiration. For any given level of agricultural development, therefore, these problems will be ameliorated if non-beneficial evapotranspiration in reservoirs, canals, irrigation ditches, and farm fields can be reduced. Use of reflecting or evaporation-inhibiting films in reservvoirs, control of unwanted plants in irrigation canals, and new field mulching techniques are promising methods for this purpose.

All methods of saving and increasing the upstream water supply will be beneficial to the downstream users, because they will thereby be provided with extra water for leaching and carrying off dissolved salts. We need to find ways of increasing runoff and underground flow from the watersheds and, in areas of salty underground water, ways of reducing seepage losses. Downstream users will also benefit from research and development on salt-tolerant crop varieties.

Much of the salt content of at least some main streams is contributed by a few tributaries or springs. If these salt sources could be identified and isolated, salinity problems in river development would be greatly reduced.

Research and development to increase crop yields per acre and per month of growing time (hence per acre foot of water), and incentives that will encourage farmers to grow primarily winter crops, or crops with a short growing season, could be very helpful in saving water.

Use of sodium and calcium chlorides to de-ice sidewalks and roads is increasing. Injury to, and death of, trees has been observed along roadsides or in nearby areas where runoff water has become impounded. The small areas affected by such practices do not warrant naming this problem as one of national concern. Such local problems can be solved by proper drainage of road runoff and selection of resistant species for bordering streets.

HOUSEHOLD, INDUSTRIAL, AND TRANSPORTATION WASTES

Insofar as contamination of soil is concerned, household wastes do not present a problem in urban areas. They are either carried off in the sewage or are collected and deposited in delimited areas by city agencies. The problem in rural areas, although it may be of some importance, is still difficult to assess. Certainly, wastes from rural sewage and other household sources enter the soil, but they do so only in localized areas.

The synthetic detergents have been given some attention. Those in common use during the past decade are resistant to microbial and other types of degradation, but detergents do not seem to be a major soil pollutant. Moreover, biodegradable detergents are now being widely employed.

Various state and Federal surveys have indicated that household wastes in general do not constitute an important soil-pollution problem nationally.

Most industrial waste problems are associated with air or water pollution rather than soil pollution. Of the soil pollution problems that do exist, several arise from the settling of airborne materials or from the infiltration into soil of waterborne materials. In some instances, for example, in the food industry, such contaminants are organic in nature and most are quickly degraded once they reach the soil. In recent years, the levels and significance in soils of many airborne contaminants has been decreasing. At the same time, many of the worrisome waterborne pollutants have been rendered ineffectual by chemical treatment of liquid effluent before its release or by their containment in small areas by lagooning practices. Most of the problems of soil pollution from industrial wastes which remain are of purely local concern and their solution can be achieved by recognized practices.

Nevertheless, acid mine-drainage and surface-soil changes from strip-mining in the coal regions of the United States remain as problems of significant proportions. As much as 1 million acres of land may be involved in the eastern half of the country. Acid mine-drainage is serious in the eastern United States; because of low rainfall and naturally alkaline soils, the problem is not serious in the West. Proper channeling of drainage waters from mining operations and lands affected by them can keep the problem in bounds. The areas of soil covered by deep-mine tailings are of little significance, but the areas of topsoil affected by strip-mining operations are considerable. In some instances, improvement and revegetation of lands affected by strip-mining have been attempted. Some of these efforts have been successful, but in other instances it appears that aging of the soil to improve texture, and application of copious quantities of soil amendments to restore proper nutrient status and optimum pH will be required. An evaluation of acid mine-drainage was conducted during the second session of the 87th Congress. Water pollution was the primary interest of that report.

Exhausts from various transportation media are a source of soil pollution along major routes of travel. Of apparent significance presently is the lead residue from the combustion of lead-containing fuels. Studies have shown that the lead content of soils and plants along roadways varies directly with traffic volume and decreases exponentially with distance from the highway. The direction of prevailing winds skews the distribution. Although it has been suggested that the lead in the plants, some of which presumably is absorbed from the soil, is a health hazard, the fraction of land area affected significantly is small. A pilot survey, especially along a few heavily traveled highways that extend for great distances through important agricultural lands, is desirable in order to assess the importance of this problem.

CONCLUSIONS

The contamination of this country's soils has been increasing, and the problem of soil pollution has grown until it is now a matter of immediate national concern. The severity and magnitude of some aspects of the general problem are appreciated, but the importance of several types of soil pollution has been minimized or even overlooked. In view of the significant proportion of our land that is being polluted, some for disturbingly long periods, an urgent need exists for a strong Federal effort designed to clarify the problems of soil pollution and to control practices which lead to soil pollution so as to minimize the deterioration of our valuable soil resources.

It is essential that the Nation be continually aware of the pollution status of its soils. The sources and types of pollutants are many, their residence times in soil are varied, and their effects on crops, animals, humans and the soil inhabitants diverse. In order to maintain the requisite continuing vigilance and appraisal and to provide the public and government with the information needed for intelligent action, a specific agency in the Department of Agriculture should be assigned the responsibility of evaluating the current status of soil pollution, coordinating the on-going programs and making recommendations and reports for new research and courses of action. No agency presently has this responsibility, and the scope and magnitude of the issue have grown, with no group in government specifically responsible for drawing attention to soil pollution and making recommendations as to how to cope with it.

This agency should prepare an annual report to Congress which should serve as a vehicle to inform the nation of the status of contamination of its soils and to make Congress and the public aware of the chief problems and needs in regard to soil pollution.

Particular attention clearly needs to be given to pesticides, but other actual or potential pollutants should not be ignored. These include radionuclides, lead, salts from irrigation and from roads, mulching materials and other substances applied for the purposes of conserving water, soil-borne pathogens of humans and animals, industrial and household wastes, and other substances which may be added directly to soil or which enter it indirectly. As needed, this agency should propose appropriate monitoring, research, control, and corrective actions.

FINDINGS

(1) The U.S.D.A. should establish an appropriate unit to assess continually the pollution status of the Nation's soils and to report its findings to the Congress. This agency should correlate and coordinate the research, control, abatement and monitoring activities of the Federal government and make suggestions as to new or additional courses of action.

(2) Funds should be made available to support basic and applied research designed to develop new or better methods of preventing, controlling, or minimizing soil pollution and to understand the behavior, persistence, metabolism and fate of alien substances in soils. In some instances research is underway, but additional funding is required. In other instances, no funds exist for the needed investigations, and new monies will have to be provided.

(3) Programs should be established to train individuals competent in the area of soil pollution. Many programs exist for the training of scientists competent to deal with problems of air and water pollution, but there is a great need for the development of interdisciplinary educational programs involving soil scientists.

(4) Public awareness of soil contamination problems is not very far advanced. The public has been made aware of practices which have advanced agricultural production without accompanying information about possible adverse effects. Much of the public awareness program is in the hands of agricultural extension workers. This group is oriented

toward the justification of practices that increase agricultural production. They have not been supplied with information about research advances to permit them to promote alternate methods of pest control or other practices that will minimize soil pollution. Extension programs should be modified to meet the needs for a public awareness of the critical nature of soil pollution. The setting of satisfactory examples in all government lands and in all government operations will assist in the educational program.

(5) To avoid or minimize the extent of soil contamination, private industry should be encouraged to develop chemicals and other materials which, when introduced into the soil, will be converted into innocuous products at a rate sufficiently rapid to prevent significant accumulation of pollutants.

(6) The pesticide registration agency, in its registration of pesticides, should take into consideration the duration of time during which the chemical or its toxic derivatives will remain in the soil.

(7) More research should be supported on methods for the control of soil-borne pests by means which do not involve use of chemicals that remain in soil for long periods. The use of resistant varieties of plants, degradable chemicals, new methods of land management or cropping procedures, and biological pest control techniques are some of the approaches that should be considered.

(8) A pilot survey is needed to assess the significance and the rates of accumulation of lead from vehicle exhausts in various soils and plants, especially those located close to heavily traveled highways. The U.S. Department of Agriculture in collaboration with the Department of Health, Education, and Welfare should conduct such a survey, determining whether the lead in the plants passed through the soil.

(9) Minimization of land impairment by industrial and mining wastes should be a national policy.

(10) Attention needs to be given to accumulation of salts in irrigated areas.

(a) Federal agencies concerned with water quality should make detailed studies of the sources of salt coming into the western rivers and should seek ways of isolating these sources from the rivers wherever possible.

(b) Research and development on conserving and increasing water supplies in semi-arid parts of the United States should be supported by appropriate Federal agencies in order to ameliorate salinity problems, as well as for other reasons, and part of the costs should be assigned to this objective. Such methods include—

(1) reduction of evaporation from reservoirs,

(2) reduction of nonbeneficial evapotranspiration in canals, irrigation ditches, and farm fields,

(3) increasing runoff and underground flow from watersheds,

(4) reduction of seepage losses in areas of salty underground water,

(5) increasing crop yields per acre and hence per acre-foot of irrigation water.

(c) Because total consumptive use of water in irrigation depends on the area of land irrigated, the number of months of irrigation, and the growing season, the amelioration of salinity problems should be taken into account in formulating agricultural policies. Incentives or controls which tend to reduce the number of cultivated acres, the acreage devoted to summer crops, and the acreage in crops with a long growing season will be beneficial in minimizing salinity problems.

(d) Because the value of water diminishes as its salt content increases (at least above a certain minimum salinity) water quality as well as water quantity should be taken into account by Federal and state agencies in the planning and design of river basin developments in the arid and semi-arid regions of the United States.

(e) In all irrigation developments supported with Federal or state funds, accurate surveys should be made of the type as well as the amount of clay minerals in the soils. Extreme care should to be taken not to irrigate soils containing montmorillonite clays with high-sodium irrigation waters.

APPENDIX Y2

Health Effects of Environmental Pollution

JAMES L. WHITTENBERGER, *Chairman*
A. J. HAAGEN-SMIT
LINCOLN E. MOSES
WILLIAM H. STEWART, (Member until June, 1965)
JOHN R. BAGBY, JR., *Staff*
BRUCE DULL, *Staff*

Contents

INTRODUCTION

Although chemical and thermal pollution of streams and the smokiness and grime of industrial areas have long disturbed citizens locally, there was no general concern on the part of the medical profession or official health agencies until after World War II. Interest in water pollution had centered in microbiological contamination and limited research had been done to determine whether severe urban atmospheric pollution might have adverse effects on health.

During and following World War II, vast changes have taken place, and apprehension has become widespread about the threats to health from chemical pollution of the environment. Some of the newly important factors are the rapid growth of population, urbanization, the rise of nuclear power and greatly expanded chemical technology, the use of pesticides, increasing prominence of the automobile in our culture, and, not least, the redefinition of health to include mental and social well-being. Many conflicts have resulted. Society demands the convenience of individual high speed transportation, for example, but pays for the convenience in terms of highway accidents (48,000 deaths and 1½ million injuries in 1964), traffic congestion, and air pollution, as well as loss of esthetic values, land, and natural resources as larger and larger highways are built through the countryside, parks, and residential areas.

Two developments in the 1940's brought environmental pollution to public awareness and focused attention on health effects. The highly popular climate of the Los Angeles basin had always contained the seeds of an air pollution problem, but it was not until the mid-1940's that eye-smarting and respiratory irritation became evident, from the combined indirect effects of increasing population, industrialization, and use of the automobile as the almost sole means of transportation.

A more dramatic event occurred in Donora, Pennsylvania, in the autumn of 1948, when almost half of the population became ill and 17 persons died (compared to an expected 2 for the period) when the community, set in a narrow valley, was blanketed for several days by a stationary fog that accumulated the chemical waste products of the heavily industrialized valley.

These developments at home, and the recognition of health effects in other countries, have emphasized the reality of the health aspects of pollution and have tended to make health protection the major reason for control. In many ways, this is sound—to assure that this country will not have another "Donora episode," and to reduce or eliminate the causes of the nuisance effects in Los Angeles County and elsewhere. Too often, however, health effects are stressed, even exaggerated, while other valid reasons for control are not used. Lack of evidence to substantiate health claims weakens the case for control.

Meanwhile, the control of waterborne disease was becoming even more effective. During the 15-year period, 1946–1960, there were only 228 known outbreaks of disease or poisoning attributed to drinking water; within this interval, there were three times as many outbreaks and cases in the earliest 5-year period as compared with the latest. In the 15-year period only 16 deaths were attributed to waterborne disease, 8 from typhoid fever, 4 from chemical poisoning, and 4 from infections other than typhoid. Since infectious hepatitis has come to the fore as a major communicable disease during this period, it is interesting to note that of the 115,690 cases reported between 1956 and 1960, only 417 were ascribed to polluted water.

In contrast to this excellent record, a large outbreak of gastroenteritis in Riverside, California, in late May and early June of 1965 illustrates the need for extreme vigilance in protection of public water supplies. Several thousands of persons were infected with *Salmonella typhimurium* within a few days; the organism was identified in the city's water supply, which must have been heavily polluted for a short time, before chlorination was instituted. The source of the contamination has not been found and several features of the epidemic have not been explained.

The trend for food-borne outbreaks has been stable for this period, except for milk-borne disease, which has decreased. Airborne infections and illness due to airborne pollens are continuing health problems, but the subpanel did not concern itself with these forms of environmental pollution.

DEFINING THE PROBLEM

It is traditional to divide influences on man into "genetic" (or "constitutional") and "environmental" factors. Accepting the artificiality of this separation, we believe it is necessary here to comment briefly on working definitions of "environment," since sociologists, epidemiologists (and others) differ in their use of the term. " Environment constitutes the sum of all social, biological, and physical or chemical factors which compose the surroundings of man. Although focusing attention on the health effects of alterations of the physical environment, we recognize the equally great and often greater importance of social and biological factors.

In the changes of disease patterns with time, there is a secular behavior which cannot be explained on a genetic basis, since the time intervals are too short. Thus, the growing epidemic of lung cancer in this century, and the almost-as-dramatic decrease in stomach cancer in the U.S., must be attributed to some change in the environment. The extent to which the changes are social, biological, or physico-chemical is not known (i.e., changes of smoking habits, eating habits, other living habits, virus infection patterns, community air pollution, changes in food technology). Before we can associate a disease or a trait with a specific component of the physical environment (e.g., water pollution or air pollution), we must be able to allow for differential effects of environmental factors acting on the populations being compared. This is usually very difficult because of the complex interrelations among such factors as poor physical environment, substandard housing, low income, overcrowding and poor diet (i.e., poor social and biological environment).

KINDS OF DIRECT EFFECTS ON MAN

The scope of possible health effects depends upon one's definitions of health and well-being and the classification of possible effects.

The subpanel adopted the following classification, listed in increasing order of severity.

A. Annoyance, irritation, and inconvenience.
B. Physiologic effects of unknown clinical significance.
C. Worsening of existing disease or disability and general increase of sickness.
D. General increase in death rate.
E. Initiation of specific progressive disease.

A. Annoyance, irritation, and inconvenience.—These effects are difficult to measure, but nonetheless real and important. They include sensory perceptions, such as tastes and odors, and irritations of the eyes, nose, and throat which are not accompanied by demonstrable organic injury or disease. Such reactions to environmental pollution can be serious nuisances and interfere with performance without causing physical illness or shortening of life. Well known examples are the reactions to Los Angeles-type smog and to the unpleasant odors of diesel exhaust and polluted waters. These nuisances vary locally but in some form and intensity are common to most urban and industrial areas, and even many recreational areas heavily used by man.

B. Physiologic effects of unknown clinical significance.—Sensory perceptions and various physiologic responses to pollutants can be precisely measured, but their clinical significance is unknown. In acute exposure of the lungs to smoke or specific chemicals, an asthmatic response occurs in normal as well as diseased individuals. It is not known whether repeated exposures and physiologic reactions of this type lead to respiratory disease.

People are exposed to carbon monoxide from tobacco smoking, heavy highway traffic, and certain occupational situations. Although physiologic effects of carbon monoxide are well understood, there is no sound evidence on the clinical significance of these low-level exposures.

Similarly, the bones and body fluids of everyone contain lead compounds which are in part a by-product of civilization. Present levels are apparently not causing disease or disability, but the margin of safety between present levels and deleterious levels is not certain for the more susceptible elements of the population.

Traffic and other noises associated with everyday activities constitute another environmental pollutant that affects people psychologically and perhaps physiologically. The clinical significance is unknown.

C. Worsening of existing disease or disability and general increase of sickness.—Such effects might include increased frequency of asthmatic attacks, increase of cough or shortness of breath from cardiac or pulmonary disease, or a general increase of ill health or absenteeism.

Numerous studies have been undertaken to measure effects of this kind in persons exposed to air pollution. Results of different studies have been inconclusive and contradictory. Epidemics of asthma have been described in several cities, but in general the evidence attributing them to air pollution is inconclusive. In Minneapolis asthmatic attacks appear to be related to grain mill dust and in New Orleans they appear to be predictable from meteorological conditions although the specific agents have not been identified.

Limited studies based on household interviews and records of sickness-absenteeism have suggested that nonspecific acute respiratory ailments may be significantly associated with community pollution as measured by dustfall and particulate sulfates. These studies need to be repeated using larger samples, better environmental measurements and better experimental design.

The evidence is even less clear with respect to chronic nonspecific respiratory diseases such as emphysema and chronic bronchitis. Epidemiologic studies in this country have shown cigarette smoking to be so strongly associated with these diseases that other exposures to atmospheric pollution in the community do not appear significant.

A promising technique that has proved useful in England is the "diary" method of relating atmospheric conditions to whether a patient with pulmonary or cardiac disease feels better or worse on a given day. Although there is marked variability among a group of "bronchitic" patients, in general they feel worse when atmospheric pollution is bad, the temperature, humidity, and other environmental conditions being similar.

D. General increase in death rate.—This effect is a later stage or more severe form of the effects noted under C. In this case, measurement of effects is by death records instead of household interviews, hospital admissions, or employment and school attendance records.

Specific hazards from atmospheric pollutants have been demonstrated most vividly in episodes of acute exposure. Reports from industry, agriculture, and the home point out dangers from accidental contact with high concentrations of a variety of toxic materials. On the community level, there have been several episodes in the past 35 years in which an atmosphere abruptly altered by a combination of temperature inversion and pollution can be held accountable for producing disease and death.

In December 1930, the heavily industrialized Meuse Valley in Belgium underwent several days of fog, smoke, and atmospheric stagnation. Within some three days many hundreds of the Valley residents described respiratory tract symptoms, and 60 deaths were attributed to the smog. The Donora, Pennsylvania, disaster in October 1948 resulted from a similar atmospheric stasis and could be held accountable for innumerable respiratory illnesses and 17 deaths. In Donora, as in Belgium, oxides of sulfur and other residues of the combusion of fuels were felt to have been in part responsible.

The London, England, episode of December 1952 was the most severe atmospheric poisoning ever recorded; a combination of fog and temperature inversion had blanketed a substantial portion of the British Isles for some days. London, in particular, was subjected to the associated gradual build-up of atmospheric pollutants, and approximately 4000 excess deaths occurred during the single week which encompassed the pollution episode. The bulk of the deaths occurred among the elderly and those with chronic cardiac and respiratory diseases, although deaths due to almost all causes were somewhat elevated. Similar but much less serious experiences have subsequently occurred in New York City and London.

Analyses of these acute air pollution experiences have pointed out certain similarities: (1) The epistodes resulted from abnormal concentrations of materials commonly emitted into the atmosphere and not from unusual or unexpected pollutants; (2) all were associated with atmospheric inversion and unusual weather conditions, including fog; (3) the pattern of atmospheric pollution included an initial build-up of several days prior to recognition of increased morbidity and mortality; (4) fatalities were observed predominantly among the elderly and those with preexisting cardiac and respiratory diseases; (5) the mechanism of disease initially appeared to involve the effects of chemical irritants on air-exposed, sensitive, membranous surfaces of the body.

While excess of daily mortality over expected rates is an indicator of atmospheric pollution, it is nonspecific and other causes such as an influenza epidemic or a heat wave must be excluded before the evidence is convincing. A heat wave in a city the size of New York or Los Angeles may cause hundreds of excess deaths; these are usually not noticed because the excess is spread over many causes of death, with none specifically attributed to heat. In Los Angeles several years ago a period of intense atmospheric pollution was accompanied by an excess of deaths; however, there was concurrently a heat wave that was sufficient in itself to account for the higher than usual mortality.

E. Initiation of specific progressive diseases.—Examples in this class would be the development of cancer, emphysema, or heart disease in persons who have had intense exposure to environmental pollution, with adequate control of other conditions which are known to favor the onset of these diseases.

Except when specific pollutants such as beryllium, radon, or asbestos are present, the conditions are seldom met for relating air pollution to a specific disease. Community pollution has long been suspected as a cause of lung cancer. Lung cancer incidence has grown in several countries roughly in parallel with urbanization and industrialization and it appears to be more common in cities than in rural areas. However, cigarette smoking has been shown to be strongly associated with lung cancer incidence, overshadowing all other factors except in certain industrial exposures. On the other hand, the urban-rural differences in lung cancer incidence can be accounted for by several plausible hypotheses in addition to the air pollution theory. Much more research will be necessary before the role of factors other than cigarette smoking can be evaluated.

NEED FOR FURTHER STUDIES

A. Epidemiologic research.—In the study of chronic effects from low concentrations of pollutants, it is difficult to conceive of animal experiments that would be completely relevant to human experience. Accordingly, the greatest emphasis should be placed on epidemiologic research and its correlation with clinical and laboratory investigations of man. More use should be made of data obtainable from populations exposed to relatively high concentration of specific pollutants in industry. With the cooperation of industry, and with improved methods of collecting, recording, and processing information, this could be a powerful method of study.

Other population groups under standardized medical surveillance and exposed to different kinds and levels of community pollution could be studied. Routine examinations of school children, athletes, and pregnant women would be useful in this regard if supplemented by lung function tests and questionnaire data specifically designed to elicit environmental effects.

Since air pollution varies greatly in composition and intensity from place to place and from country to country, international epidemiologic studies should be undertaken on a larger scale than hitherto attempted, with strict requirements for standardization of methods, both for evaluation of effects and for measurement of the environmental exposure.

Much more attention should be given to characterizing the environment in which people actually live. Air quality and water quality measurements are too often irrelevant to what the population is breathing and drinking. The air indoors cannot be assumed to reflect outdoor conditions, as indicated by the very few studies done thus far. In Rotterdam, for example, the particulates indoors averaged about 80 percent of the outdoor level in the immediate vicinity, whereas the SO_2 levels were only 20 percent of the outdoor values. In a few homes the SO_2 was higher inside and in general the SO_2 varied with the age of the dwelling, type of heating unit, fuel used, smoking habits of the occupants, and other factors.

Air sampling and analysis also need to be improved to give data of more biological value. Particle measurements other than weight should be made, for prediction of aerodynamic behavior. Analysis of potentially carcinogenic hydrocarbons needs to be greatly improved; most of such compounds in the air are probably adsorbed on particles in the smallest size range.

B. Laboratory studies.—Research should be increased to determine acute biological effects of common air pollutants.

Present information is very limited even for the gases most suspected of human health effects. Carbon monoxide (CO) has been extensively studied by physiologists, biochemists, psychologists, and physicians, but we still do not know for certain whether chronic effects occur after prolonged exposure, the extent to which skilled performance is impaired by low concentrations of CO in the body, and whether patients with cardio-respiratory diseases are especially suspectible to CO.

For sulfur dioxide we suspect a role in health effects in the more polluted cities; however, we have no knowledge of the distribution of susceptibility in the population and are uncertain of the extent to which the effects of SO_2 may be enhanced by the presence of other gases and particulates in the air.

Even less information is available on the acute effects of oxides of nitrogen and oxidants, compounds which are of increasingly widespread concern to air pollution experts.

Some of the data needed on human effects could be obtained from volunteers in laboratories or penal institutions, and from appropriately selected samples of industrially-exposed and non-industrially-exposed populations.

New methods of study need to be developed and applied. Such methods may include behavioral studies, more detailed analysis of respiratory and cardiovascular functions, and better correlations of biochemical, physiologic and anatomic data. Preliminary development of such methods should be carried out in appropriate species of experimental animals.

Epidemiologic studies should be supplemented by animal research on long-term exposures. Environmental and animal care requirements must be especially rigorous for such studies. Genetic effects and cancer induction may be studied most effectively in this manner.

C. The public health problems of lead and asbestos.—Recent studies of atmospheric lead in Los Angeles, Cincinnati and Philadelphia have been reassuring as to time trends in the past five years. Concomitant examination of blood and urine levels in a sample of 2300 people showed a spread of values consistent with increasing exposure to atmospheric lead associated with smoking, place of residence, or occupational exposure to automotive exhaust. Blood levels were below those associated with clinical lead poisoning and none of the persons examined had symptoms or illnesses thought to be associated with the body burden of lead. However, experts differ in their opinions as to the margin between average levels in the population and levels known to be harmful. It is unfortunate that baseline data on body burdens of lead were not obtained in the 1920's before leaded gasoline was generally in use.

In addition to continuing surveillance of body levels of lead, there is need for more intensive research on the uptake and excretion of lead by the body, the mechanisms of action of lead on biological systems, and the relationships between tissue levels and the presence of impairment or disease, or increase of the aging process.

Recent discovery that many city dwellers have asbestos fibers in their lungs indicates previously unrecognized exposure of the general population to asbestos fibers, at least in urban centers. Industrial experience has shown some types of asbestos to be strongly associated with lung cancer and other diseases. Specifically we need to know: 1) the importance of fiber type and size in the development of various diseases and conditions (most of the studies to date have implicated types of asbestos mined in South Africa); 2) the relationship of dosage to the incidence of disease; 3) mechanisms involved in observed associations between asbestos and disease; 4) the concentration of free asbestos in the immediate environment of man and the sources of this asbestos. Extensive epidemiologic studies will be needed, with careful assessment of environmental exposure through air sampling and analysis and measurement of asbestos fibers in human material.

FINDINGS

A. Surveillance.—A surveillance system should be developed to supplement the benchmark surveillance system, with continuing observation of mortality and morbidity trends that might be specifically related to environmental pollution. Considerable research will have to be done to determine the most sensitive indices to use for different kinds of pollution, the locations to be sampled, and the types of people to be sampled. Air sampling should be on an airshed basis. The people sampled should include the most susceptible elements of the population, based on age, occupation, presence of disease, and other relevant factors. For example, the body burden of lead should be measured in children as well as traffic policemen, garage workers, and others exposed in their occupations. Lead levels do not change rapidly and only a few hundred persons per year need to be sampled.

B. Recruitment and training of scientific manpower.—Increase of research and other activities related to environmental pollution will require increased recruitment and graduate training in many fields; two of these of particular importance in environmental health are toxicology and epidemiology. Steps should be taken to strengthen both of these fields.

The efforts of the National Institutes of Health and the Bureau of State Services to increase training and research in toxicology should be strongly encouraged. The skills of the toxicologist are those of the biochemist and pharmacologist, and there is much in common between the problems of the environmental toxicologist and the problems of adverse reactions to therapeutic drugs. Close integration is needed between these fields and the related basic sciences.

Epidemiology has traditionally been a speciality of physicians. With extension of the scope of epidemiology to include the study of the causes of non-infectious diseases, it is essential not only to continue recruiting epidemiologists from the limited supply of physicians but to attract scientists from other relevant fields. Modern epidemiology deals necessarily with the complexities of the social environment as well as with the components of biological and physical environment; it leans heavily upon the quantitative methodology of the statistician and should exploit fully the opportunities offered by computers.

Major contributions to epidemiologic theory and practice could be made by members of several disciplines, particularly mathematical statistics, applicd mathematics, and the more mathematically-oriented social sciences. Accordingly, recruitment efforts should be directed to these other fields in addition to medicine.

Increased support should be provided to the Epidemic Intelligence Service of the Public Health Service, Communicable Disease Center, to allow that Service to expand its training of epidemiologists at the maximum possible rate, and at least at a rate that will permit a doubling of output in 5 years.

In addition, summer courses in practical epidemiology should be developed specifically for junior members of medical faculties who could, in turn, teach the use of the tools of epidemiology to medical students. The subject matter of this teaching should be limited to practical epidemiology and biostatistics, with emphasis on the detailed review of specific epidemiological problems: tabulation, matching, and analysis of basic data extracted from morbidity and mortality and census records, and the actual conduct of field surveys.

Practical field training for medical students as well as graduate physicians should be supported through residencies in certain of the larger well-staffed city-county health departments and in certain State health departments. Support to schools of public health should be continued for specialization in epidemiology, and residency field training should also become a part of this training. Grants should be provided to schools of medicine and schools of public health for the support of summer field training programs in preventive medicine and public health, particularly epidemiology, in order that medical students may acquire practical field experience and, it is hoped, an interest in preventive medicine as a career. Special purpose grants should be provided to schools of medicine and schools of public health to support expanded programs in the teaching of preventive medicine and its constituent disciplines.

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APPENDIX Y3

Benchmark Surveillance

AARIE J. HAAGEN-SMIT, *Chairman*

LOUIS H. RODDIS, *Vice Chairman*
NYLE C. BRADY
RAYMOND J. JESSEN
JAMES L. WHITTENBERGER
W. J. YOUDEN
JOHN L. BUCKLEY, *Staff*

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INTRODUCTION

Monitoring and surveillance of the exposure of the citizens of the United States to pollution has been confined, with few exceptions, either to monitoring of those airs, waters, foods and soils which seem most likely to be noxious or to the routine inspection of foods and waters. Clearly, these were the places where effort was initially most needed, where protection against acute dangers could best be provided. We dare not relax this sort of monitoring; rather we will have to expand and deepen it.

We have come now, however, to regard pollution as a problem that involves each of us, that is a broad national concern. It is no longer enough to try to deal with specific situations alone. We need to know for pollution, just as we long have for economic affairs, what things are like for the nation as a whole, and how things are changing.

We need now to begin to learn how much pollution our people are exposed to in general. We need to know this for each kind of pollution we have come to recognize as important. We need to know this first for all Americans, which means knowing it in terms of some average in which each person is weighed equally. As soon as we can, we need to know it for broadly defined portions of our country. Indeed, as we gain in experience and skill in such measurements, we are likely to want to know about our exposures to pollution in more detail, asking for example about higher levels for each kind of pollutant such that only some small fraction of our population is exposed to more than that.

We need a continuing National Environmental Quality Survey.

We are not prepared to give a blueprint of just what such a Survey would begin by including or just how it should be organized. We can indicate its goals, some of the difficulties it must overcome, and some of the possibilities before it. More detailed study than we have been able to give is needed, and needed soon.

It is clear, for example, that at least three environments need to be considered separately:

(1) the tissues, fluids, and bones of our body, what the doctors have long called our *internal environment,*

(2) what we eat, drink, breathe, and rub against, our *immediate environment,*

(3) our land as a whole, area by area, our *general environment.*

A change, favorable or unfavorable, in our general environment is likely to be reflected, after an appropriate time, in our immediate environment, whose change, in its turn, may be reflected in our internal environment. It is only by monitoring all three that we can both understand the present and have warning of the future.

FINDINGS

(1) Immediate steps should be taken to plan and institute a National Environmental Quality Survey, whose first main function is to provide benchmark data on the internal, immediate, and general environments of the people of the United States.

(2) Consideration should be given to making whatever agency is given responsibility for this Survey a clearinghouse for results and techniques of measurement of environmental quality and for the corresponding details of measurement programs, in progress or planned.

(3) An appropriate agency should be set up in the Department of Commerce to carry out these functions.

DISCUSSION

Government agencies monitor various channels of pollution for the purpose of detection and control. Today our food, water, and air are generally kept within levels that safeguard health from rather serious damage due to wanton or accidental pollution. Techniques of measurement and sampling used by these agencies generally seem adequate for such purposes, although there may be opportunities for gain in efficiency in sampling; in a few instances the validity of data acquired may be questionable.

At the same time, it is quite clear that no agency is specifically concerned with the problems of determining the main stream of pollution, the direction in which it is going, and the speed with which changes take place. In a few cases, and usually for local areas, data gathered are brought together in a single place and examined to determine as well as possible the trends in pollution. In other cases, this is not done. In the case of pesticides, an effort is being made to draw up a national monitoring program, but so far the plans are not complete and funds are not available. Pollution is going to be a continuing and growing problem due to ever increasing production of goods (up about 4% per year) new technologies, new materials, increasing density of populations in urban centers, etc. The United States needs surveillance over the pollution problem on a broad national basis in order to allocate resources most effectively for abatement and control, to estimate the over-all effectiveness of expenditures on pollution control at the present time, and to alert the nation to incipient problems before they become acute. Publication of the results in an unimpassioned way will lead to responsible public awareness and will help to avoid crash programs initiated in a climate of crisis.

Surveillance of the kind needed cannot be provided effectively by a control or action agency. Examples of the success of such separate programs are the Bureau of the Census which keeps track of our people, their housing accommodations, the number of unemployed, etc., and the National Health Survey which keeps a running account of the state of health of our nation. Neither of these agencies is concerned with action and both are highly regarded sources of impartial information although each has had its detractors.

The current problem of pollution information in the United States seems similar to that of unemployment information in the late 1930's and early 1940's and that of morbidity and general health information in the 1950's. In both cases the supply of statistics was abundant, but "action" and "control" agencies provided conflicting results. Moreover, it wasn't a matter of whether we had any unemployment or what the effects of unemployment were, or what the appropriate measures of control were. The matter seemed to be "how much was there" and "what were the trends," "are public measures increasing it or decreasing it," "where and how much?" The responsibility for measurement of unemployment was placed in a nonaction agency, even though that agency was not used to the problems associated with the current measurement of unemployment.

Similarly, with health statistics the problem was not of insufficient statistics, but of conflicting statistics. There were no measurements of trends of chronic and acute illnesses, no satisfactory way of assessing whether public and private programs were in fact accomplishing national goals or not. The National Health Survey in the Public Health Service has done an excellent job in solving these problems. It is a part of the Center of Health Statistics, a nonaction agency. The basic data are collected by the Bureau of the Census.

The pollution problem today seems to be in the same stage of statistical uncertainty as were unemployment and health—much good work on specifics and on controls, little on general surveillance. A responsible public awareness must be founded on a responsible measurement program. We can expect better legislative programs to be forthcoming after we see more clearly what is happening and what is ahead if nothing is done.

We need a national agency charged with the responsibility for surveillance of pollution in its essential ramifications. It should be free of all responsibility for compliance, control, management or any similar actions. It should be concerned with surveillance, not with monitoring. Therefore, it should not be charged with the responsibilities of warning. Warning and action should remain in the domain of existing agencies.

A number of government agencies are already actively measuring one aspect of pollution or another. A complete description would be out of place here, but some broad indications are important.

The *internal environment* is dealt with at present by the U.S. Public Health Service and the Atomic Energy Commission. Neither has an extensive or regular "in-house" program, but in cooperation with other agencies or by contract with other institutions they maintain a reasonable surveillance of body levels of Sr^{90}, I^{131}, certain pesticides, and lead.

The *immediate environment* is dealt with at present by the Food and Drug Administration through its several sampling programs, particularly its total diet studies; the U.S. Department of Agriculture through its meat and poultry inspection programs, and the Public Health Service through its surveillance of shellfish and interstate carrier water supplies, its studies of institutional diets, its pasteurized milk network for radioactive contaminants, and some of its air sampling programs.

The *general environment* is dealt with by the Public Health Service through its water pollution surveillance system, its various air monitoring systems, including those for particulate materials, airborne radiation, and sulfur dioxide, by the Geological Survey with its water quality stations; by the Fish and Wildlife Service through its sampling of fish and wildlife for pesticide residues; and by the Department of Agriculture through its pesticide monitoring programs. There has been little done as yet on soil pollution in general, air pollution in outlying areas, pesticides in waters, etc. Although considerably more can be done toward consolidating these data than is being done, even the substantial volume of data presently collected by these agencies cannot be put together in such a way that the influence of many, if any, of the sundry pollutants on our inner and outer environments can be evaluated for the nation as a whole or major regions thereof, and trends determined. The data just aren't collected for that purpose.

THE SURVEY AND ACTION AGENCIES

Sampling modifiable situations for quality raises a problem which may be unfamiliar. Economical sampling, especially when the main purpose is to measure changes in time, usually involves returning to the same person or sampling point in surveys made at successive times. If the person or point is to be as representative in later surveys as in earlier ones, it is important that the results of earlier surveys do not lead to changes in the sampling unit's quality. This means that if one sampling point falls on an unusually polluted stream, or the air pollution at another changes suddenly and drastically for the worse, we must have thought through the consequences of allowing these facts to become known to any agencies, local, state or Federal, with responsibilities for action to abate such situations.

If the quality survey routinely passes on such information, and any reasonable fraction of these instances are abated by action agencies *because* the information was passed on, it will be necessary to use more expensive methods of sampling which do not involve returning to previously used sampling points. If, on the other hand, the information is not passed on, some responsibility for unabated pollution will have to be borne by the Quality Survey. In practice, it would seem that a compromise will have to be worked out, in which information about very drastic cases is passed on as a special warning, while less drastic cases—which are after all representative of many other situations across the country—have their anonymity preserved.

Consider a simple instance of this problem. If 2% of all locations are highly polluted, and a sample of all locations is tested, a few of the sample locations will prove to be highly polluted. If the identity of these locations is made known, and their pollution cleaned up, a resurvey of the same locations would find no single case of high pollution, although about 2% of all locations would still be polluted. If a sample of 100 new locations were tested in the resurvey, the 2% of highly polluted locations would be fairly represented, thus eliminating this source of bias. Because resurvey of an independent sample could not take advantage of the similarities in pollution at one point tested at two times, however, a much larger sample would be required.

Clearly this need for anonymity makes it unusually difficult, and probably impossible, to establish the National Environmental Quality Survey within an agency, and probably even within a department, that has action or enforcement responsibilities.

RELATION TO ONGOING PROGRAMS

The need to avoid duplication of activities and facilities is great. The Quality Survey must make as much use as possible of both collection and analysis facilities of the agencies now monitoring pollution. Its needs for a representative sample will certainly dictate many new collection points. These may often be best operated and manned by the agencies already concerned with such measurements, though issues of anonymity may force the Quality Survey to carry out its own sampling in certain cases.

The possibility of compositing samples for analysis seems to make it possible for the Quality Survey to depend upon the laboratories of other agencies for analysis, to the extent that these facilities are able to provide appropriate and timely measurements.

The exact relationships with existing monitoring and surveillance programs will clearly take careful consideration, but good will and good judgment can lead to much cooperation and reasonable economics.

A POSSIBLE APPROACH TO SAMPLING THE IMMEDIATE ENVIRONMENT

The problems of measurement and sampling for surveillance of the immediate environment seem to be those of first getting a sample of people (or places where people are) and measuring the air, food and water they consume. Even measuring the cumulative effect of their environment such as radioactivity in their bones, deposits of asbestos in their lungs, levels of lead in their blood, and so forth falls in this category because it deals with people. Hence, a representative sample of people is basic to understanding the forces at work on our immediate environment.

One possible approach to this would run as follows: For example, a sample of 100 communities of say 100 families each would provide an adequate basis for discussion. A generally representative sample of communities would be distributed in about 40 states including both the metropolitan and rural zones. Air sampling stations should be set up in a manner that the breathing air of the community is measured, perhaps with specially designed small devices to supplement the present types, particularly for particulate matter and other substances that may be quite local in prevalence. Attention in this survey should be given to the food we eat, the water we drink, and the things we rub against, as well as the air we breathe. The total diet scheme now used by the Food and Drug Administration seems a likely approach but the sampling and analytical details will no doubt be different than the present FDA total diet survey.

In more detail, the immediate environment could perhaps be approached as follows: The objective here is to obtain a basic sample of dwelling units to represent all dwelling units in the U.S. (and perhaps important regions or subgroups) and measure the pollutant content of air, food and water "used" by the people living in the sample dwelling units. By grouping the sample households in, say groups of five, a sample of 10,000 dwelling units could comprise 100 communities with 20 groups of five dwelling units each. Since each group of five could be confined to a single city block (or in the rural areas, its equivalent) the sample could consist of 2,000 sample blocks, all of which need not be used for all observations. Although the optimal number would depend on such factors as the natural variability of the pollutant over space and through time, on costs of data collection gadgetry, analyses and accuracy requirements let's say for illustration that only five of the 20 single blocks in each community should have air monitoring equipment at the start (suitable to measure the more critical components of pollution). Since these would be placed in close proximity to the sample dwelling units to measure the nature of the "home environment" of people, additional devices would be needed at appropriate places to measure air along the main travel routes of commuters and shoppers, and in and around places of work. When properly brought together, the information should permit reasonably good estimates of cumulative and peak exposure levels of air pollutants.

SOME ASPECTS OF THE INTERNAL ENVIRONMENT

In a portion of the sample chosen for measurement of the immediate environment, data could be obtained on the health status of the residents of the homes. Techniques would be similar to those of the National Health Survey but would be modified to include items of particular relevance to environmental pollution. Reported effects of pollutants on the individuals sampled would be recorded. Medical histories would be supplemented, on a volunteer basis, by limited laboratory tests and measurements of chemical substances in body fluids such as blood and urine. Lead and pesticide residues are examples of pollutants that could be sampled in this way. For these and other chemicals such as radioactive pollutants, an additional sampling program might be developed in which the relevant tissues for analysis would be obtained from autopsies and surgical specimens.

A POSSIBLE APPROACH TO SAMPLING THE GENERAL ENVIRONMENT

One approach here would be by drainage areas. A sample of 100 drainage areas in the United States could serve as a representative example. Within each sample area, air pollution could be measured but the main emphasis would probably be on soil and water. Streams should be sampled at various points to determine general pollution levels, independent of whether the sampling point is at a water intake for a municipal water system or at a political boundary. The object is to measure general stream pollution from industrial and civic use and from pesticides. Lands must be sampled with equal care, considering living things as well as soils. Sampling should involve biological as well as chemical evaluation.

In more detail, it is proposed that a small drainage area be used as the basic unit on which to establish a continuing system of monitoring the general environment. The drainage area may range in size from a few square miles to several hundred square miles, depending on the part of the U.S. being dealt with. It is suggested that about 100 would be an adequate number to start with. They should be selected by use of modern probability methods.

The waters of a single drainage area may vary from small trickles to large lakes. In sampling these waters, however, we can take advantage of the way in which the waters flow from smaller streams into larger ones, and from larger ones into rivers and lakes.

The lands of a drainage area may vary even more widely: highly cultivated farm lands may grade through rangelands to rocky mountains and deserts. All are part of the general environment; the pollution of all must be considered in the overall result. We can take advantage of what we know about the likelihood of pollution of different kinds of land in planning the details of the sampling, but we must give all lands their appropriate chance to contribute to the final result.

APPENDIX Y4

Atmospheric Carbon Dioxide

ROGER REVELLE, *Chairman*

WALLACE BROECKER
HARMON CRAIG
C. D. KEELING
J. SMAGORINSKY

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Section I. CARBON DIOXIDE FROM FOSSIL FUELS—THE INVISIBLE POLLUTANT

INTRODUCTION

Only about one two-thousandth of the atmosphere and one ten-thousandth of the ocean are carbon dioxide. Yet to living creatures, these small fractions are of vital importance. Carbon is the basic building block of organic compounds, and land plants obtain all of their carbon from atmospheric carbon dioxide. Marine plants obtain carbon from the dissolved carbon dioxide in sea water, which depends for its concentration on an equilibrium with the carbon dioxide of the atmosphere. Marine and terrestrial animals, including man, procure, either directly or indirectly, the substance of their bodies and the energy for living from the carbon compounds made by plants.

All fuels used by man consist of carbon compounds produced by ancient or modern plants. The energy they contain was originally solar energy, transmuted through the biochemical process called photosynthesis. The carbon in every barrel of oil and every lump of coal, as well as in every block of limestone, was once present in the atmosphere as carbon dioxide.

Over the past several billion years, very large quantities of carbon dioxide have entered the atmosphere from volcanoes. The total amount was at least forty thousand times the quantity of carbon dioxide now present in the air. Most of it became combined with calcium or magnesium, freed by the weathering of silicate rocks, and was precipitated on the sea floor as limestone or dolomite. About one-fourth of the total quantity, at least ten thousand times the present atmospheric carbon dioxide, was reduced by plants to organic carbon compounds and became buried as organic matter in the sediments. A small fraction of this organic matter was transformed into the concentrated deposits we call coal, petroleum, oil shales, tar sands, or natural gas. These are the fossil fuels that power the world-wide industrial civilization of our time.

Throughout most of the half-million years of man's existence on earth, his fuels consisted of wood and other remains of plants which had grown only a few years before they were burned. The effect of this burning on the content of atmospheric carbon dioxide was negligible, because it only slightly speeded up the natural decay processes that continually recycle carbon from the biosphere to the atmosphere. During the last few centuries, however, man has begun to burn the fossil fuels that were locked in the sedimentary rocks over five hundred million years, and this combustion is measurably increasing the atmospheric carbon dioxide.

In the geologic past, the quantity of carbon dioxide in the atmosphere was determined by the equilibrium between rates of weathering and photosynthesis, and the rate of injection of volcanic carbon dioxide. On an earthwide average, both weathering and photosynthesis must speed up when the carbon dioxide content of the air is increased, and slow down when it is diminished; consequently, over geologic time the carbon dioxide in the air must have risen when volcanic activity was high, and must have gone down when volcanoes were quiescent. On a human scale, the times involved are very long. The known amounts of limestone and organic carbon in the sediments indicate that the atmospheric carbon dioxide has been changed forty thousand times during the past four billion years, consequently the residence time of carbon in the atmosphere, relative to sedimentary rocks, must be of the order of a hundred thousand years.

The present rate of production of carbon dioxide from fossil fuel combustion is about a hundred times the average rate of release of calcium and magnesium from the weathering of silicate rocks. As long as this ratio holds, precipitation of metallic carbonates will be unable to maintain an unchanging content of carbon dioxide in the atmosphere. Within a few short centuries, we are returning to the air a significant part of the carbon that was slowly extracted by plants and buried in the sediments during half a billion years.

Not all of this added carbon dioxide will remain in the air. Part of it will become dissolved in the ocean, and part will be taken up by the biosphere, chiefly in trees and other terrestrial plants, and in the dead plant litter called humus. The part that remains in the atmosphere may have a significant effect on climate: carbon dioxide is nearly transparent to visible light, but it is a strong absorber and back radiator of infrared radiation, particularly in the wave lengths from 12 to 18 microns; consequently, an increase of atmospheric carbon dioxide could act, much like the glass in a greenhouse, to raise the temperature of the lower air. [Water vapor also absorbs infrared radiation, both in the range of the CO_2 band centered at 15 microns, and at wave lengths near 6.3 microns. With the average concentration of water vapor in the lower air at mid latitudes, the effect of carbon dioxide absorption is reduced to about half that which would exist in an absolutely dry atmosphere. (Möller, 1963.) Ozone, which is an important constituent of the upper air, also absorbs some infrared at wave lengths around 9.6 microns, but its principal effect on air temperature is due to its absorption of ultraviolet and visible sunlight.]

The possibility of climatic change resulting from changes in the quantity of atmospheric carbon dioxide was proposed independently by the

American geologist, T. C. Chamberlain (1899) and the Swedish chemist, S. Arrhenius (1903), at the beginning of this century. Since their time, many scientists have dealt with one or another aspect of this question, but until very recently there was little quantitative information about what has actually happened. Even today, we cannot make a useful prediction concerning the magnitude or nature of the possible climatic effects. But we are able to say a good deal more than formerly about the change in the quantity of atmospheric carbon dioxide, and about the partition of carbon dioxide from fossil fuel combustion among the atmosphere, the ocean, and the biosphere.

THE RECENT INCREASE IN ATMOSPHERIC CARBON DIOXIDE

During the five years from 1958 through 1962, 5.3 x 10^{16} grams of carbon dioxide were produced by the combustion of coal, lignite, petroleum and other liquid hydrocarbons, and natural gas (see Tables 1 and 2).

TABLE 1.—*Carbon Dioxide Produced by Fossil Fuel Combustion, 1950–62*

[10^{16} grams]

Year	Coal [1]	Lignite [2]	Liquid Hydro-carbons [3]	Natural Gas [4]	Total	As % of Atmospheric CO_2 in 1950
1950	0.37	0.09	0.17	0.04	0.67	0.29
1951	.38	.09	.20	.05	.72	.31
1952	.38	.09	.21	.05	.73	.31
1953	.38	.09	.22	.05	.74	.32
1954	.38	.09	.23	.06	.76	.32
1955	.41	.10	.25	.06	.82	.35
1956	.44	.11	.27	.07	.89	.38
1957	.45	.13	.29	.07	.94	.40
1958	.46	.14	.29	.08	.97	.41
1959	.48	.14	.32	.09	1.03	.44
1960	.50	.14	.34	.10	1.08	.46
1961	.48	.15	.36	.10	1.09	.46
1962	.50	.15	.39	.11	1.15	.49
Total	5.61	1.51	3.54	.93	11.59	4.93

[1] Assumed carbon content, coal=75 percent.

[2] Assumed carbon content, lignite=45 percent.

[3] Assumed carbon content, liquid hydrocarbons=86 percent.

[4] Assumed carbon content, natural gas=70 percent. (Corresponding to a mixture by volume of 80 percent CH_4, 15 percent C_2H_6 and 5 percent N_2.)

Source: Computed from Table 2.

TABLE 2.—*World Production of Fossil Fuels—1950–62*

[Millions of Metric Tons]

Year	Coal	Lignite	Liquid Hydro-carbons[1]	Natural Gas[2]	Total
1950	1,340	530	540	155	2,565
1951	1,375	550	620	180	2,725
1952	1,375	550	655	200	2,780
1953	1,380	555	690	210	2,835
1954	1,375	550	725	220	2,870
1955	1,500	630	790	240	3,160
1956	1,595	665	860	260	3,380
1957	1,625	765	905	285	3,580
1958	1,665	825	930	305	3,725
1959	1,730	845	995	345	3,915
1960	1,810	875	1,075	375	4,135
1961	1,760	900	1,140	405	4,205
1962	1,805	905	1,235	440	4,385
Total	20,335	9,145	11,160	3,620	44,260

[1] Includes Petroleum and Natural Gasoline.

[2] Assumed density of 8×10^{-4} gm cm^{-3} (1000m^3=0.8 ton).

Source: World Energy Supplies. Statistical Papers, Series J, United Nations, New York.

This is 2.25 percent of the 2.35 x 10^{18} grams of carbon dioxide present in the atmosphere in 1950 (assuming an atmospheric carbon dioxide concentration of 300 ppm by volume—445 ppm by weight—and a mass of 5.2 x 10^{21} grams for the entire atmosphere.) On the average during 1958–1962, the CO_2 produced each year by fossil fuel combustion was 0.45 percent of the quantity in the atmosphere.

Beginning in 1958 and extending through 1963, two nearly continuous series of measurements of atmospheric CO_2 content were made. One of these series was taken at the U.S. Weather Bureau station near the top of Mauna Loa Mountain in Hawaii (Pales and Keeling, 1965), the other at the United States scientific station at the South Pole (Brown and Keeling, 1965). The measurements were carried out on an infrared gas spectrometer, with a relative accuracy for a single measurement of about ±0.1 ppm. The observing stations are located near the centers of vast atmospheric mixing areas, far from uncontrollable sources of contaminants. Because of these nearly ideal locations, together with the high precision of the instruments, and the extreme care with which the samples were taken, these measurements make it possible to estimate the secular trend of atmospheric CO_2 with an accuracy greater by two orders of magnitude than ever before. Some fifteen thousand measurements were carried out during the five-year period.

The data show, clearly and conclusively, that from 1958 through 1963 the carbon dioxide content of the atmosphere increased by 1.36 percent. The increase from year to year was quite regular, close to the average annual value of 0.23 percent. By comparing the measured increase with the known quantity of carbon dioxide produced by fossil fuel combustion, given in Table 4, we see that almost exactly half of the fossil fuel CO_2 apparently remained in the atmosphere.

Tables 3 and 4 show that between 1860 and 1940 the amount of CO_2 produced by fossil combustion, chiefly coal, was 7.9 percent, and by 1950, 10.3 percent, of the estimated atmospheric CO_2 content in 1950. By 1959, the total CO_2 production was equal to 13.8 percent of the atmospheric CO_2. Unfortunately, the accuracy of measurements of atmospheric CO_2 before 1958 is too low to allow estimates of the secular variation, and it is therefore impossible to compute directly whether the fraction of fossil-fuel CO_2 remaining in the atmosphere throughout the past hundred years has been constant, or slowly or rapidly changing.

TABLE 3.—*Carbon Dioxide Produced by Fossil Fuel Combustion, 1860–1959*

[10^{16} grams]

Decade	Coal [1]	Lignite [2]	Liquid Hydro-carbons [3]	Natural Gas [4]	Total	As % of Atmos-pheric CO_2 in 1950
1860–69	0.46	0.01			0.47	0.20
1870–79	0.70	.03			.73	.31
1880–89	1.06	.05	0.02		1.13	.48
1890–99	1.49	.08	.04	0.01	1.62	.69
1900–09	2.33	.15	.10	.02	2.60	1.11
1910–19	3.10	.21	.19	.04	3.54	1.53
1920–29	3.26	.31	.48	.07	4.12	1.75
1930–39	3.16	.35	.74	.12	4.37	1.86
1940–49	3.74	.49	1.14	.25	5.62	2.39
1950–59	4.11	1.07	2.44	.62	8.24	3.49
Total	23.41	2.75	5.15	1.13	32.44	13.81

[1] Assumed carbon content, coal=75 percent.

[2] Assumed carbon content, lignite=45 percent.

[3] Assumed carbon content, liquid hydrocarbons=86 percent.

[4] Assumed carbon content, natural gas=70 percent. (Corresponding to a mixture by volume of 80 percent CH_4, 15 percent C_2H_6 and 5 percent N_2).

Source: Computed from Table 4.

TABLE 4.—*World Production of Fossil Fuels, 1860–1959*

[Millions of Metric Tons]

Decade	Coal	Lignite	Liquid Hydro-carbons [1]	Natural Gas [2]	Total
1860–69	1,660	85	5	....	1,750
1870–79	2,560	180	15	....	2,755
1880–89	3,850	285	55	10	4,200
1890–99	5,405	495	140	40	6,080
1900–09	8,455	880	310	80	9,725
1910–19	11,240	1,270	590	155	13,255
1920–29	11,850	1,875	1,510	285	15,520
1930–39	11,500	2,135	2,335	485	16,455
1940–49	13,570	2,995	3,605	970	21,140
1950–59	14,960	6,465	7,710	2,400	31,535
Total	85,050	16,665	16,275	4,425	122,415

[1] Includes petroleum and natural gasoline.

[2] Assumed density of 8×10^{-4} gm cm^{-3} (1000m^3=0.8 ton).

Sources: From 1860 to 1949, United Nations, Department of Economic and Social Affairs: "World Energy Requirements". Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 1, pp. 3–33, 1956. For 1950–59, United Nations, World Energy Supplies. Statistical papers, Series J, United Nations, New York.

There are measurements of a somewhat different kind, which can give us useful information however. These are determinations of the so-called "Suess Effect."

PARTITION OF CARBON DIOXIDE AMONG THE ATMOSPHERE, THE OCEAN, AND THE BIOSPHERE

Because the fossil fuels have been buried for millions of years, they contain no Carbon 14. (This radioactive isotope is produced in the atmosphere by cosmic ray bombardment of nitrogen, and it has a half-life of only about six thousand years.) Consequently, the addition to the atmosphere of CO_2 from fossil fuel combustion, and its subsequent partition among the atmosphere, the ocean, and the biosphere will cause the ratio between radioactive and nonradioactive carbon to decrease. This manifests itself as a measurable reduction in the amount of radioactive carbon, for example, in tree rings grown in recent years compared with rings that grew during the 19th Century. This reduction, due to fossil fuel combustion, is called the "Suess Effect," after Professor Hans Suess, who first observed it (see Revelle and Suess, 1956).

The measurement of the "Suess Effect" is beset with many difficulties, the chief among them being that the Carbon 14 content of the atmosphere—more precisely the ratio of C^{14} to $C^{12}+C^{13}$—varies by 1 or 2 percent from century to century apparently depending on the long-term variations in sunspot intensity. Tree ring measurements show that this ratio went up during the 15th and 17th Centuries, and down during the 16th and 18th, in each case by about 2 percent (Suess, 1956). Prior to the atomic weapons tests of the mid-Fifties, the ratio was lower by between 1 and 2 percent than in the middle of the 19th Century. This change during the past hundred years was apparently largely due to the "Suess Effect."

Taking the "Suess Effect" as between 1 and 2 percent over the period from 1860 to 1950, during which time the total carbon dioxide produced from fossil fuels was 10% of the atmospheric CO_2, and assuming that presently occurring changes in the magnitude of the "Suess Effect" are in the same proportion to CO_2 from fossil fuel combustion as in the past, we can compute both the relative sizes of the oceanic and biosphere reservoirs that are taking up part of the added CO_2, and the partition of CO_2 between these reservoirs. The amount taken up in the biosphere will be different if there are two or more sources of additional carbon dioxide, than if fossil fuels are the only source, but the amount absorbed by the ocean will not vary. Implied in the calculation is the further assumption that any CO_2 from other sources will have about the same ratio of C^{14} to total carbon as the atmosphere. Details are given in Section II.

The calculation shows that if the oceanic layer mixing with the atmosphere is several hundred meters thick, the amount of exchangable carbon in the biosphere is less than or about equal to that in the atmosphere. These are both "reasonable" values. On the other hand, if another significant source of CO_2 is assumed for the last few decades, the amount of CO_2 added to the biosphere becomes so large that it should have been observed. In fact, no increase in the biosphere has been noted. Perhaps the most striking result is that the ocean takes up a relatively small fraction of the total added CO_2, probably about 15%. In the past, the usual scientific belief has been that by far the larger part of any added CO_2 would be absorbed in the ocean. This is undoubtedly true if we consider a sufficiently long time period, of the order of thousands or even, perhaps, hundreds of years, because the ocean as a whole contains nearly sixty times as much carbon dioxide as the atmosphere. But over shorter times, only the uppermost layers of the ocean take part in exchanges with the air. Moreover, most of the oceanic carbon dioxide is present as carbonate and bicarbonate, balanced against metallic cations, and a marked increase in oceanic CO_2 therefore requires an increase in cation concentration, which can be brought about only by rock weathering or solution of calcium-rich sediments. These are slow processes.

PROBABLE FUTURE CONTENT OF CARBON DIOXIDE IN THE ATMOSPHERE

We can conclude with fair assurance that at the present time, fossil fuels are the only source of CO_2 being added to the ocean-atmosphere-biosphere system. If this held true throughout the last hundred years, the quantity of CO_2 in the air at the beginning of the present decade was about 7% higher than in the middle of the last century (see Table 3).

Throughout these hundred years, the rate of fossil fuel combustion, and thus of CO_2 production, continually increased, on the average about 3.2 percent per year. The amount produced in 1962 was almost 25 times the annual production in the mid-1860's. The rate of increase may be accelerating. During the eight years from 1954 to 1962, the average rate of increase was 5%.

We can ask several questions about the future CO_2 content of the atmosphere. Two of these questions are:

(1) What will the total quantity of CO_2 injected into the atmosphere (but only partly retained there) be at different future times?

(2) What would be the total amount of CO_2 injected into the air if all recoverable reserves of fossil fuels were consumed? At present rates of expansion in fossil fuel consumption this condition could be approached within the next 150 years.

The second question is relatively easy to answer, provided we consider only the estimated recoverable reserves of fossil fuels. The data are shown in Table 5. We may conclude that the total CO_2 addition from fossil fuel combustion will be a little over 3 times the atmospheric content, and that, if present partitions between reservoirs are maintained, the CO_2 in the atmosphere could increase by nearly 170 percent.

The answer to the first question depends upon the rate of increase of fossil fuel combustion. Table 6 shows that if this combustion remains constant at the 1959 level, the total CO_2 injected into the atmosphere by the year 2000 will be about 28 percent of the atmospheric content in 1950. If the average rate of increase of combustion continues at 3.2 percent per year, the quantity injected into the atmosphere by the year 2000 will be about 42 percent; if the 5% rate of increase during the last 8 years persists, the quantity injected will be close to 60 percent. Assuming further that the proportion remaining in the atmosphere continues to be half the total quantity injected, the increase in amospheric CO_2 in the year 2000 could be somewhere between 14 percent and 30 percent.

Based on projected world energy requirements, the United Nations Department of Economic and Social Affairs (1956) has estimated an amount of fossil fuel combustion by the year 2000 that with our assumed partitions would give about a 25 percent increase in atmospheric CO_2, compared to the amount present during the 19th Century. For convenience, we shall adopt this figure in the following estimate of the effects on atmospheric radiation and temperature.

TABLE 5.—*Estimated Remaining Recoverable Reserves of Fossil Fuels*

	10^9 Metric Tons	Carbon Dioxide Equivalent, 10^{18} grms	As % of Atmospheric CO_2 in 1950
Coal and Lignite [1]	2,320	5.88	252
Petroleum and Natural Gas Liquids [2]	212	.67	29
Natural Gas [3]	166	.43	18
Tar Sands [2]	75	.24	10
Oil Shales [2]	198	.63	27
Total	2,971	7.85	336

[1] Assumed to be 20 percent lignite containing 45 percent carbon, and 80 percent bituminous coal containing 75 percent carbon.

[2] Assumed carbon content of petroleum, natural gas liquids, and hydrocarbons recoverable from tar sands and oil shales=86 percent.

[3] Assumed composition of natural gas by volume: CH_4=80 percent, C_2H_6=15 percent, N_2=5 percent.

Source: Computed from data given by M. King Hubbert, "Energy Resources, A Report to the Committee on Natural Resources of the National Academy of Sciences—National Research Council," NAS Publication 1000–D, 1962, pp. 1–141.

TABLE 6.—*Estimates of Carbon Dioxide From Fossil Fuel Combustion in Future Decades, Assuming Different Rates of Increase of Fuel Use*

Year	As percent of Atmospheric CO_2 in 1950		
Growth rate, percent/year	0	3.2	5.0
1959	13.80	13.80	13.80
1969	17.30	18.00	18.47
1979	20.79	23.79	26.15
1989	24.28	31.94	37.90
1999	27.77	41.96	58.75
2009	31.26	57.04	93.14

POSSIBLE EFFECTS OF INCREASED ATMOSPHERIC CARBON DIOXIDE ON CLIMATE

One of the most recent discussions of these effects is given by Möller (1963). He considers the radiation balance at the earth's surface with an average initial temperature of 15°C (59°F), a relative humidity of 75 percent, and 50% cloudiness. We may compute from his data that with a 25 percent increase in atmospheric CO_2, the average temperature near the earth's surface could increase between 0.6°C and 4°C (1.1°F to 7°F), depending on the behavior of the atmospheric water vapor content. The small increase would correspond to a constant absolute humidity, that is, a constant weight of water in the atmosphere. The larger increase would correspond to a constant relative humidity, that is, as the temperature rose, the water vapor content would also rise to maintain a constant percentage of the saturation value. A doubling of CO_2 in the air, which would happen if a little more than half the reserves of fossil fuels were consumed, would have about three times the effect of a twenty-five percent increase.

As Möller himself emphasized, he was unable to take into account the vertical transfer of latent heat by evaporation at the surface and condensation aloft, or of sensible heat by convection and advection. For this reason he was unable to consider the interactions between different atmospheric layers in a vertical column. In consequence, Möller's computations probably over-estimate the effects on atmospheric temperature of a CO_2 increase. A more comprehensive model is being developed by the U.S. Weather Bureau. This includes processes of convection and of latent heat transfer through the evaporation and condensation of water vapor. Meaningful computations should be possible with this model in the very near future. But climatic changes depend on changes in the general circulation in the atmosphere, and these will be related to the spatial distribution and time variation of carbon dioxide and water vapor. The ratio of CO_2 to water vapor is higher in the polar regions than in low latitudes, higher in winter than in summer, and much higher in the stratosphere than near the ground. For example, the volume of carbon dioxide in the atmosphere at high latitudes is about half the volume of water vapor, while near the equator it is less than a tenth of the water vapor volume. As a result, the radiation balance of the earth will be affected differently at different seasons, latitudes, and heights by changes in the atmospheric CO_2 content. Without a comprehensive model incorporating both the fluid dynamics and the radiation transfer processes of the atmosphere it is not possible to predict how these effects will perturb the general circulation. Such a model may be available within the next two years.

Models of atmospheric thermal equilibrium in which vertical convection is allowed to maintain the observed vertical temperature gradient have recently been constructed by S. Manabe of the U.S. Weather Bureau (Manabe and Strickler, 1964; Manabe, 1965). These show that the effect of infra red absorption from the present atmospheric carbon dioxide at mid latitudes is to maintain a ground temperature about 10°C (18°F) higher than would prevail if no CO_2 were present. An increase in the CO_2 content without a change in absolute humidity would, according to these models, produce a somewhat smaller surface temperature rise than that estimated by Möller. But a considerable change would occur in the stratosphere, where the CO_2 concentration by volume is perhaps 50 times that of water vapor. A 25% rise in carbon dioxide would cause stratospheric temperatures to fall by perhaps 2°C (3.6°F) at an altitude of 30 kilometers (about 100,000 feet) and by 4°C (7°F) at 40 kilometers (about 130,000 feet).

One might suppose that the increase in atmospheric CO_2 over the past 100 years should have already brought about significant climatic changes, and indeed some scientists have suggested this is so. The English meteorologist, G. S. Callendar (1938, 1940, 1949), writing in the late 1930's and the 1940's on the basis of the crude data then available, believed that the increase in atmospheric CO_2 from 1850 to 1940 was at least 10%. He thought this increase could account quantitatively for the observed warming of northern Europe and northern North America that began in the 1880's. From Table 2 and our estimate of the CO_2 partition between the atmospheric, the ocean, and the biosphere, we see that the actual CO_2 increase in the atmosphere prior to 1940 was only 4%, at least from fossil fuel combustion. This was probably insufficient to produce the observed temperature changes. [But it should be noted that up to 2.5% of the atmospheric carbon dioxide (after partition with the ocean and the biosphere) could also have been added by the oxidation of soil humus in newly cultivated lands.]

As Mitchell (1961, 1963) has shown, atmospheric warming between 1885 and 1940 was a world-wide phenomenon. Area-weighted averages for surface temperature over the entire earth show a rise in mean annual air temperature of about 0.5°C (0.9°F). World mean winter temperatures rose by 0.9°C (1.6°F). Warming occurred in both hemispheres and at all latitudes, but the largest annual rise (0.9°C or 1.6°F) was observed between 40° and 70° N latitudes. In these latitudes, the average winter temperatures rose by 1.6°C (2.8°F).

The pronounced warming of the surface air did not continue much beyond 1940. Between 1940 and 1960 additional warming occurred in northern Europe and North America, but for the world as a whole and also for the northern hemisphere, there was a slight lowering of about 0.1°C (0.2°F) in mean annual air temperature (Mitchell, 1963). Yet during this period more than 40% of the total CO_2 increase from fossil fuel combustion occurred. We must conclude that climatic "noise" from other processes has at least partially masked any effects on climate due to past increases in atmospheric CO_2 content.

OTHER POSSIBLE EFFECTS OF AN INCREASE IN ATMOSPHERIC CARBON DIOXIDE

Melting of the Antarctic ice cap.—It has sometimes been suggested that atmospheric warming due to an increase in the CO_2 content of the atmosphere may result in a catastrophically rapid melting of the Antarctic ice cap, with an accompanying rise in sea level. From our knowledge of events at the end of the Wisconsin period, 10 to 11 thousand years ago, we know that melting of continental ice caps can occur very rapidly on a geologic time scale. But such melting must occur relatively slowly on a human scale.

The Antarctic ice cap covers 14 million square kilometers and is about 3 kilometers thick. It contains roughly 4×10^{16} tons of ice, hence 4×10^{24} gram calories of heat energy would be required to melt it. At the present time, the poleward heat flow across 70° latitude is 10^{22} gram calories per year, and this heat is being radiated to space over Antarctica without much measurable effect on the ice cap. Suppose that the poleward heat flux were increased by 10% through an intensification of the meridional atmospheric circulation, and that all of this increase in the flow of energy were utilized to melt the ice. Some 4,000 years would be required.

We can arrive at a smaller melting time by supposing a change in the earth-wide radiation balance, part of which would be used to melt the ice. A 2% change could occur by the year 2000, when the atmospheric CO_2 content will have increased perhaps by 25%. Since the average radiation at the earth's surface is about 2×10^5 gram calories per square centimeter per year, a 2% change would amount to 2×10^{22} calories per year. If half this energy were concentrated in Antarctica and used to melt the ice, the process would take 400 years.

Rise of sea level.—The melting of the Antarctic ice cap would raise sea level by 400 feet. If 1,000 years were required to melt the ice cap, the sea level would rise about 4 feet every 10 years, 40 feet per century. This is a hundred times greater than present worldwide rates of sea level change.

Warming of sea water.—If the average air temperature rises, the temperature of the surface ocean waters in temperate and tropical regions could be expected to rise by an equal amount. (Water temperatures in the polar regions are roughly stabilized by the melting and freezing of ice.) An oceanic warming of 1° to 2°C (about 2°F) occurred in the North Atlantic from 1880 to 1940. It had a pronounced effect on the distribution of some fisheries, notably the cod fishery, which has greatly increased around Greenland and other far northern waters during the last few decades. The amelioration of oceanic climate also resulted in a marked retreat of sea ice around the edges of the Arctic Ocean.

Increased acidity of fresh waters.—Over the range of concentrations found in most soil and ground waters, and in lakes and rivers, the hydrogen ion concentration varies nearly linearly with the concentration of free CO_2. Thus the expected 25% increase in atmospheric CO_2 concentration by the end of this century should result in a 25% increase in the hydrogen ion concentration of natural waters or about a 0.1 drop in pH. This will have no significant effect on most plants.

Increase in photosynthesis.—In areas where water and plant nutrients are abundant, and where there there is sufficient sunlight, carbon dioxide may be the limiting factor in plant growth. The expected 25% increase by the year 2000 should significantly raise the level of photosynthesis in such areas. Although very few data are available, it is commonly believed that in regions of high plant productivity on land, such as the tropical rain forests, phosphates, nitrates and other plant nutrients limit production rather than atmospheric CO_2. This is probably also true of the oceans.

Biological processes are speeded up by a rise in temperature, and in regions where other conditions are favorable higher temperatures due to increased CO_2 might result in higher plant production.

OTHER POSSIBLE SOURCES OF CARBON DIOXIDE

We are fairly certain that fossil fuel combustion has been the only source of CO_2 coming into the atmosphere during the last few years, when accurate measurements of atmospheric carbon dioxide content have been available. Carbon dioxide may have been produced by other sources during earlier times but it is not now possible to make a quantitative estimate. However we can examine the order of magnitude of some of the possible inputs from other sources, on the basis of our knowledge of the processes that might be involved.

Oceanic warming.—The average temperature of the ocean cannot have increased by more than 0.15°C during the past century, since any greater warming would have caused a larger rise in sea level than the observed value of about 10 centimeters. A more probable upper limit is .05°C, because most of the sea level rise can be accounted for by glacial melting. An average .05°C rise would correspond to 0.5° in the top 400 meters. This would cause a nearly 3% rise in the CO_2 partial pressure.

After equilibration with the atmosphere, the partial pressure in both the air and the uppermost ocean layer would be higher by about 2.5%.

Burning of limestone.—Annual world production of carbon dioxide from the use of limestone for cement, fluxing stone, and in other ways, is about 1% of the total from fossil fuel combustion, or 4 x 10^{-5} of the atmospheric CO_2 content per year.

Decrease in the carbon content of soils.—Since the middle of the Ninetenth Century, the world's cultivated farmland has been enlarged by about 50%. This is an increase of close to a billion acres or 1.6 million square miles, corresponding to 2.7% of the land area of the earth, and perhaps to 5% of forests and grass lands. Most soil humus is believed to be concentrated in forests and grassy areas. Assume that the total humus is equal to twice the amount of carbon in the atmosphere and that half the carbon in the humus of the newly cultivated lands has been oxidized to carbon dioxide. The total injected into the atmosphere from this source becomes less than 5% of the atmospheric CO_2.

Change in the amount of organic matter in the ocean.—About 7% of the marine carbon reservoir consists of organic material. Since a 1% change in the carbon dioxide content of the ocean changes the CO_2 pressure by 12.5%, a decrease by 1% in the marine organic carbon (which would increase the total oceanic carbon dioxide by .07%) would raise the carbon dioxide pressure of the ocean and the atmosphere by about 1%. An increase in the temperature of water near the surface, during the past one hundred years, could have speeded up the rate of oxidation of organic matter relative to its rate of production by photosynthesis. Measurements of the content of organic matter in the ocean are neither accurate enough nor sufficiently extended over time to allow a direct estimate of this possibility. A change of several percent could have occurred without detection.

Changes in the carbon dioxide content of deep ocean water.—The deep ocean waters contain about 10% more carbon dioxide than they would if they were at equilibrium with the present atmospheric content. This is a result of the sinking of dead organic remains from the surface waters and their subsequent oxidation in the depths. The combination of biological and gravitational processes can be thought of as a pump that maintains a relatively low carbon dioxide content in the surface waters and in the atmosphere. If the pump ceased to act, the atmospheric carbon dioxide would eventually be increased five fold. Variations in the effectiveness of the pump could have occurred without detection during the past 100 years, and could have caused notable changes in the atmospheric carbon dioxide content.

Changes in the volume of sea water.—During the Ice Age the volume of sea water varied by about 5%. Changes of this magnitude would change the carbon dioxide content of the atmosphere by 10 to 15%.

But during the last several thousand years, variations in oceanic volume have been small. During the past hundred years, world average sea level has varied by less than 10 centimeters. This very small volume change would have no appreciable effect on the atmospheric carbon dioxide.

Carbon dioxide from volcanoes.—Over geologic time, volcanic gases have been the principal sources of new carbon dioxide injected into the atmosphere. On the average the influx of volcanic CO_2 must have balanced the extraction from the atmosphere by rock weathering. The present rate of influx of volcanic CO_2 is close to a hundred fold less than that from fossil fuel combustion. No data exist on the worldwide level of volcanic activity over geologic time. It is conceivable that the level has fluctuated by two orders of magnitude, and that the fluctuations persisted for millenia, or even for millions of years.

Changes due to solution and precipitation of carbonates.—Calcium and magnesium carbonate precipitation on the sea floor lower the total CO_2 content of ocean water, but increase the carbon dioxide pressure and the free CO_2 content. Conversely, chemical weathering of limestone and dolomite on land lower the atmospheric CO_2 and the free CO_2 content of the sea, but increase the total oceanic CO_2. The rates of these processes are about one order of magnitude lower than the present rate of production of carbon dioxide by fossil fuel combustion.

We conclude that the only sources of carbon dioxide comparable in magnitude to fossil fuel combustion during the last 100 years could have been a decrease in soil humus due to the increase in the area of cultivated lands, a decrease in the content of "dissolved" organic matter in the ocean, or a lowering of the carbon dioxide content of deep ocean waters. Marked changes in the oceanic regime would have been necessary for the latter two processes to have significant effects. As we have shown, none of the three processes are likely to be significant at the present time. Nor are any oceanographic data available which suggest that the required changes in the ocean occurred during the last hundred years.

CONCLUSIONS AND FINDINGS

Through his worldwide industrial civilization, Man is unwittingly conducting a vast geophysical experiment. Within a few generations he is burning the fossil fuels that slowly accumulated in the earth over the past 500 million years. The CO_2 produced by this combustion is being injected into the atmosphere; about half of it remains there. The estimated recoverable reserves of fossil fuels are sufficient to produce nearly a 200% increase in the carbon dioxide content of the atmosphere.

By the year 2000 the increase in atmospheric CO_2 will be close to 25%. This may be sufficient to produce measurable and perhaps marked changes in climate, and will almost certainly cause significant changes in the temperature and other properties of the stratosphere. At present it is impossible to predict these effects quantitatively, but recent advances in mathematical modelling of the atmosphere, using large computers, may allow useful predictions within the next 2 or 3 years.

Such predictions will need to be checked by careful measurements: a series of precise measurements of the CO_2 content in the atmosphere should continue to be made by the U.S. Weather Bureau and its collaborators, at least for the next several decades; studies of the oceanic and biological processes by which CO_2 is removed from and added to the atmosphere should be broadened and intensified; temperatures at different heights in the stratosphere should be monitored on a worldwide basis.

The climatic changes that may be produced by the increased CO_2 content could be deleterious from the point of view of human beings. The possibilities of deliberately bringing about countervailing climatic changes therefore need to be thoroughly explored. A change in the radiation balance in the opposite direction to that which might result from the increase of atmospheric CO_2 could be produced by raising the albedo, or reflectivity, of the earth. Such a change in albedo could be brought about, for example by spreading very small reflecting particles over large oceanic areas. The particles should be sufficiently buoyant so that they will remain close to the sea surface and they should have a high reflectivity, so that even a partial covering of the surface would be adequate to produce a marked change in the amount of reflected sunlight. Rough estimates indicate that enough particles partially to cover a square mile could be produced for perhaps one hundred dollars. Thus a 1% change in reflectivity might be brought about for about 500 million dollars a year, particularly if the reflecting particles were spread in low latitudes, where the incoming radiation is concentrated. Considering the extraordinary economic and human importance of climate, costs of this magnitude do not seem excessive. An early development of the needed technology might have other uses, for example in inhibiting the formation of hurricanes in tropical oceanic areas.

According to Manabe and Strickler (1964) the absorption and reradiation of infrared by high cirrus clouds (above five miles) tends to heat the atmosphere near the earth's surface. Under some circumstances, injection of condensation or freezing nuclei will cause cirrus clouds to form at high altitudes. This potential method of bringing about climatic changes needs to be investigated as a possible tool for modifying atmospheric circulation in ways which might counteract the effects of increasing atmospheric carbon dioxide.

Section II. DETAILED COMPUTATIONS

Calculation of the Relative Sizes of the Ocean and Biosphere Reservoirs and the Probability of Other Sources of Carbon Dioxide at the Present Time

A portion of the carbon dioxide coming into the atmosphere will be transferred to the ocean, and another part will enter the biosphere. We can test the possibility of carbon dioxide sources other than fossil fuel combustion by examining the relative sizes of the required ocean and biosphere reservoirs.

Let

$A = CO_2$ in atmosphere.
$B =$ equivalent CO_2 in the part of the biosphere that exchanges with the atmosphere.
$M = CO_2$ in the oceanic reservoir that exchanges with the atmosphere.
ΔA, ΔB, $\Delta M =$ changes in CO_2 content of these reservoirs.
$s = \dfrac{-\Delta C^{14}O_2}{C^{14}O_2}$ in the reservoir system, $A+B+M$.
$a = \dfrac{\Delta A}{A} =$ fractional change of atmospheric CO_2 content.
$fA = CO_2$ produced by fossil fuel combustion.
$bA = CO_2$ produced by other processes.

Then, at equilibrium,

$$\Delta A + \Delta B + \Delta M = (f+b)A$$
$$\Delta A = aA$$

$\Delta M = oM$, where $o = \dfrac{a}{12.5}$, owing to the buffer mechanism of sea water (Bolin and Eriksson, 1958).

And assuming that CO_2 produced by other processes has approximately the same C^{14} content as the atmospheric CO_2, and knowing that fossil fuel CO_2 contains no C^{14}.

$$A + B + M = \frac{f}{s} A$$

Solving for ΔB, M, and ΔM, we find

$$\Delta B = A\left(o+f+b+oc-\frac{of}{s}-a\right) \tag{1}$$

$$M = A\left(\frac{f}{s}-1-c\right) \tag{2}$$

$$\Delta M = oA\left(\frac{f}{s}-1-c\right) \tag{3}$$

Where

$$c=\frac{B}{A}$$

We know from measurements of tree rings grown during the middle of the Nineteenth Century, compared with those grown during the last few years, that for the period 1850–1950

$0.02 \geq s \geq 0.01$ (the "Suess Effect")

During this same period, $f=0.1$, hence

$$\frac{f}{5} \geq s \geq \frac{f}{10}.$$

The series of atmospheric CO_2 measurements at Mauna Loa and Antarctica from 1958–1963 show that during these years

$$a=\frac{f}{2}.$$

Substituting in equations (1), (2) and (3) we find, for different values of b and $\frac{B}{A}$, the values shown in Table 7 for $\frac{M}{A}$, $\frac{\Delta M}{f}$ and $\frac{\Delta B}{f}$.

From this table we see that with a "Suess Effect" of 2% (the most probable value), with fossil fuel combustion as the sole source of additional CO_2, and with "effective" biosphere sizes of 2.5 to 0.5 times the atmospheric CO_2, the oceanic reservoir is 2.6% to 6.0% of the volume of the oceans, equivalent to a layer of water 100 to 240 meters thick just below the surface. The size of the oceanic reservoir varies inversely with the size of the biosphere. For a "Suess Effect" of 1% (probably too low), and the same range of biosphere sizes, the assumed layer of complete mixing contains 11% to 14% of the ocean volume, and has an effective thickness of 440 to 560 meters.

TABLE 7.—*Possible Sizes of Oceanic and Biosphere Reservoirs and Partition of Added CO_2 Among Reservoirs*

$b=0$; $s=0.2f$; $a=0.5f$ ($f=0.1$)

$\frac{B}{A}$	$\frac{M}{A}$	$\frac{\Delta B}{f}$	$\frac{\Delta M}{f}$	$\frac{\Delta B}{B}$	$\frac{\Delta M}{M}$
0.5	3.5	0.36	0.14	0.072	0.004
1.0	3.0	.38	.12	.038	.004
1.5	2.5	.40	.10	.027	.004
2.0	2.0	.42	.08	.021	.004
2.5	1.5	.44	.06	.018	.004
$b=0$; $s=0.1f$; $a=0.5f$					
0.5	8.5	.16	.34	.032	.004
1.0	8.0	.18	.32	.018	.004
1.5	7.5	.20	.30	.013	.004
2.0	7.0	.22	.28	.011	.004
2.5	6.5	.24	.26	.010	.004
$b=.5f$; $s=0.2f$; $a=0.5f$					
0.5	3.5	.86	.14	.172	.004
1.0	3.0	.88	.12	.088	.004
1.5	2.5	.90	.10	.060	.004
2.0	2.0	.92	.08	.046	.004
2.5	1.5	.94	.06	.038	.004

A layer of water a few hundred meters thick would be acceptable to oceanographers as defining mixing over several decades. Hence, if the "Suess Effect" is close to 2%, the size of the biosphere reservoir is probably about equal to, or less than, that of the atmospheric reservoir. This coincides with other estimates that the effective size of the biosphere on land, including both living organisms and humus, ranges from ½ to one times the atmospheric carbon content. Possibly the organic content of the oceanic mixing layer should be included in the biosphere reservoir, but this is only a few tenths of the atmospheric CO_2.

In terms of the amounts of carbon they contain, the biosphere reservoir is much smaller than the oceanic reservoir. However, over short times in the ocean, only the relatively small "free" CO_2 content (dissolved and hydrated carbon dioxide) needs to be taken into account. Most of the oceanic carbon dioxide is present as carbonate and bicarbonate, and because of the peculiar buffer mechanism of sea water they do not have a very large quantitative effect on the partition between the sea and the air.

The Table shows if sources other than fossil fuel combustion had contributed much carbon dioxide to the air within the last few decades, the biosphere would have increased in size by what is probably an observable amount. Such an increase has not been noted. We can conclude that, at least during the recent past, fossil fuel combustion has been the only significant source of CO_2 added to the ocean-atmosphere-biosphere system. The available data do not rule out the possibility that in earlier decades carbon dioxide may have come from oxidation of marine or terrestrial humus, as well as from fossil fuels, but if so, more than half of the amount produced was re-absorbed in the biosphere and the ocean.

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APPENDIX Y5

Solid Wastes

JOHN C. CALHOUN, JR., *Chairman*
PATRICK CONLEY
AARIE J. HAAGEN-SMIT
NORMAN HACKERMAN
LEONHARD KATZ
GEORGE J. MASLACH
LOUIS H. RODDIS
JAMES E. HILL, *Staff*

Contents

SUMMARY AND FINDINGS

The problems of solid wastes have not been so immediately pressing as those of gaseous and liquid wastes. In the long run, however, solid waste problems are likely to be the more critical. The subject is broader than the simple disposing of solids. Measures for handling solid wastes have a direct bearing on the character of both air and water pollution, which must be taken account of in solid waste management.

The solid waste problem is heterogeneous and includes a number of separate areas of deliberate waste management. The different parts of the solid waste spectrum, however, are not subject to equal degrees of deliberateness nor to equivalent levels of sophistication of treatment. The handling of human solid wastes is relatively advanced in its technology, whereas other aspects of solid waste treatment have not moved very far from the invention of the garbage pail and the city dump. Some forms of solid waste are taken immediately from the home to ultimate disposal, while other forms go through a significant amount of processing and salvaging.

Waste management systems can be categorized according to the stimuli that lead to deliberate waste management programs. These are:

(1) Control of health or hazard,
(2) Economic incentive or salvage of a waste product,
(3) Conservation or future economic value, and
(4) Removal of an esthetic insult.

The level of attention to waste management, the degree to which technology has been developed, and the evolution of management techniques are approximately in the order in which these stimuli are listed. Orderliness, per se, appears to have no economic or health incentive and must be encouraged according to other values. Consequently, those pollution problems that fall in the eye-displeasing category, such as automobile hulks, are the most difficult to handle.

Solid wastes can be classified according to many schemes. Our living and waste management practices produce a logical division for this discussion into the categories of sewage, meaning principally human and organic wastes that are carried by water and treated as a unit in our usual disposal systems; trash and garbage, meaning primarily the material picked up in cities from the average home and commercial establishment; automobile hulks; and demolition material.

Sewage.—Sewage handling is the least primitive of solid wastes disposal technologies. There are large capital investments in sewage disposal systems in most of our cities, yet their solid content loads are relatively low. The existing water carrying systems for sewage should be studied to determine if they offer a convenient way for collecting and transporting additional solid wastes. The load on the sewage systems has changed principally through the advent of the home garbage grinder. It appears feasible to add other solid content to the carrying water and thereby transport a larger part of our solid wastes to the central sewage disposal plant. This may apply especially to collected trash that can be ground at special stations.

It is important also to examine other means of altering the existing water-transported sewage disposal operation, for example, by partially decentralizing waste treatment to combine home septic tanks or their equivalent with centralized sewage disposal systems. Also, it might be possible to introduce closed cycles for water-carried sewage handling at the individual home, with the solid sludge being disposed of separately.

Existing legislative and federal demonstration programs have been directed toward handling the traditional sewage load and to the development of centralized sewage treatment. Increased attention should be given to comprehensive solid waste collection to be integrated with existing collection and treatment systems. Such integration will require re-examination of the suitability of existing processes for adequately treating the new types of wastes arriving at the central disposal plant. Existing systems have been devised with little contribution from chemists, biologists and other scientists.

The research and demonstration programs of the Department of Health, Education, and Welfare should give increased support to major alterations in existing sewage handling systems, to substitute systems, and to various combinations of centralized and decentralized collection or treatment including decentralized systems applicable to situations which obtain in rural and small communities.

The Department of Health, Education, and Welfare should utilize its contracts and grants in the sewage treatment field to encourage contributions from chemists, biochemists, microbiologists and biologists for developing innovations in the technology of sewage treatment.

Trash and garbage.—The technology of trash management is in a more primitive state. There is need not only for improvement of components in the existing systems for handling trash, but also for a careful look at new systems. It is necessary to stimulate regional authorities to bring political units together for management of solid wastes, and to consolidate waste management systems having to do with all pollution matters. Planners should recognize the importance of waste disposal systems. Land beneficiation should be a goal to be achieved through designs for the ultimate disposal of trash.

Specifically:

(a) The Department of Health, Education, and Welfare should be authorized to establish design competitions, followed by construction of prototypes for demonstration, for the purpose of improving existing solid waste systems. Examples are competitions for design of trucks that efficiently gather and compact trash from individual homes or for incinerators to improve the solid waste combustion process.

(b) The Department of Health, Education, and Welfare should be authorized to initiate demonstration projects for new and improved systems of handling solid wastes to show what can be done to approach the problem from other than traditional methods. As an example, an air-actuated system might be constructed for extracting waste periodically from a home depository into a central collection system. Such demonstration projects should bring together city managers, design engineers and manufacturers to gain the optimum efficiency of customer demand, available technology and management. Demonstrations must be carried on in cities of sufficient size to give the kind of pollution load that accompanies concentrations of populations. This would include cities of a hundred thousand or more and particularly cities that are now suffering from saturation due to their geographical location or to inadequate disposal systems. Funding formulae should be developed to team the Federal Government with local political units for stimulating the development of appropriate effective and efficient waste disposal equipment.

(c) Funds should be made available through the Department of Health, Education, and Welfare for use in government installations, in order to demonstrate innovation, as for example at large military bases which offer a possibility for dealing with defined populations. Military bases contain the complex mix of waste disposal problems found in large population centers.

(d) All agencies involved with approvals of urban and regional plans should recognize the inclusion of urban waste systems and the allocation of land for this purpose as prerequisites to approving or funding. This matter should have equal priority with transportation, school, or water supply systems. The ultimate disposal of trash should be designed to achieve land beneficiation as a goal.

(e) The Department of Housing and Urban Development should embark upon an immediate program of funding projects for cities to use present technology to clean up obviously critical solid waste practices, such as open dump burning or unsanitary land fill.

Auto Hulks.—The junk automobile problem does not appear to be a technological matter, but rather one of management and incentive for disposal. The principal eyesore results from the storage of automobile hulks which have been or still are being processed for removal of spare parts until such times as the scrap steel market makes it profitable to sell them. These hulks are in private ownership on private lots and there is very little in the way of a health or hazard problem to generate action. The problem is sufficiently widespread, however, to make it a public issue.

The basic short range problem is how the storage of automobile hulks can be changed to reduce the number and screen the necessary remnant. Part of this question concerns the focus of responsibility for this problem. The hulk is the product of a processing operation which starts with the acquisition of an old automobile. The automobile is processed for its parts and the dealer makes sufficient profit to enable him to store the hulk as a dead item. It is not certain, however, that the cost for the ultimate disposal of the hulk can be absorbed by the junk auto processor.

Steel is a valuable natural resource and part of the total question should be its conservation. Aside from the esthetic reason for eliminating auto hulk storage, there are conservation reasons why centralized accumulation of these hulks might be considered.

Specifically:

(a) A tax should be devised to provide an incentive for eliminating long-term storage or holding of junk automobiles; for instance, an annual Federal or State license might be imposed on all automobiles except those currently licensed for road use; or, a personal property tax might be placed upon junk cars. The tax approach has fewer difficulties than any of the subsidy approaches considered by the subpanel.

(b) The Bureau of Mines should increase markedly its studies and research to speed the recycling of junk car steel, and to provide means for storing junk car hulks in excess of current demands of the iron and steel market.

(c) The Department of Commerce should investigate providing general aid to alleviate the junk car problem in small and remote communities by sponsoring a "clean-up train" which would collect, dismantle, and compress junked automobiles and other outsized items.

Demolition.—Demolition wastes are increasing in volume at a rapid rate as a result of urban renewal and massive highway development programs. It is too early to see all the ramifications of this solid waste problem. To reduce the requirement for land fill areas some attention should be given to the salvage of demolition wastes.

The Corps of Engineers, the Bureau of Public Roads or other suitable agency should be authorized to undertake research and demonstration projects dealing with the recovery of salvageable products from demolition wastes and their possible recycling to new construction.

General considerations.—Overall, the subpanel views the solid waste problem as tied to the production and consumption of our technological society. A frequently quoted figure estimates the unit output of municipal solid wastes to be 1,600 pounds per capita per year or 4.5 pounds per capita per day. Currently, this means 250 billion pounds of municipal solid wastes per year for which the collection and disposal costs are estimated variously to be 1.5 to 2.5 billion dollars. It is desirable to keep the problem from becoming any bigger than it is now. This will require an analysis in depth of the system aspects of solid waste disposal.

The National Academy of Sciences and the National Academy of Engineering should jointly undertake an intensive study of the broad area of disposal of sewage, trash and garbage, emphasizing the system aspects and the types of innovation needed to give new stimulus and direction to solid waste technology.

City planners and urban designers should consider the use of land for fill and for waste disposal operations as a high priority use. There should be consideration of the importance of artificial green belts following land-fill operations, as well as of naturally preserved green areas within the urban community integrated with waste disposal practices. Many of the problems that exist are sociological and political rather than technological. In many instances, progress will be a matter of stimulation by a few leaders and by knowledgeable city planners and administrative managers. It is important that cities recognize this problem and obtain qualified and trained personnel for responsible jobs in designing and operating waste disposal systems. The subpanel recognizes a considerable public education job in this field, and the lack of attention to solid waste management problems in the universities indicates a need for stimulation of the academic community.

Fellowships and grants should be available through the Department of Health, Education, and Welfare program for universities to embark upon systems engineering studies at the graduate level and upon programs in public administration, environmental sciences or similiar area studies pertinent to the solid waste field. This effort should be directed toward the involvement of academic faculties and graduate students as a means of catalyzing the entire educational community in this field.

Although every technological advance contributes to our waste problem in some form, the automobile seems to be the source of many of our problems, ranging all the way from automobile exhaust to automobile hulks and human wreckage resulting from automobile use. Appropriate Federal agencies should give special attention to research on all aspects of automobiles, including methods of energy conversion, safety procedures, and safety devices. Research in this field could pay big dividends in preventing some future large-scale waste disposal and pollution problems.

MAGNITUDE OF THE PROBLEM

It has been said that the human race is rapidly burying itself in its own waste. This is, undoubtedly, an overstatement of the case, but even a cursory view of the magnitude of the problem leaves the haunting impression that mankind must embark on a course of positive action to avoid being engulfed in its own debris.

The nature of solid waste is highly variable. Both its composition and its distribution are closely linked with national growth and technological advance. The problems engendered depend not only on the quantity and substance of those wastes but on factors of geography, technology, economics, government and public attitudes.

Comprehensive statistics on the magnitude of all solid waste generated in the United States are not available. Data that can be formulated on specific types of waste or on waste accumulations in certain geographic areas are difficult to reconcile into a projection representing the total. The following figures are presented to convey a picture of the quantities of waste and the dollar figures involved in treatment, disposal, and salvage. They provide a frame of reference rather than even an approximate compilation of the gross quantity of solid waste that is generated.

A frequently quoted estimate of the unit output of municipal solid wastes is 1,600 pounds per capita per year or 4.5 pounds per capita per day. For our present population this means 250 billion pounds of municipal solid waste per year. The collection and disposal costs are estimated to be 1.5 to 2.5 billion dollars, i.e. something less than a cent per pound. By 1980, the per capita output is estimated to be 5.5 pounds per day.

The composition of municipal solid waste is highly variable with geographic location and even with the season of the year, but one source indicated the following general composition:

	Percent
Paper	45
Grass, brush, and cuttings	15
Garbage	12
Ashes	10
Metallics	8
Glass and ceramics	6
Miscellaneous	4

The changing nature of municipal wastes can be seen from figures obtained from the City of Philadelphia. In 1959 rubbish amounted to 380,000 tons; in 1964, 567,000 tons. Ashes, in 1959 amounted to 120,000 tons; in 1964, only 37,000 tons. Garbage, in 1957 was 162,000 tons; in 1964, 128,000 tons. Street sweepings in 1959 were 100,000 tons; in 1964, 137,000 tons. In this same city in 1964, 600,000 tons of waste were handled by private collection compared to 869,000 tons handled by the city. One analyst has estimated that for the nation about 1.5 billion dollars are expended by local governments for waste collection and 1.3 billion dollars by private entities.

Solid wastes of industrial origin comprise another category of major magnitude. The interactions of industrial material flow are complex and industry contributes to both the total waste problem and to the conservation of useful raw material. Significant amounts of waste are salvages and recycled. An obvious example of the magnitude is industrial scrap, generated at a rate of 12 to 15 million tons annually. The gross tonnage of non-ferrous scrap is not available but a measure of importance can be gained from the fact that in 1963, recovery from scrap materials included 974,426 tons of copper, 493,471 tons of lead, and 268,255 tons of zinc.

The total secondary materials industry is estimated to be a 5–7 billion dollar a year operation. This figure provides at least a gauge of the magnitude of solid waste generated when one considers that only a relatively small part of our waste supports this salvage industry.

The paper industry generates 25 to 30 million tons annually of waste from paper and paper products. In 1964, some 9 to 10 million tons were salvaged and recycled to the industry. In 1962, about 263,000 long tons of reclaimed rubber were consumed in the United States, about 15 percent of the new rubber consumption. The same year 7.6 billion pounds of plastics were produced with about 10 percent recovered and rechanneled into the industry.

Our orientation to convenient containers has a high potential for litter if it is not kept under control. In 1962 more than 18 million tons of paper went into the manufacture of various types of paper packaging and containers. The statistics of 48 billion metal cans a year (250 per person), 26 billion bottles and jars (135 per person), 65 billion metal and plastic caps and crowns (338 per person), plus more than a half billion dollars a year of miscellaneous packaging material is indicative of the vast quantity of material which ultimately will need to be discarded. As a recent newspaper item facetiously reported, "Americans last year bought and presumably squeezed 1,244,126,428 metal squeeze tubes, half of which contained toothpaste."

Large quantities of waste material result from the mining of solid fuels, metals, and nonmetallic minerals. Most of this is in the form of waste rock, mill tailings, and smelter slag accumulated at mine, mill, and smelter sites. During 1963, some 5.6 billion tons of material were mined in the United States, of which 3.3 billion tons were waste rock or mill tailings discarded at the site of operation. A striking example of the magnitude of this problem is found in the large piles of overturned earth resulting from strip mine operations.

The disposal of demolition waste material is growing in parallel with urban renewal and superhighway construction programs. In addition to containing many burnable materials, this waste contains masonry, plastic, tile, metal, stones, and dirt. It is usually desirable land fill material, and for a period Los Angeles County reportedly was using 5,000 tons per day in its fills. The reported figure for Philadelphia in 1964 was 50,000 tons. Much demolition material is burned on site or is used in private land fill operations so a total figure is difficult to estimate.

NATURE OF THE SOLID WASTE PROBLEM

It is customary to classify waste products and the attendant disposal problems into three parts—atmospheric, liquid, and solid. This division assumes that each of the categories can be considered as a separate subject. It is, in fact, impossible to separate solid wastes disposal from the air and water pollution problems. Air pollution may be aggravated by the burning of solid waste refuse; the household grinding of garbage eliminates a solid waste but increases the liquid waste load. The disposal of solid wastes by land fill may produce problems of pollution for ground water supplies. Conversely, the abatement of an air pollution problem, especially one involving particulates, may produce an additional solid waste burden.

Parts of solid waste management can be considered within narrow boundaries of a particular material, a single collection process, or a typical disposal method. It becomes more evident each day, however, that overall decisions of policy and method for solid waste control must be coupled with similar decisions related to liquid and atmospheric situations. Virtually every approach to considering the nature of the solid waste problem will reinforce the need to adopt a unified point of view.

Because solid wastes include not only the output of households and municipalities but also the discards of business, industry and agriculture, there is variety among the handling procedures. After a material reaches the discard point, its handling can be divided into three steps: *Collection*, which includes storage and transfer, as well as pick-up; *Processing*, which may take on a variety of forms including the salvage of usable and useful portions; and *Disposal*, which includes any treatment necessary for making the disposition effective. By the time the disposal point is reached, the waste should have been reduced to a minimum both in volume and in usable material, but such is rarely the case.

The handling of household wastes involves all three of these steps in a coordinated way. Agricultural wastes, on the other hand, are often disposed of near their points of origin, without processing. Industrial wastes are generally homogeneous and may be high in salvage value. Their disposal may be a smaller problem than their rehandling. The collection, processing and disposal of discard automobiles is done usually as three separate uncoordinated operations.

Methods of ultimate disposal are limited. Incineration of combustibles, composting, animal feeding, disposal at sea of material that will not float, and land filling are essentially the methods that have been used. Incineration is in reality only a process to reduce the volume of material that ultimately must be buried or carted off to sea. The residue will be of the order of 20 percent of the original. Composting is likewise a volume reduction processing technique for salvage purposes, not an ultimate disposal method. The residue becomes a land enrichment resource. Hog feeding of garbage is also a recycling of a waste to a productive industry. Land fill and ocean disposal are the two basic alternative ultimate burying methods for unwanted things.

It is estimated that less than half of our cities currently have satisfactory refuse disposal systems. Our larger cities, in particular, have operations that combine disposal methods, the most common being joint use of incinerators and land fill.

The handling of solid wastes is a mixture of private and public services. Private incinerators and private land fills operate in the same communities with public incinerators and public land fill operations. In the Los Angeles area there are 25 active land fill sites, 15 private and 10 municipal. House-to-house trash pickup may be by community-run service or by contracted service under franchise. In one major city it is possible to recognize at least five separate collection systems—(a) commercial garbage collections; (b) municipal garbage collections by contract; (c) municipal refuse pickup; (d) licensed scavengers; and (e) apartment houses and industrial disposals.

Collection practices are undergoing rapid change, due to technological and sociological factors. Home owners prefer the convenience of combined trash pickup. Even when disposal practices are unified, collection is still decentralized. Los Angeles County disposal services, for example, handle collections made in separate cities, perhaps by as many as twenty different methods.

A large number of salvage industries have grown up to cope with the reclamation of waste materials and with their re-introduction as raw materials into the technological cycle. The discarded automobile, for example, is processed in two ways—first, for spare parts, and then for its metallic content, particularly for scrap steel. Copper recovery is now equal to 80 percent of new domestic copper. Reclaimed lead is about twice that of our domestic mine production.

The National Association of Secondary Material Industries has some six hundred companies as members. These companies deal in nonferrous scrap, paper stock, rubber and plastics, textiles, wood pulps, precious metals, hair, feathers, and a wide variety of other materials. Some scrap materials compete in a national market, i.e. scrap copper. Others compete in a local market, i.e. scrap paper.

Salvage is also undergoing change. Cost of labor is the primary barrier because hand sorting is still basic to the process. Unless trash is separated at the source the chance for salvage is low. Most metropolitan areas do not permit salvage at the incinerator or land fill site.

Technological changes, such as those that have replaced natural fibers with synthetics in clothing, have an impact upon what may be usefully collected. Market changes have almost ruled out collecting of such items as paper by the Scout organizations and Salvation Army. Urban planning and zoning changes have a tendency to rule out the junk collector. Baltimore is said to have lost 50 percent of its junk shops in the last ten years. The trend appears to be toward larger units just as has been the case in other businesses. The members of the National Association of Secondary Materials Industries handle a greater volume of material than in the past with a smaller number of individual companies.

The large population centers now dramatically portray the economic problems having to do with changes in collection methods, with storage, and with land fill requirements for the large volume of materials involved. The large number of local government jurisdictions that exist in the average metropolitan region compounds the problem of effective waste management. The complexities resulting from a large variety of waste materials, a variety of sources, the salvage aspects, the tie in with water and air pollution, and the logistics of transfer and disposal create problems of waste management that seem to be best tackled by a regional and system approach.

The motivation for control of solid wastes can sometimes be found in factors relating to public health and safety. This is not so obvious an element as in the past, however, because of the overall advance in health control. Other motivations for management arise from the economics of salvage or recovery of usable materials. Now emerging are management considerations based upon long-range conservation needs, upon esthetic values tied in with displeasing views and undesirable odors, and upon the simple desire to keep ourselves free from litter.

How rapidly is the solid waste problem growing? This question is related to numbers of people, but population growth is not the entire answer. Population concentration is also a big factor. More importantly, the amount of solid wastes depends upon standard of living and the state of technological development. The problems of the junk automobile and the discarded beer can are only the more obvious evidences of a general situation resulting from the advances of a consuming society. In a very direct manner, the two cars in every garage, the TV in every room, the convenient packages for distributing goods, and the great volume of printed material will cause our waste disposal system to expand. As the use of any commodity rises, there will be a point at which the commodity becomes a discard in sufficient quantity to create a solid waste problem.

In perspective, our industrialized society is based on an organized materials input system, highly motivated by consumer demand and enterprise economics. We are organized to collect widely scattered resources, process them, change them in form and distribute useful goods to the public. On the waste output side of this picture the same steps can be recognized, essentially in reverse. The steps of collecting from the consumer (reverse distribution), salvage and waste processing (reverse manufacturing), and disposal (reverse resource acquisition) are disorganized compared to the complex organization on the resource acquisition side. Furthermore, consumer demand and enterprise economics are largely missing from disposal practices, the entire activity being thought of as a public service.

In this overall picture there is some feedback, particularly with respect to scarce materials. The feedback is essentially dictated by the economics of materials consumption. A key problem is how to effect a greater tie between the waste output and the materials consumption so that consideration of ultimate disposal may be a factor in the design or marketing of new materials. The closing of the loop can be based on a number of devices, such as taxes on newly used materials, subsidies for reclaimed materials, or conditions imposed upon design criteria.

The overall nature of the problem is such therefore that attention should be given to—

(1) The improvement of organization and systemization of the waste material outflow portion of our consuming society,

(2) The improvement of technology dealing with this outflow and with the separate steps of collecting, processing and disposing, and

(3) The adoption of practices and policies that will close the loop between the materials consumption and the waste production parts of our society so that decisions relative to consumption will consider the waste product problem.

SALVAGING AND RECLAIMING

Were it not for the re-use of scrap materials there would be insufficient raw materials available to take care of the needs of our basic industries.

The recovery of materials from wastes and scrap in the United States is an enterprise estimated to range from 5 to 7 billion dollars annually. It is apparent, also, that were it not for the economic incentive that inspires the effort to salvage and reuse the vast tonnage of waste handled by this industry, the problem of solid wastes disposal in the United States would be of much greater magnitude.

The logical approach toward solutions of the solid waste problems is one of conservation, i.e. to minimize generation of waste material, to salvage and reuse the maximum quantity of waste, and to dispose finally of the irreducible amount in a manner devised to enhance or conserve the value of the final disposal site. The concepts of resource reclamation should guide our actions in solid waste management.

Salvage is most readily carried out where the waste material is homogeneous and of high value. This is most frequent in commercial or industrial operations. When salvageable material is mixed with garbage and other refuse, its reclamation is difficult because the main control of salvage and reclamation is economics.

Complete figures are not available, but a significant percentage of the economically salvageable solid wastes are reclaimed. As a general rule, the amount and type of waste salvaged is directly related to the balance between cost of collection versus sale price. To illustrate, a large volume of waste newsprint was formerly collected from households and salvaged. With current low prices and the high costs of collection, the same waste newsprint is now picked up as trash and is disposed of by incineration or dumping.

The highest percentage of salvage is made of the high value, high density metal scrap materials. Even with the number of surplus junk cars now visible an average of 26.6 million tons of scrap iron per year was purchased in the period 1958–1963. This is a significant part of the annual new steel production in the United States. Nearly all of the major nonferrous scrap materials are eventually salvaged for reuse. About 957,000 tons of copper were recovered from scrap in 1963. This represented about 40 percent of the total supply of copper in the United States for that year and 80 percent of the total copper produced by domestic mines. The lead recovered from scrap amounted to about 494-000 tons—almost double the 253,000 tons of lead produced in mines in the United States during 1963. The annual volume of aluminum scrap is about 25% of the total aluminum supply. The pattern is evident from these figures.

The structure of the National Association of Secondary Material Industries, a trade association of scrap dealers, gives an overview of commercial waste salvage operations. The Association is made up of one functional and 5 commodity groups: (1) Foreign Trade Division; (2) Metal Dealers Division, a group composed of scrap dealers who process, segregate, bale and ship all types of metals; (3) Secondary Metal Institute, which includes smelters, refiners, and ingot makers of all metals; (4) Paper Stock Institute; (5) Textile Division; (6) Scrap Rubber and Plastics Institute. In addition, a separate organization, the Institute of Scrap Iron and Steel, represents ferrous metal scrap dealers.

Collection is the backbone of waste salvage but most advances mitigate against the individual collector. Junk yards are not generally considered a community asset from the esthetic standpoint, and it is increasingly difficult to retain or obtain space to conduct the business. Recent activities in urban renewal and zoning regulations tend to displace these yards and make it extremely difficult for them to relocate. As a result, the number of waste material collectors is decreasing. Apparently, this is partly compensated by a few larger yards handling more of the business. However, a serious reduction in the waste collection capacities is viewed with considerable alarm by the industry.

Attempts to salvage material from municipal operations have generally been short lived. The reclaiming of tin cans has perhaps been an exception. The total volume of material of salvage value in this category is large but so widely dispersed, and so frequently intermingled with garbage and other trash, that the cost of separating and processing for salvage is prohibitive. Some trash collection systems are based on separation by the householder of the various types of refuse, but the general trend, based on convenience to the householder and cost of collection, is toward combined collection. Scavenging is not now practiced, usually because of safety and operational reasons in effective management, at large incinerators and land fills, but scavengers are still licensed to pick up from households in some cities.

Regulations or practices far removed from waste management may have an impact upon the economics of salvage. The introduction of synthetics, for example, had an adverse effect upon reclaiming textile wastes. The wool labeling regulations that require specifying the presence of used wool is a deterrent to salvage in the eyes of the industry. The use of special additives for coloring or conditioning both to textiles and to paper, created extra problems for reuse.

Reclaiming practices in waste management are not limited to materials that are recycled for their basic material content, but include also the use of garbage to feed animals, the use of heat generated from incineration, the useful products from composting, and the upgrading of land values as a result of fill. In short, solid waste can be viewed as a resource for certain purposes, and this resource value has been the motivation for carrying out some waste management operations. It forms the basis for most of the private participation in waste management systems.

Of these methods, garbage feeding and land filling are the two used most widely. In order to further advance the uses of waste, research and development steps will be necessary. No doubt many discarded materials, especially of organic nature, can be reclaimed or rebuilt as higher order molecules rather than being reduced to air pollutants and carbon. Another area where research dividends might be achieved would be the treatment of masonry and concrete demolition products for possible reuse as structural material. The use of such products, rather than natural gravel, as a foundation material for freeways does not require a large extension of the imagination.

ORGANIZATIONAL AND SOCIOLOGICAL PROBLEMS

Problems of pollution control and waste disposal are aggravated today by the growing geometrical restrictions of the old core city, the surrounding urban spawl, and the outer shell of intensively utilized agricultural land. The traditional method of going beyond the populated area to bury refuse and to process waste is no longer always possible. The concepts of social acceptability which forced the removal of odorous and unsightly waste treatment areas to the fringes of the old city now are demanding new and esthetically acceptable methods of accomplishing intracity waste management.

Because of the inter-relationships among the many sectors of a modern metropolitan community, separate solutions to problems of waste management are essentially impossible. The effect of almost any discrete and local solution is merely to change the name of the agency responsible for enforcing restraints by shifting the locus of the problem or exchanging one form of pollution for another.

Jurisdictional agencies concerned with environmental control include health departments at the national, state, and local level; water pollution control boards; sanitation districts; air pollution control districts; fish and game commissions; park and recreation departments; and numerous other branches at all levels of Government. Under their uncoordinated aegis significant and highly important research projects have been directed to specific problems of air pollution, water pollution, radioactive wastes, refuse disposal, detergent removal, vector control, pollution travel, and food sanitation. All of this research bears upon the greater problem of wastes management in the human environment. The results of this work have been and continue to be, productive and revealing, but the aggregate results grow less rapidly than the overall problem they are intended to resolve.

Fragmentation of governmental jurisdictions, whether at the administrative, regulatory, operative, or investigative level, precludes an effective direct attack on the overall problem. The problem is too complex to encompass or resolve within any part of such an organizational framework. The fragmentary structure invites a fragmentary approach. Often this results in solutions by one section that increase the problems which confront another section; e.g., a problem in refuse disposal becomes a problem in air pollution or water pollution. To give scale to this problem it should be noted that a recent study of the San Francisco Bay Area waste situation by the Association of Bay Area Governments revealed 78 separate entities to be involved in a welter of jurisdictional overlaps in the various facets of refuse disposal, water pollution and air pollution.

The inescapable conclusion is that it is now clearly necessary to treat the whole urban-suburban-rural complex, constituting a modern community, as a single entity within which wastes management problems must be resolved. Full regard must be given to the interrelationships of all environmental factors, to the total insult of pollutants to man's physical and mental health and well being, to all sources of pollutants and to all methods for control.

Public attitudes concerning responsibility for wastes likewise contribute in an important manner to the problems of waste management. Any material becomes a discard when its owner no longer considers it of sufficient value to retain. Its disposal is generally a financially unrewarding act. Any suggestion that he should thereupon invest more money in it, for the sake of disposal, is likely to be considered absurd, however inclined he may be to object to polluted water, smog, rodents, unsightly debris, and other conditions which result from his loss of interest in ownership.

Ensnared in this public economic spirit, engineers and community officials responsible for management of wastes have tended to respond in a negative manner. In general, they have apologized for the fact that waste handling systems cost anything at all. They often retreat from expedient to expedient on the basis of cost in dollars instead of leading the public to understand that waste management is worth whatever it costs within the framework of honest engineering and sound public health practice; and that the cost is the price man must pay for the benefits of a modern urban-industrial-agricultural society. Too often improved waste management systems fall prey to the administrative official who sets up a policy of no-spending-at-all as the ideal goal of municipal government, or finds it more politically and socially rewarding to confine tax spending to more popular public works, or to monumental developments having greater cultural appeal than waste handling systems.

There is also a problem of awareness on the part of public leaders. The average opinion-former in today's metropolitan community does not know about the total breadth and complexity of this problem.

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Moreover, the municipal engineers, who should be among the best informed, are generally too occupied with daily operational problems to maintain the forward planning that will permit them to be ahead of the promoters of particular schemes. This lack of awareness appears to extend also into the university. Graduates in engineering and public administration rarely have any concept of the intricacies of the waste management problem of the metropolitan regions.

There is a large problem of local self-education. Broad groups must be convinced that area waste management is no more expensive than local problem management and could be much more effective. Most importantly, esthetic considerations must be an integral part of the planning formulations and not be treated as a fringe benefit. The value, and, in turn, the public cost for esthetics must be a component in the decision-making process.

Financial restraints are also limiting factors in a variety of ways. The average community and public administrator needs to know that a proposed waste management system will work. There is no room for taking a risk. Consequently, the only financially feasible systems for many city engineers and managers to recommend are those that are proven. There is a need for metropolitan regions to develop within their public works financing structure sufficient leeway to afford experimentation and limited demonstration leading to improved systems. One means of accomplishing many of these objectives is to establish regional authorities. The County of Los Angeles appears to be doing this successfully at least for its solid waste disposal and water waste disposal systems.

TECHNOLOGY

The technology for handling solid wastes has changed very little over the years. The incentive for instituting changes has been low, except where health and hazard factors have been operative. Since these forces have been of most concern in relation to human waste and waterborne effluents, the technology in those areas has advanced faster than that related to refuse and other forms of solid waste.

Even as the management of solid wastes becomes a critical issue, the technology appears to be directed toward improvement of existing techniques rather than toward the development of new systems. Although improvements should be sought there must also be programs undertaken to insure that new technology is examined and has a fair trial.

One of the difficulties related to technological development is the impracticality of demonstrating new methods on a small scale. It is not sufficient for a method to satisfactorily serve a single dwelling. Whatever is used on one home must fit into the total community picture of many homes. Thus, the individual home incinerator or sewage disposal unit must have operating parameters that will meet community standards. For waste disposal technology to advance it must be possible to try, as a prototype or on a demonstration basis, entire new systems that involve complete communities having a sufficiently complex mix of waste problems for an evaluation of all parameters.

Examination of our solid waste technology is needed at all levels—the development of hardware, the design and creation of new systems, the combining of two or more techniques, the alteration of existing systems, and the development of new uses for processed waste.

Hardware still is based essentially upon the trash can and the collecting truck. The home grinder for garbage has appeared in recent years and this has shifted part of the solid waste load to water carried systems. We should examine the possibility of developing solid waste grinding on a more massive scale to make still greater use of the carrying capacity of water waste disposal systems already installed.

Technology is needed for improving the only two methods of solid waste disposal or treatment which are considered generally acceptable—sanitary land fill and incineration. Too few sanitary land fills have been adequately planned and engineered, with the result that the ultimate benefits of filled land have not been realized. Design and operation of incineration facilities have not taken fully into account the recovery of heat, the associated air pollution problems, nor final disposal of ash residue. Indeed, it can be stated that high temperature incineration has never really been tried. Nor, in this country has there been a development to equal that in Europe for incineration in large municipal power plants complete with steam generators, dust collectors and electrostatic precipitators.

Technology has solved the problems of bringing large volumes of material into the central core city and suburban area. It ought also to be able to solve the problem of moving waste materials out. Land fill sites within the metropolitan region are becoming scarce. Furthermore, much of the land that could be upgraded by compost or other residue may be in remote areas. The imagination can visualize the development of pipeline systems or the use of existing rail and highway transport systems to aid this purpose. There are many situations where mine cavities and quarries might be used for disposal of refuse if the transportation problem is solved. It is quite possible that a program could be developed to combine municipal composting with the rehabilitation of nearby land that has been strip mined.

Technology perhaps has its greatest opportunity in finding new methods of processing waste or of using waste products. This may require means for tagging manufactured products in order to facilitate separation. For example, non-magnetic cans might be made slightly magnetic. The conversion of solid waste to gases or other products by the use of bacteria, the destructive distillation of some waste components, and the use of wastes as a basis for chemical manufacture have been suggested as possibilities. Composting might be more generally useful if large scale markets can be developed for the compost product.

Many stirrings can be seen in the technology field. Recently cited potential improvements include the following:

Sanitary land fills:

(1) Large sanitary land fills can be operated more efficiently in conjunction with transfer stations. Los Angeles has proven the economics of operating large-scale sanitary land fills which handle as much as 3,500 tons per day. This is made possible by careful planning, sound engineering and the use of modern earth moving equipment. Transfer stations are also utilized to shorten the hauls of the collection vehicles and decrease the number of vehicles arriving at the land fill.

(2) A new concept of sanitary landfilling being developed will use a specially designed machine to excavate an eight-foot trench 42 inches wide, compact the refuse, extrude it into the bottom of the trench, backfill, and compact the excavated earth in continuous operation. This "instant sanitary land fill" machine is designed to process up to 10 cubic yards of refuse in three minutes or less. The completely self-contained and self-powered machine will be operated by two men working in all-weather cabs. One engine will be used for propulsion and control, and the other will be used to operate the refuse compacting and extruding equipment.

Incineration:

(1) The City of New York plans to install an electrostatic precipitator in one of its refuse incinerators at a cost of approximately $400,000 for a 250-ton-per-day plant. This will be the first such installation in the United States.

(2) In Oceanside, New York, the Town of Hempstead, Long Island, the first specially-designed, mechanically-stoked incinerator is being built to burn bulky refuse. The 750-ton-per-24-hour plant will include steam boilers, power generation, and desalting facilities.

(3) The City of Detroit has built two small incinerators for slow burning bulky brush and trees. They experimented with the first and accordingly made some alterations in the plans for the second. A great deal of further experimental work needs to be done on the problem of disposing of slow burning bulky refuse.

(4) A Washington, D.C., firm is producing a mobile incinerator to burn trash during the collection process. A two man unit, it provides for fuel from liquefied petroleum, and will handle bottles and cans as well as paper. It was designed specifically for service in park areas.

Composting:

(1) The techniques of composting are quite well known, as evidenced by the number of successful composting plants in Europe. Within the past few months, contracts have been signed for plants in the United States in Elmira, New York, St. Petersburg, Florida, and Houston, Texas. These plants should provide critical information on the marketability of compost.

(2) The Public Health Service, in cooperation with the Tennessee Valley Authority, has plans for a solid waste research facility to test and demonstrate a process of composting mixed refuse and raw sewage sludge for ultimate use as either a soil conditioner or fertilizer.

Water carriage of solid wastes:

(1) The Garchey System is used in a few European countries. Basically, it is a vacuum system with water added as a lubricant. Refuse is put into a tube or duct usually in the kitchen sink of the apartment, and then sucked down into a holding tank in the basement of the building or piped to a larger central station. From there it is pumped into a collection-tank truck for transport to the final disposal site. This system requires a large amount of space for the duct work and presents problems in the transferring of the wastes to the collection vehicle.

(2) The Los Angeles County Sanitation Districts have made studies on transporting refuse hydraulically in their existing large size sewers. Mixed household refuse is collected by the normal methods, taken to a nearby grinding station where it is ground, the metal and glass are removed by magnets and gravity, and the rest is discharged into a trunk sewer. This, of course, makes more work for the sewage treatment plant, but it also produces more methane—a source of energy for the plant, and results in sizeable savings in hauling costs. The results of these studies have been very favorable.

Compression and capillary drying techniques:

(1) Some thought has been given to baling refuse under high pressure at transfer stations and disposing of these bales at

sea, where they would sink, due to the high density, or in land fills, where they would take up much less room than non-baled refuse. However, no actual studies have been made to date.

AUTOMOBILE HULKS

The current junk car problem is generally conceded to be "visual pollution" rather than a serious hazard to the health or well-being of the Nation. Its genesis is primarily economic rather than technological.

The ferrous scrap industry in recent years has provided annually for remelting 25 to 30 million tons of processed iron and steel scrap, of which 4 to 5 million tons were from junk automobiles. This represents 4 to 5 million discarded automobiles on the basis of a ton of salvageable scrap iron in each car. Hence, en masse, old automobile hulks represent a source of an important metal. Their reconversion to industrial use is, and should continue to be, the objective.

The unsightly picture currently presented by junk cars has become of major national significance within the past decade. The negative reactions can be attributed to increased accumulations of hulks in scrap yards or scrap storage areas, and a "king size" litterbug tendency to abandon useless hulks on the streets or highways and in the farmyards. Essentially, the reason for the accumulation and casual discard of old automobiles is that although nominally a source of valuable metal, junk cars are now a surplus commodity.

A number of influences are acting to interrupt a normal recycling of scrap from old cars back into steel furnaces. The cost of collecting, processing, and transporting auto hulks is high and the price of the product as No. 2 bundles is low compared to other more desired forms of ferrous metal scrap; changes in the steel-making process require less scrap than formerly; and closely paralleling the rapid increase in motor car production, the number of automobiles junked each year is steadily increasing.

With the exception of the war years, the average age of passenger cars on the highway in the United States has been fairly stable since 1935. The survival curve for passenger cars shows that about 50 percent of a given model will have disappeared at the end of about 10 years. At about the age of 5 years, the rate of disappearance begins to accelerate. This explains, in part, the increase in scrappage experienced recently, because the cars produced in the relatively high production years of the middle 1950's have reached the age where the annual disappearance rate is high. Part of the current problem is, undoubtedly, a speculative holding of old hulks for a higher price but, basically, the cost of marketing does not warrant reclaiming this material, so the hulk is stored or dumped.

Altering the storage of junk automobiles is compounded by a number of economic and legal considerations. The auto wrecking and scrap business is a multi-billion dollar industry serving a useful purpose. Action that might eliminate or materially reduce the effectiveness of this business would probably compound the problem. Rights of ownerships (personal property), individual rights and principles of private enterprise may be involved. A number of court decisions have already been rendered voiding action taken to solve this problem in violation of these basic rights.

Some relief can be expected now that the industry is conscious of the problem and is aware of the bad public image created by junk automobile yards. Possibly more important, the industry already feels and can foresee restrictive repercussions. The trade associations, such as the Institute of Scrap Iron and Steel, are advocating fencing, tree planting, and other screening measures. Individual scrap dealers are making a conscious effort to improve the appearance of existing yards. Municipalities are evolving means to handle abandoned cars in urban areas, although municipal collection of cars has in turn resulted in unsightly storage yards filled with these vehicles. The problem of legal ownership has delayed prompt disposal of the hulks, but some municipalities have working agreements with scrap dealers to take the hulks off of their hands.

The widely scattered hulks stored at homes and farmsteads throughout the country are more difficult to cope with than the concentrated urban accumulations. Usually, the cost of transportation makes disposal to regular industrial scrap outlets impractical. The hulks are private property stored on private land, so that local governmental action is restricted. As an immediate approach, an educational clean-up campaign appears to be a feasible solution.

Auto parts salvage establishments are, or could be, acceptable industrial sites; the origin of unsightliness is the storage of auto hulks. A permanent solution will necessarily have to cut down on the number of hulks in storage. Among the possible methods for achieving this goal it has been suggested that government purchase the hulks from the owners, or that the government support a price differential that would assure the recycling of hulks to the steel furnaces. Although some precedent has been established for such an approach by government actions in other commodities, either solution has many attendant problems.

Responsibility for the ultimate disposal of the automobile might be related either to the manufacture or purchase of an automobile. One possibility is a purchase excise tax (disposal subsidy) so arranged as to provide a sinking fund for ultimate disposal of the car at the end of its useful life. Some research is in progress to find uses for auto hulks other than as scrap steel. The most promising seems to be combining the scrap with low grade taconite ore in order to make it magnetic and improve its characteristics. Some other possibilities that might be investigated include:

(a) Design automobiles so they can be more easily cannibalized;
(b) Increase the interchangeability of automobile parts, so that the junk car might be cannibalized more rapidly for its parts;
(c) Improve the salvage process by a reversal of "production line" technique, including the economics of super-scale centralized scrap yards;
(d) Consider the reconcentration of automobile hulks, in effect building an artificial iron mountain as a future resource;
(e) Institute a clean-up train which would collect, dismantle and compress junk cars in remote places. The junk car problem is a specific problem of certain communities which are remotely located and some local aid might be provided for such rural communities.

One topic that should be given considerably more thought is the long-range picture with respect to automobile manufacture and its bearing on the problems of junk cars, solid wastes, and other pollutant effects. The composition of automobiles may change radically in the next few years. The entry of fuel cells, turbine energy and body parts framed from plastics or other synthetics would have a decided effect on air pollution, as well as on other solid waste problems.

APPENDIX Y6

Combined Sewers

JOHN C. GEYER, *Chairman* LEONHARD KATZ

Contents

THE PROBLEM

The drains of a city carry two types of liquids; storm water or surface runoff from streets, roofs, lawns, and paved areas; and used or spent water from houses, industries and all other kinds of establishments that are supplied water from either a public or private source. In the separate system of sewage, storm water is collected, transported and disposed of through a *storm drainage system,* while the spent water supply or sanitary sewage is carried by a *sanitary sewerage system.* When both types of waste water are collected in a single set of underground drains the system is a *combined* one.

Ancient cities had elaborate drainage systems to remove runoff from rainfall. In those times domestic wastes were cast into the streets and flushed intentionally or otherwise into these drains. Combined systems of sewerage have thus been in use for some thousands of years. The problems associated with them remain still to be solved.

In modern times, as in ancient, drainage systems grew piecemeal. Water courses were first walled to save space, then covered, then used for the disposal of every kind of liquid and water-carried waste. Nearby discharge points were foul smelling so larger drains were built to collect the effluvium from smaller ones and the nuisance points were moved elsewhere. These systems had dozens if not hundreds of outlets along the major water or river fronts of older cities.

The idea of building separate systems to collect sanitary sewage was tried about the beginning of the 20th century but first efforts failed and the combined system of sewerage continued to be favored. It worked and it was cheaper; old systems could not be separated except at great cost and new systems couldn't be kept separate for lack of control over who connected what to what.

It might be interjected that when streams in flood are carried in pipes the sizes required are very large. Drains as big as vehicular tunnels are not uncommon. One truck which fell into a collapsed drain was never found.

The rivers and bays and canals stank. Something had to be done. It seemed impossible and perhaps was impractical to carry the enormous volumes of flood waters to distant points of discharge, to say nothing of putting them through elaborate treatment plants. Interceptors were devised which ran along the water fronts beneath the numerous combined sewer outlets and intercepted sanitary sewage when it wasn't raining. Regulating devices and weirs of many kinds were used to admit measured amounts of sewage to the interceptors. When it rained everything else went overboard through the old outlets. New York City has 218, Chicago has 362 and Cleveland has 420.

The overflow rates could easily be 100 times as great as that to the interceptor so during a storm as much as 99 per cent of the sanitary wastes might escape untreated to the nearby water. And this is not all the problem. Solids that are stranded or settle out in these big old drains are flushed through the outlet during storms. Cities grow but interceptors don't. The time comes when sanitary sewage begins to spill even when it isn't raining. Regulators stick open or shut or get plugged—more sewage is spilled somewhere—sometimes continuously. All these works are out of sight and easily out of mind. Little is known about what actually happens. Monitoring and maintenance on existing systems with existing forces is often out of question.

The waterfronts, canals and streams that receive combined sewage overflows are beginning to smell bad again and with increasing frequency. Something will have to be done. If the goal is to make receiving waters esthetically pleasing and suitable for at least limited recreational use, then the job is going to be a big one.

THE JOB

For discussion, the following division of the material to be collected, moved and disposed of is convenient: storm water is made up of rainwater and surface flushings; sanitary sewage consists of used water supply which carries domestic, industrial and other wastes. Combined sewage is a mixture of the two. Since most sewerage systems leak, ground water enters when the water table is above the sewer and sewage escapes when it is below. The job at hand can be attacked at any point from origin to ultimate disposal, or water can be recycled by actions which affect (1) the amount of water stored or moved or used at any point in time and space, and (2) the character and amount of substances (dissolved or suspended) that are present in the water, also at any point in time and space. For simplicity three classes of materials carried in water will be considered: suspended solids, biologically oxidizable organics (BOD), and nutrients as represented by phosphates. Other things are involved ranging from barrels and concrete blocks to radioiodine from thyroid patients and gasoline from garages.

The average annual quantities of sanitary sewage produced in American cities range usually from 100 to 150 gallons per person daily. For densities ranging from 2 to 30 persons per acre this gives flows ranging from 200 to 4,500 gallons per acre per day (0.2 to 5 acre ft per acre per year). Peak hourly rates from large areas may be three times as great. The quality of sanitary sewage, which varies considerably depending on water use, type of industries and so forth, has been well established. Typical numbers are suspended solids—200 mg/1, BOD—200 mg/1, and PO_4—10 mg/1.

The quantities of storm runoff vary over a wide range. Most import factors involved are: size of area and portion paved, rainfall intensities and durations, soil type and condition and surface slopes. Storm drains and combined sewers are designed for flow rates ranging from 0.4 to 3 million gallons per acre per day. Such high flows occur only for short periods, hours or less, at relatively rare intervals, 2 to 10 years or more. However, the drains flow partly filled whenever it rains enough to produce surface runoff.

The quality of storm runoff and the quality of combined sewage are highly variable and not well known. Available data present a confusing picture. Yet the matter of quality is extremely important when considering possible solutions for the combined sewerage problem. If, for example, storm runoff from a separate drain is not of significantly better quality than overflow from a combined sewer, then separation of a combined system will provide a partial solution only. Evidence suggests that this may sometimes be the case. The reason is that all the dust, dirt, litter and curbings that settle on or are generated in a city, often are swept or flushed intentionally into the drains where they lie until the first good rain carries them on to the outlet. Thus it is quite possible that in some situations partial treatment (as by sedimentation) of combined sewage might accomplish more than separation of the system.

In the absence of facts it has generally been supposed that the first flush of runoff swept the drains and that flows from the latter part of storms carried less foreign material. Perhaps this is so if a storm lasts long enough, but such data as have been gathered suggest that generalizations of this kind are apt to be wrong as often as right.

The mammoth job of correcting or reducing the pollutional effects of combined sewage overflows is difficult to discuss in an intelligible way. There are too many situations, each with its many peculiarities. And the opportunities for altering in time and space the quantity and quality of the liquids and solids involved are numerous indeed.

POSSIBLE SOLUTIONS

The beginning will be made by sorting out some of the possibilities, it being understood that any measure may accomplish multiple ends and that multiple measures will doubtless be required when dealing with any real life situation.

The problem of combined sewage overflow can be attacked by—

(a) Separation of sewage systems.

(b) Increasing interceptor sizes.

(c) Construction of express sewers.
(d) Reducing input of storm runoff.
(e) Reducing solids load in storm runoff.
(f) Reducing input of sanitary sewage.
(g) Reducing solids load in sanitary sewage.
(h) Storage of flow in the system.
(i) Removal or alteration of solids in the system.
(j) Terminal treatment of overflows.
(k) Installation of measuring and monitoring.
(l) Improved operation and maintenance.

Separation of combined systems.—Separation, partial or complete, involves many alternatives. The existing system can be used either for storm runoff or sanitary sewage and a new system built to carry the flows that are to be excluded. Complete separation by either plan is quite expensive; some $10,000,000 per square mile or $1,000 and above per family. These costs do not account for the economic loss and inconvenience associated with entering all the streets, properties and buildings to break existing connections and install new drains. The cost and agony occasioned a city by this procedure would be so great that complete separation will proceed, if at all, only very slowly.

Partial separation by construction of a new storm water system to drain just the streets, yards, parking lots and new buildings would greatly reduce overflows without requiring construction of such an extensive system. This approach avoids the difficult business of tearing into existing buildings and properties in order to separate roof and other rainwater drains from the sanitary lines.

Another plan is to separate the systems in all new construction and redeveloped areas, first discharging both types of drains into the existing combined sewer. Over the years as cities are rebuilt whole watersheds could then be separated.

A study is soon to start, under American Society of Civil Engineers sponsorship with Public Health Service financial support, of separation by building a system within the system. The solids in sanitary sewage would be ground and the resulting suspension pumped through small plastic lines, threaded through existing house sewers, into pressure pipes hung in the existing combined system located in the street. Whether such a system can be made to work and, if so, would be accepted by householders and health officials remains to be demonstrated. Solutions will be found only by expending time and effort on development and demonstration of innovations of equally novel kinds.

Increasing interceptor size.—The customary thing to do when the load on a facility exceeds its capacity is to enlarge it. Interceptors should be no exception. In the past this has been done by building new and larger interceptors to reduce the frequency and amount of overflow. Such action has been compelled in places like Rock Creek Park, Washington, D.C., where the unsightliness and hazard of sewage solids along the stream were unusually objectionable.

Construction of new interceptors to relieve the old ones is not a complete solution and is difficult and costly. But so are other alternatives.

Construction of express sewers.—Our cities were once small settlements along the shore or river bank. Growth has been toward higher ground so the newer areas must be drained through the older. This is one reason why interceptors become overloaded. Newly developing suburban areas are nowadays almost universally provided separate sewers even though the old city may be on the combined system. Storm water is released to nearby drainage ways and sanitary sewage is discharged into the old combined system to mingle with surface runoff and go overboard when it rains.

Where the situation permits, it would obviously be desirable to carry separate sanitary sewage direct to the treatment plant. Sewers which do this are sometimes called express sewers. They cross the old combined sewer areas in pipes that are free of all connections with combined sewers. Such sewers relieve the load on interceptors. If a new interceptor must be built anyway, the old one may conveniently serve as the express sewer.

Reducing input of storm runoff.—Drainage practice in the United States has, as a general proposition, been directed toward getting rid of rainwater as fast as possible. Roofs are steep and yards are graded and streets sloped to drain rapidly. Rapid drainage has many disadvantages: drains are more costly, downstream flooding is more severe, combined sewer overflows are larger and more frequent, and water that might soak in the ground is lost.

Urbanization can greatly increase runoff rates, but it need not. And as the courts move toward placing responsibility for increased downstream flood damage on the upstream municipality or developer, steps will be taken to correct this situation. In fact, at least one county is now requiring developers to provide designs or works that assure no increase in the natural runoff rate.

The water should be stored, detained, delayed and where possible allowed to soak into the ground to replenish ground water and maintain the dry weather flow of streams.

Summer thunderstorms, which cause the most difficulty, rarely last very long. Although instantaneous rainfall rates may be as high as 6 or more inches per hour, the total fall is not often greater than two inches. If water could be stored to a 2 inch depth over all of an area there would be no runoff whatever. All the area can't be used, but less storage will knock off the peak, and some areas can be used for storing at much greater depths than a couple of inches.

Where are the potential storage places? Roofs, parking lots, backyards, ponds and lakes, public parks, etc. In the arid west, yards have walls and curbs to prevent the escape of rain water. It is precious. On Long Island there are hundreds of storage and soakage pits, to which water is diverted from the streets, and from which it goes into the ground and replenishes the local water supply. Soil type, topography, geology, intensity of development and many other factors influence the choice of method or methods for reducing the inputs of storm water runoff.

Reducing the solids in storm runoff.—What becomes of dirt and debris washed or discarded into storm water inlets? They wind up in the river. The more dirt and litter swept up and hauled away, the less polluted will be the waterfront. With cars parked everywhere it is difficult to sweep streets so in many cities high pressure water sprays on tank trucks are used to flush streets. Any measure that reduces the litter, garbage, droppings and filth cast on the public streets and alleys will reduce pollution of the city's waters.

Erosion of sediment from newly graded land and excavated earth is a problem that, in its own right, needs attention. When the eroded material settles in combined sewers it aggravates the problem of deposition of solids from sanitary wastes and increases the pollutional effects of overflows. Erosion control and sewer cleaning are indicated.

Reducing input of sanitary sewage.—If less water were used in the home or a way could be found to recycle water for certain uses, the load on interceptors, treatment plants and rivers might be reduced somewhat. Homes have many water using devices, all of which no doubt have an optimum and a minimum practical rate of water consumption. The question may well be raised as to whether or not toilets, washers and grinders, are designed and operated for efficient use of water.

Recycling of water will involve some prior treatment so is discussed below as one aspect of reducing the pollutional or solids load in sanitary sewage.

Reducing solids in sanitary sewage.—There are many possibilities for reducing the pollutional material carried by sanitary sewage. Only a couple will be mentioned. All are accompanied by the problem of finding alternate ways of transporting and disposing of the materials which would otherwise have been carried away down the sanitary sewers.

Garbage is a good material to consider first for some important points can be illuminated. The discharge of garbage to the sewers is very popular with householders even though the practice significantly increases the load on treatment plants and the pollutional effect of storm water overflows. Some cities tried to hold the line and keep garbage out of sewers. Others bought everybody a grinder and stopped surface collections. The garbage grinder, like the sewer itself, is here to stay, at least until a cleaner, simpler, more convenient way of collecting and transporting household wastes is found. Those who tried to hold the line against garbage grinders were overwhelmed.

Treatment of sanitary wastes near the point of origin would reduce the settlement in combined sewers and the overflow of pollution during storms. Settling (or septic) tanks or other devices serving homes or groups of homes and apartments are a possibility. Secondary treatment and reclamation of water for irrigating trees and grass or for goundwater replenishment could accompany such schemes.

Private disposal, by septic tanks and cess pools or soakage pits, has not been successful because the ground plugs up, water tables are high in the spring, periodic rebuilding and maintenance are required. Such systems operated in conjunction with and discharging, when need be, to a sanitary sewer may have merit in some situations.

One advantage of treatment near the point of origin is that separation of solids and liquids is easier and more complete, the sooner it is accomplished. A serious disadvantage is that the removal and disposal of solids from the separation devices would be a burdensome operation, attended no doubt with considerable nuisance. Aerobic stabilization by blowing air through sewage for some hours before sending everything down the sewer might be a way to dodge this difficulty. Much more could be said as to possibilities and their pros and cons. It would all be speculation.

Storage of flow in the system.—Storm water storage tanks have been built in a few places and are at present being considered in others. Columbus, Ohio and communities in the Detroit area have such tanks; Halifax, Nova Scotia, is studying them. The usual idea is to build large shallow tanks beside the combined sewers in such a way that the tanks must fill as the sewer fills. This greatly dampens out peak flow rates and allows a higher portion of the total surface runoff and contained solids to be handled by the interceptors. Cleaning requires attention.

Storage in which water is accumulated to be pumped later at modest rates back to the sewer should be studied. Sedimentation and cleaning could be made more effective and construction sites more readily found. The ingenious Chicago scheme is described below.

Sewers and main interceptors in Chicago are placed at relatively shallow depths and laid on flat slopes. During heavy rains water accumulates on the surface and combined sewage backs up in basements throughout the city. Complete separation has been estimated to cost $2.3 billion. Consideration of cost of storage space in the streets, in the sewers, in holding tanks and in flood ways led to investigation of storage in caverns excavated deep in rock formations below the city. The project would consist of a system of galleries, 30 x 60 ft, 600 ft beneath the streets in which storm water could be temporarily stored. Large pump-turbine installations would be used with part of this space for generating electricity on the pumped-storage plan. When it rained this equipment could be cycled to discharge stored floodwaters at a gradual rate into the Illinois River well downstream from the urban area. Construction cost is estimated at one half billion dollars. Sale of peaking power and possibly excavated rock would defray part of the expense. This imaginative scheme is being given further study. Many questions remain, one being how the many miles (100±) of galleries would be kept clean.

Large combined sewers have in themselves a significant amount of storage space which is efficiently used only on rare occasions. The reasons are: First, since thunderstorms usually cover limited areas, some sewers may be loaded while most are empty. And second, sewers run full only when the "design" storm is reached or exceeded. During lesser rains, of which there are many, much storage space in most systems is unused. The possibilities for making better use of available storage space merit more attention.

Removal or alteration of solids in the system.—Opportunities for removing or stabilizing sewage solids within the system itself should not be overlooked. If deposition during dry weather flow is a problem, deposition could perhaps be turned to advantage by using sewers as settlers from which solids are periodically removed. The interior of a sewerage system has a very large surface area with which the sewage is in contact for considerable periods of time. This surface contact opportunity might well be used to stabilize sewage solids during passage through the system, particularly if the gross solids have been removed by settling. Designs to promote these ends should be studied.

Terminal treatment of overflows.—Treatment by settling of solids from excess storm water flows has been practiced in England for many years. Storm standby tanks go into operation when the capacity of treatment facilities are exceeded. What seems to be needed under American conditions are settling tanks at the terminal ends of overflows from combined sewers. These may stand empty to serve first as storage tanks, then as settlers if they overflowed. Overflows might be chlorinated. After the storm the tank contents, solids and all, can be sent down the interceptor to the regular municipal sewage treatment plant.

Measuring and monitoring.—At present almost nothing is known about the quantity, character and frequency of overflows from combined systems. Flow measuring and quality sampling devices should be installed on many such overflows, particularly those suspected of contributing significantly to water front pollution.

Improved operation and maintenance.—Operating and maintenance forces of the usual municipal sewage department rarely find time for proper inspection and servicing of the dozens if not hundreds of regulators and overflow control devices on the interceptors of a combined sewerage system. Routine inspection is needed, or even better, a telemetered warning system which informs the central office when sewage is spilling because of improper function of some device. With such systems crews can be sent immediately to trouble spots.

Conservation and planning.—In the humid regions of the United States enough rain falls on a city to supply all the water it needs. This water, unfortunately, comes in sudden bursts and is piped away as rapidly as possible. Planning for new or rebuilt cities should look toward conservation and use of this water, especially where groundwater replenishment is possible, or lakes for recreation are needed.

Another problem related to planning is the growing need for replacement of the underground services in centers of the older cities. As deterioration of systems for supplying water, sewer, gas, electricity, communication and heat continue, the time will come when streets must be laid open or manholes entered to repair some service even more often than now. The interruptions to surface traffic may well become unbearable. Many cities have service tunnels of limited extent and purpose in downtown areas. Extension of these systems and inclusion of all services in them will require a planning operation of major proportions. Finding solutions for the combined sewer problem should be considered an important part of such coordinated planning for improvement of all underground utilities.

LEGISLATIVE ACTION

The Water Quality Act of 1965, authorizes the Secretary (of HEW) to make grants to any State, municipality, or intermunicipal or interstate agency for the purpose of assisting in the development of any project which will demonstrate a new or improved method of controlling the discharge into any waters of untreated or inadequately treated sewage or other waste from sewers which carry storm water or both storm water and sewage or other wastes, and for the purpose of reports, plans, and specifications in connection therewith.

The Act authorizes appropriation of $20,000,000 per fiscal year for the purpose of making grants under this section.

Unfortunately the above authorization does not clearly provide money for research and development but rather for assisting on a 50–50 matching fund basis, in the development of any project which will *demonstrate* a new or improved method. This kind of support may not produce much research and development, particularly if innovations are involved. Cities which put up 50 percent of the cost will be looking for a high percent probability that the demonstration will in fact successfully solve a problem they are faced with. Before such probability of success can be assured in connection with many of the types of measures discussed in this report, there must be a long background of research, field investigation, equipment development and testing, engineering planning and design and economic study. All these things may be done only to reach the conclusion that a demonstration is not warranted. It is a mistake to think that any and all attractive ideas can be demonstrated to be practical.

Better definition of purposes and more flexibility in use of funds for research, field investigation, development and demonstration in finding solutions to the combined sewer problem are desirable. When research is needed on questions that cannot be answered now, 100 percent support by HEW funds would be appropriate. A somewhat lesser percent might stimulate development work and engineering studies. Demonstrations of uncertain outcome, which, nevertheless, are needed to find bugs and costs, might carry a sharing ratio different than those schemes that are pretty sure to work as envisioned.

FINDINGS

An appropriate *ad hoc* group of Federal, state and local officials should be established to study the need for Federal support of research, development and demonstration as a means for stimulating a more active search for solutions to the combined sewer problem. This group could suggest cost sharing arrangements for the different kinds of work it could recommend budget requirements at all government levels and it could establish the review and coordination mechanisms needed to assure an aggressive, efficient attack on the problems caused by outmoded combined sewerage systems in the great cities of the United States. Billions of dollars are at stake.

APPENDIX Y7

Effects of Chlorinating Wastes

MARTIN ALEXANDER, *Chairman*

JOHN C. GEYER DERIC O'BRYAN, *Staff*

At present it appears that proper chlorination of water supplies and wastes has no deleterious effects. Although chlorine is toxic to some aquatic life, it is far less toxic than other waste chemicals that it can be used to destroy. Also chlorine reacts quickly with other chemicals and natural materials in water and is dissipated rapidly through aeration so that its effect on aquatic life is neither extensive nor long lasting.

Chlorine in many forms is used as an oxidant, a disinfectant, and, in conjunction with other materials, as a coagulant in the treatment of wastes. Fish kills, water quality deterioration, or similar conditions of significant severity directly attributable to chlorination are rare if they occur at all.

Most findings on undesired effects of chlorinating wastes are based on laboratory studies rather than on actual, in-field observations and relate to the toxicity of chlorine and chlorine compounds. The lethal concentration of chlorine for several types of fish ranges from 0.03 to over 3.0 ppm under specific chemical and physical conditions of the water. Wastes are usually treated with chlorine in a way such that free or residual chlorine does not cause toxic conditions in receiving waters. Excess is easily controlled by adding sodium thiosulphate.

A possible deleterious effect that can develop from chlorinating wastes arises from the formation of chlorophenols in the wastes and receiving streams. The undesirable odors and tastes of chlorinated water containing phenols have been recognized for some time by water plant personnel and consumers. Concentrations of chlorine up to 0.1 ppm do not produce odor with phenol concentrations up to 0.05 ppm. Tastes of chlorophenol are detectable when the chlorine concentration is between 0.175 and 0.4 ppm and phenol is between 0.002 and 0.17 ppm. The taste threshold of chlorine alone, in redistilled water, is 5.2 ppm. Conflicting with the deleterious effects arising from the formation of cyanogen chloride and chlorophenols is the fact that if sufficient chlorine is added under the proper conditions to liquids containing cyanides and phenols the offending chemicals are destroyed.

Although chlorination of water supplies and wastes does not cause problems at present, the practice should be watched, especially if the tendency to add greater concentrations becomes widespread.

APPENDIX Y8

Agricultural Wastes

MARTIN ALEXANDER, *Chairman*

NYLE C. BRADY DERIC O'BRYAN, *Staff*

The excreta of farm animals may be a major source of water pollution; animal wastes enter the streams, rivers or lakes either in the form of surface runoff or through seepage. In some watersheds, farm animals contribute considerably more wastes than humans, and the drainage from certain land areas supporting large animal populations probably leads to significant water contamination. Pollution from animal manure is known to have reached such proportions in some areas that downstream fish kills and ground water contamination have been observed.

As the human population increases, the animal population continues to rise; however, the usable land area becomes no greater. The problem of agricultural waste disposal has grown to such dimensions that probably the major unsolved issue in the confinement housing of livestock and poultry is the handling and disposal of manure. The magnitude of the problem may be visualized in simplified terms by comparing the wastes voided by man and by the animals he raises. For example, a cow generates as much manure as 16.4 humans, one hog produces as much waste as 1.9 people, and seven chickens provide a disposal problem equivalent to that created by one person. As a result, farm animals in the United States produce ten times as much waste as the human population.

Ground water pollution arising from the disposal of livestock and poultry wastes may be evidenced in undesirable changes in taste, odor and color of the water. Moreover, when manure treatment or storage areas are improperly located, the nitrate levels in immediately adjacent water supplies may become disturbingly high. The organic nitrogen in the barnyard manure is converted to nitrate, which in turn may pollute rural wells despite the absence of indications of bacterial pollution. This nitrate-rich water, when consumed by infants, may cause methemoglobinemia. Even without overflow, sewage lagoons used for farm waste disposal may also be responsible for the pollution of the ground water.

Recent studies in several states have linked high nitrate concentrations in wells with animal feed lots, farmyards, and with wastes from the population of animals in general.

Animal manure is associated with disagreeable odors, the breeding of flies and with potential hazards to the health of man and livestock. During the feedlot finishing of beef cattle, the odor and fly problems arising from the waste accumulations become especially acute, particularly in view of the frequent proximity of suburban housing. In certain localities, manure odors have been so offensive that many farmers have been compelled to go out of operation. Animal wastes may likewise pose a hazard to human health inasmuch as they contain many pathogens common to both animals and man. Although the dangers associated with the manure of large animals is often cited, a potential hazard likewise may exist in poultry manure. Storage of manure may sometimes provide conditions favorable for the development of certain pathogenic microorganisms, and the dust raised, particularly during handling of certain dried wastes, could conceivably provide high densities of harmful microbial spores with a greater chance of serious human exposure to certain disease-producing microorganisms.

Disposal of farm animal wastes has created a major and evergrowing production problem for the American farmer. The problems of farm waste disposal, and pollution arising from agricultural sources, are aggravated by the large animal population, the sheer volume of material to be disposed of, and the unavailability of suitable disposal procedures or facilities. In hog and poultry production as well as in other livestock operations, farmers are moving to a greater degree of automation. The animals are maintained in confined areas and pastures are being replaced more and more by confinement housing so that smaller land areas are required per animal. In many regions poultry units house more than 100,000 birds in a single establishment, and the trend in the hog industry is to have confinement units marketing 3,000 to 10,000 animals per year. It is likely that the majority of hogs in this country eventually will be raised in confinement units, compounding the difficulties of farm waste management and pollution control.

It is now standard procedure to practice feedlot finishing of beef cattle, an operation in which the cattle spend three to five months in a feedlot frequently having some 100 square feet of space per animal. Here, the animals receive a rich diet and produce large quantities of manure, which must be removed regularly regardless of the accessibility or availability of land for spreading.

Despite a modest amount of research, there is yet no single method generally satisfactory for the treatment and disposal of animal manure originating in confinement livestock operations. Field spreading, composting, anaerobic digestion, incineration, lagooning, dehydration and other procedures have been attempted or proposed as possible disposal methods. Some of the procedures have been successful in certain regions, but none is widely applicable. Manure has often been disposed of by distribution to gardeners and greenhouse operators, but at the present time there is no market for the large volumes of manure produced annually. The classical method of field spreading is often effective in preventing accumulation of the wastes, but the frequent scarcity or unavailability of land often eliminates this as a feasible means of disposal. Composting has often been successfully exploited by private companies for short periods of time, but these operations usually have been short-lived; moreover, the supply of manure far exceeds the demand for compost. Each of the methods devised or suggested has its advantages, but each has distinct limitations, and more information is required before these procedures can be widely employed.

Agriculture has done an excellent job in increasing farm production and in providing the nation with the food it requires for high health and economic standards. Clearly, it is now necessary to be concerned as well with the various wastes of the production operations.

FINDINGS

(1) The Federal Water Pollution Control Act should be vigorously enforced to prevent further pollution and abate existing pollution arising from farm animal and other farm wastes.

(2) State water pollution control authorities should take strong action to prevent further pollution and abate existing pollution from farm animal and other farm wastes.

(3) Greater emphasis should be placed by the U.S. Department of Agriculture and the State Experiment Stations upon seeking new uses and markets for farm wastes.

(4) Funds should be made available to the Department of Agriculture for the development of new or better equipment for the handling and treatment of farm animal wastes. Information will be required on equipment performance and on means for the collection, processing and distribution of such wastes.

(5) Research is required on the physical, chemical and biological properties of farm animal manure and on the behavior of such farm wastes in soil and water in order to devise efficient disposal practices. These efforts will require support by the Department of Health, Education, and Welfare and the Department of Agriculture, of sanitary engineers, agronomists, public health workers, animal scientists and others.

APPENDIX Y9

Aquatic Blooms

MARTIN ALEXANDER, *Chairman*

JOHN B. MOYLE
RUTH PATRICK
LEON WEINBERGER
DERIC O'BRYAN, *Staff*

Contents

INTRODUCTION

Many surface waters of the United States are being fertilized with mineralized nutrients attributable to man's activities to such an extent that objectionable growths of algae and larger water plants appear (eutrophication). This commonly results in a deterioration of water quality, making it less desirable for domestic, industrial, and recreational uses and for fish and wildlife. Hundreds of areas, scattered nation-wide, are affected to some extent, although only the larger and more important waters have received much attention and publicity. Usually eutrophication with its attendant problems is more serious in impounded than in flowing waters; for this reason, nutrient enrichment of water and aquatic blooms will be an increasingly important problem as more dams are constructed, more waters are impounded, and more nutrient-bearing wastes must be disposed of.

Phosphates and nitrates are often primary factors promoting these undesirable changes. Present sewage treatment processes are reasonably acceptable for the removal of organic matter, breaking down most organic wastes into their inorganic constituents, and for controlling microorganisms harmful to health. However, these treatment processes do not remove much of the inorganic phosphorus and nitrogen that enter the sewage plant, and the treatment operations permit the release of nitrates and phosphates in large amounts into natural waters, leading to unwanted chemical and biological enrichment of the waters of ponds, lakes, rivers, and estuaries. Certain agricultural operations may contribute substantially to these effects.

Although phosphate and nitrate often are involved in inducing the undesirable growth of aquatic plants in water, other nutrients may be involved as well.

In its deliberations, the subpanel has examined the extent and severity of the problem in the United States, considered the relative contribution of various sources, evaluated possible means of relieving the problem, explored research directions most likely to be profitable and evaluated various corrective actions that might be undertaken on the basis of present knowledge and technology.

NATURE OF THE PROBLEM

There is nutrient enrichment or fertilization of waters with mineralized nutrients attributable to the activities of man at many places in the

United States. Such enrichment may be undesirable, desirable or inconsequential, depending upon the specific situation. In low concentrations, nitrate and phosphate seldom produce objectionable effects. However, abnormally high concentrations or continuous addition of these and other nutrients can cause deterioration of water quality. High fertility often promotes excessive growths of algae and other water plants. These growths can be a nuisance themselves and can, through their physiological demands and decay, reduce concentrations of dissolved oxygen and otherwise change waters so that they become less suitable for human use and less favorable for fish, and wild and domestic animals. Costly treatment of water supplies may be necessary for removal of unwanted plant growth and elimination of objectionable tastes, odors, and added dissolved minerals including phosphates.

Fertilization speeds up the ecological aging or eutrophication of waters. Such change is usually most rapid and most noticeable in impounded waters of lakes and reservoirs which, if they remain undisturbed, eventually become filled with organic debris along with silt and material settling from the water as a result of chemical precipitation. Eutrophication will be an increasingly important problem in the future with increased use and re-use of potable and industrial waters and as more reservoirs are built to impound and store water.

Prime consideration has been given to the importance and effects of the addition of phosphorus and nitrogen, particularly as orthophosphate and nitrate, to waters. These two essential elements for plant growth are singled out because often, but probably not always, the supply of other nutrients needed for aquatic plant growth is present in excess of the biological demand, and phosphorus or nitrogen are the elements limiting the extent or severity of the aquatic algal blooms or excessive growth of other plants. It should be emphasized, however, that many other nutrients are essential for the growth of algae and rooted aquatic plants, and in specific situations, one or more of these nutrients may be more important in promoting unwanted blooms than inorganic forms of either nitrogen or phosphorus.

EXTENT OF THE PROBLEM

An immense number of analyses of surface and ground waters exists, published and in the files of state and governmental agencies. Much information also has been gathered by limnologists for specific surface waters. Much of the analytical work, especially that of the United States Geological Survey, has been concerned with elements other than those of direct relevance to aquatic plant blooms, but the Geological Survey has considerable data on nitrate levels and some information on orthophosphate concentrations. Data on the levels in water of other forms of bound nitrogen are limited and often are of uncertain value. Much of the available analytical data on orthophosphate and phosphorus content of water does not include the bound, complexed, or other forms of the element which may contribute to algal blooms and often the quantities are expressed too grossly to be of much value for the purposes of assessing the phosphorus contribution to potential algal blooms.

For the purposes of this report, the inland waters of the United States are grouped in three general categories: (1) *soft waters* with hardness, expressed as calcium carbonate, of less than 60 ppm; (2) *hard waters,* bodies of water of intermediate hardness; and (3) *very hard waters,* with values generally exceeding 240 ppm. Soft waters are characteristic of most of the Atlantic coastal plain, the Southeast, the Pre-Cambrian rock region at the head of the Great Lakes, the extreme Northwest, and the Sierra Nevada region. The very hard or "alkali" waters are characteristic of arid and semi-arid western plains and deserts. Hard carbonate waters are characteristic of much of the interior of the United States including the farm lands of the midwest. These areas of water hardness are shown in Figure 1.

In the soft-water regions, natural concentrations of phosphorus and nitrogenous compounds are usually low. Here, impounded waters commonly do not have blue-green algal blooms, and the algal flora is characterized by diatoms and desmids. Deep soft-water lakes are usually of the classical oligotrophic type. Examples are the upper Great Lakes, Lake Tahoe in California, Crater Lake in Oregon, and the many deep lakes of northern Minnesota, Wisconsin and Michigan, New York, and upper New England. Such waters usually have total phosphorus concentrations below 0.02 ppm and often below 0.01, and the low level of biologically available phosphorus is also suggested by the fact that fish ponds in these regions often require phosphate fertilization.

When soft-water ponds in the south and oligotrophic lakes in the north are enriched with fertilizer elements, the biological changes frequently are quite obvious. Lakes that were formerly clear turn green with algae seasonally, and they become less suitable for a variety of recreational and other uses.

Hard carbonate waters are usually fairly rich in phosphorus and nitrogen, and they are generally more productive of plant life than are soft waters. Often lakes and slow-flowing streams of this type have obvious summer growths of blue-green algae. Such waters are especially susceptible to the influence of added nutrients. The shape and size of lake basins is important in determining the type of plant life. Small, shallow lakes are usually filled with rooted submerged aquatic plants, while certain large shallow lakes in which nutrients circulate throughout the summer are especially apt to produce dense growth of plankton algae. Deep hard-water lakes where there is thermal stratification usually have less

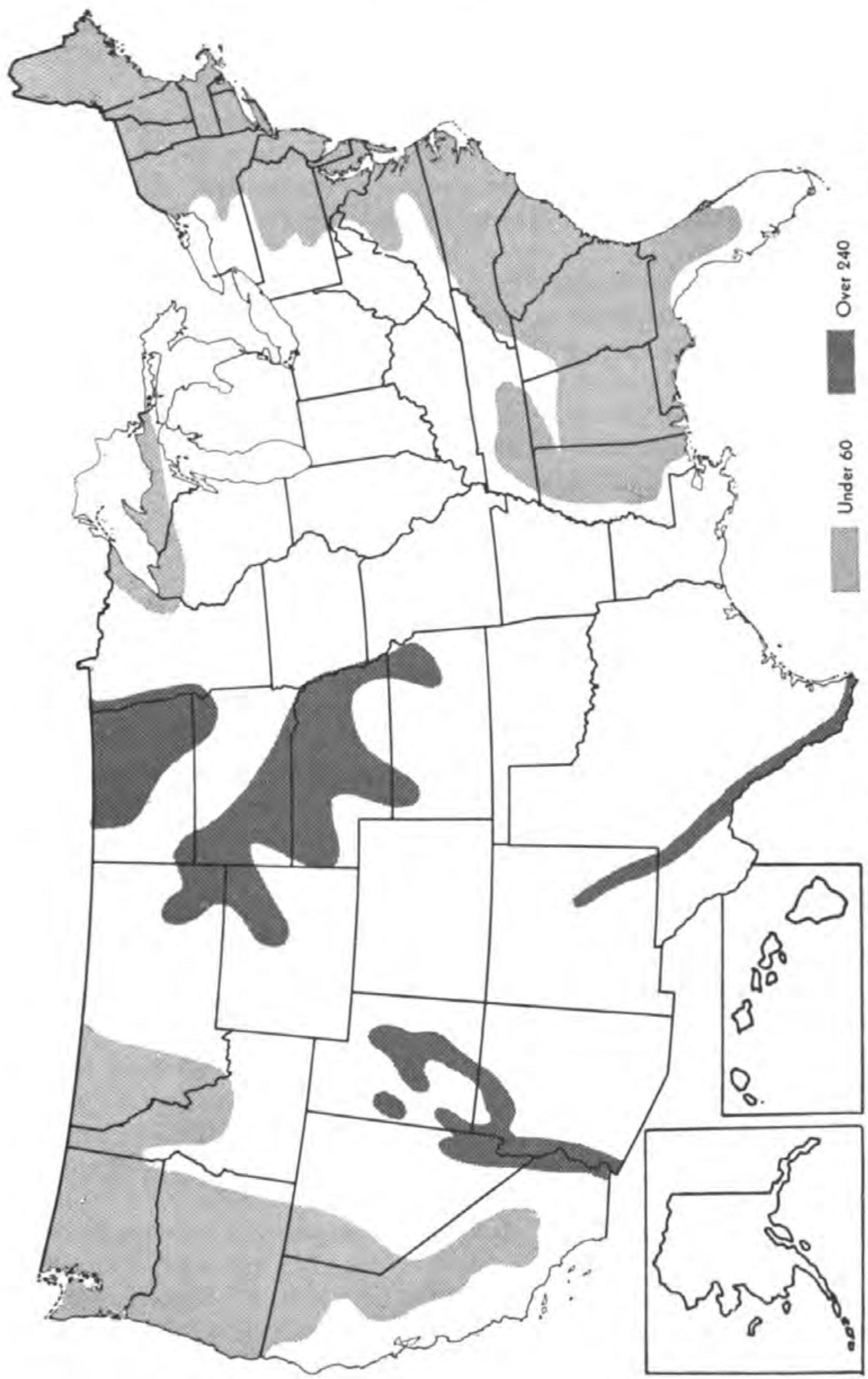

FIGURE 1.—*Generalized map of the United States showing hardness of waters expressed as ppm $CaCO_3$*

plankton algae. Where there are many hard-carbonate lakes, the concentration of total phosphorus in surface waters in summer is usually between 0.02 and 0.1 ppm, but those with marked blue-green algal blooms usually have higher concentrations.

The very hard water or alkaline lakes of arid regions are often quite fertile, and some have particularly high orthosphosphate concentrations. Some of the larger lakes frequently have blue-green algal blooms. In very arid regions, concentrations of salts may be so high that plant growth is greatly restricted.

Phosphorus in waters.—Although most attention has been given to orthophosphate, surface waters contain a variety of other forms of phosphorus, and certain of these are available to some kinds of aquatic life. Neither the identity of much of this phosphorus or its role in aquatic growth is yet clear. In lakes, the concentration of dissolved orthophosphate is usually low (below 0.02 ppm), but concentrations of orthophosphate greater than 0.033 ppm are not uncommon in rivers. Average concentration of orthophosphate phosphorus in 18 streams in Pennsylvania, Ohio, West Virginia, Kentucky and Illinois ranges from 0.033 to 2.1 ppm with a median of 0.08 ppm, and 28 streams with softer waters from the State of Washington contained from 0.003 to 0.18 ppm with a median of 0.03 ppm.

Nitrates in waters.—In lakes and other impounded waters, nitrate-nitrogen concentrations are usually quite low (below 0.1 ppm); the low levels probably result from the fact the nitrate is used by plants almost as rapidly as it appears in the water. In streams, the concentrations are usually higher than are observed in impounded waters, often being between 0.1 and 0.5 ppm as nitrate nitrogen. Seventy-seven surface waters, mostly creeks and rivers, analyzed by the Geological Survey in 1962 had nitrate concentrations higher than 2 ppm nitrate-nitrogen. The nitrate concentrations in streams of hard-water areas are usually higher than in steams of soft-water areas, median concentration for six major soft-water drainages being about 0.13 ppm and for five hard-water drainages about 0.3 ppm.

Nitrate levels are often found to be higher in streams draining farm lands than in those draining forest lands, and it is in the lakes of the corn country of the Midwest where algal blooms are most common (see Figure 2). In most lakes, the relative contribution of various sources of nitrogenous nutrients has not been established.

Certain kinds of blue-green algae, like some species of bacteria, fix atmospheric nitrogen. When the nitrogen thus fixed into organic form is mineralized, it contributes nitrate and ammonia to the aquatic ecosystem. The magnitude of this fixation has seldom been determined, but because of this process, an aquatic ecosystem that might be initially nitrogen-poor could have phosphate rather than nitrate as the element limiting

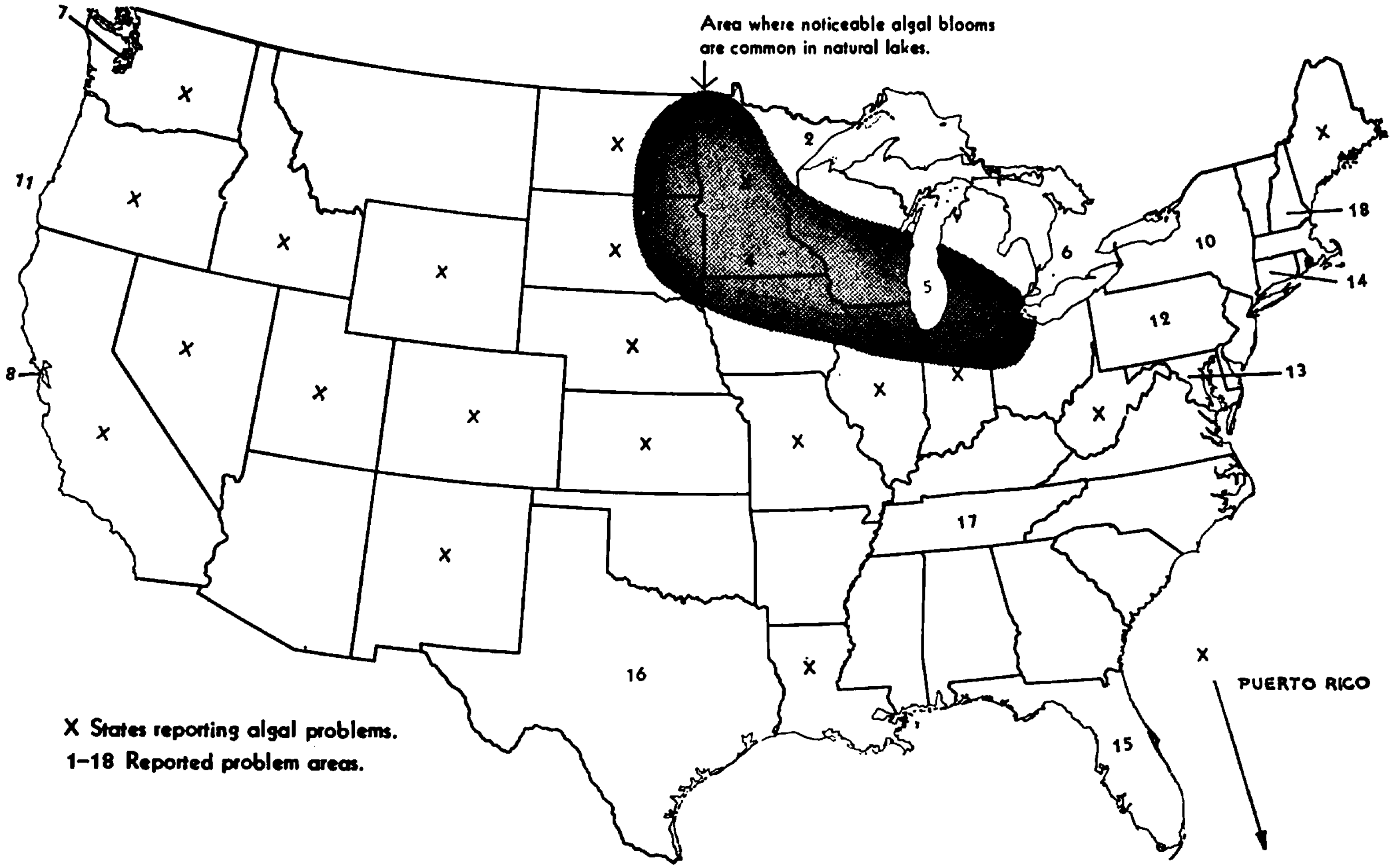

FIGURE 2.—*Algal growth problems associated with the enrichment of surface waters.*

algal growth. Under circumstances where algal fixation of N_2 is prominent, phosphorus may be more amenable to control than nitrogen.

Nitrates may accumulate in ground waters, especially where the soil is porous and the water table is underlain by an impervious layer. Nitrate is known to reach shallow wells from septic tank seepage, sewage effluent sprayed on porous soil, runoff and seepage from cattle feed lots, manure applied to farm fields, and probably from manufactured fertilizers. Shallow wells, those less than 100 feet deep, most often have high concentrations. High nitrate concentrations may also occur sometimes in waters in geologic formations below the depth of human influence, especially in sedimentary and unconsolidated rocks.

Drinking water with nitrate-nitrogen levels above 8 to 9 ppm causes methemoglobinemia or cyanosis in infants. For water given to livestock, a nitrate concentration above 5 ppm nitrate-nitrogen is regarded as unsafe, and high concentrations may result in methemoglobinemia, loss of milk production, vitamin A deficiency, thyroid disturbances, and reproductive difficulties and abortions.

Substantial contamination of ground water with nitrate has been reported in North Dakota, South Dakota, Minnesota, Iowa, New York, Pennsylvania, New Jersey, Missouri, Nebraska and Texas (see Figure 3). Recent Geological Survey data note 38 areas scattered throughout the United States where some wells have nitrate-nitrogen concentrations in excess of 3 ppm.

Algae of impounded and flowing waters.—Algal and other eutrophication problems caused by fertilization differ in flowing and in impounded or slow moving waters. In lakes and slowly moving waters, three types of planktonic blue-green algae are most apt to be troublesome. These flourish in waters warmer than 70° F. Dense plant growths or blooms accumulate along shores as ill-smelling and decaying scums and masses. Occasionally, such accumulations are toxic to domestic and wild animals. The identity of the toxin is not known, although a considerable amount of work has been done on it.

Algal blooms may develop without enrichment of nitrates or phosphates. This can occur when some toxic material eliminates most of the other aquatic flora, and the nutrients present in the system become available to a few tolerant species of algae. Blooms of blue-green algae may also result from artificial warming of waters, such as by outflow of water used to cool condensers, even though concentration of nutrients may not increase. This condition has been observed in several rivers in the eastern United States. The lack of plankton predators might also favor algal bloom. Blooms may likewise be caused by the release of nutrients following destruction of rooted aquatic plants by herbicides.

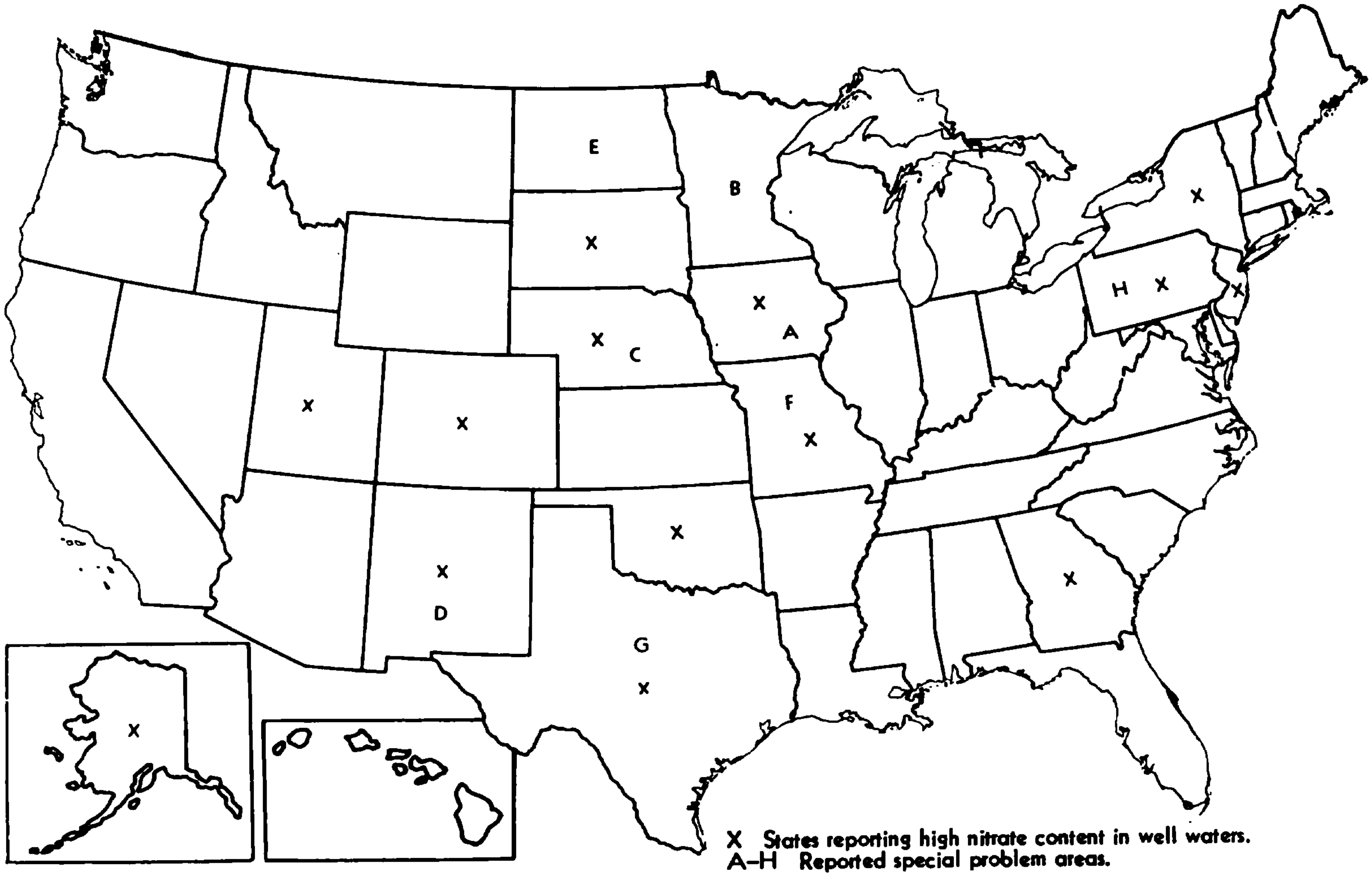

FIGURE 3.—*Reported nitrate enrichment of ground waters.*

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Lake fertilization may also cause heavy growths, even blankets of filamentous green algae, to develop along shores. A problem of this type occurs in Lake Erie and Lake Michigan.

Diatoms and, to a lesser extent, green algae dominate in the plankton of rivers. Blue-green algae are generally few in number except in impounded or slow-water reaches. The dominance of diatoms and occasionally green algae is illustrated by algal counts from 50 stations in the nation-wide Water Pollution Surveillance Network of the United States Public Health Service, where counts of algae exceeded 10,000 per cubic centimeter one or more times in 1962–63.

Seriousness of the problem.—In attempting to identify regions and localities where the addition of nutrients is creating difficulties, it is often not possible to separate the effects of mineralized nutrients from those attributable to the nutrient elements contained within organic matter added at the same time. However, since well-designed waste treatment plants reduce most organic matter to mineralized nutrients, it is assumed that eutrophication in the following localities is affected primarily by mineralized nutrients.

Serious man-induced eutrophication has been reported in the following impounded or slow-flowing waters: Lake Erie; Long Island marine waters; Lake Zoar, Connecticut; Lake Washington at Seattle, Washington; Sacramento Delta estuary, California; Madison Lakes, Wisconsin; Shagawa Lake at Ely, Minnesota; shorelines of southwestern Lake Michigan; and the lower Potomac River.

In addition, there are several hundred lakes, especially in the farming country of the Midwest, that have problems resulting from eutrophication. A considerable number of these lakes—at least one hundred—have had remedial measures applied to them, such as diversion of sewage effluent or chemical control of algae and larger aquatic plants.

In rivers, obvious eutrophication is most common below the waste outfalls of larger cities. Based on high counts of algae reported by the Water Pollution Surveillance Network in 1962–63, and other information, the following are examples of rivers that have serious problems: Connecticut River in Connecticut; Raritan River in New Jersey; Shenandoah River in Virginia; Susquehanna River in Pennsylvania; Little Miami River in Ohio; Wabash River in Indiana; Illinois River in Illinois; Mississippi River in several states; Big Sioux River in North Dakota; Platte River in Nebraska; Arkansas River in Arkansas and Oklahoma; Red River in Texas and Louisiana; and Upper Snake River in Idaho and Oregon. One or more stations on these rivers had algal counts exceeding 10,000 per cubic centimeter four or more times in 1962–63. Fifteen other rivers had such high counts fewer than four times—including the Potomac, Ohio and Missouri. Other streams having such problems are the Trinity and Brazos rivers in Texas, the Delaware River, James River in Virginia, and the Lehigh River in Pennsylvania.

Sources of nutrients.—Surface and ground waters receive nutrients from several sources. Nitrogen, phosphorus, and other plant nutrients are components of natural runoff. Rain provides an appreciable amount of fixed nitrogen. Animals, such as wild ducks and fish, fertilize waters with their excrement. Atmospheric nitrogen is fixed by some aquatic bacteria and algae. A rise in water level may release nutrients from the decomposition of flooded vegetation. Conversely, nutrients may be lost from a body of water by outflow, tie-up in sediments, volatilization, removal from the water in fish taken from it, and aquatic insects that emerge from it. Under undisturbed conditions, however, nutrient gains usually are almost balanced by nutrient losses, and eutrophication proceeds very slowly. The upper Great Lakes, for example, have been in existence for about eight thousand years, and they are still markedly oligotrophic.

Nutrients attributable to man's activities come from several possible sources, the most important of which are domestic sewage, garbage, industrial wastes, remnants of manufactured chemical products, drainage from fertilized lands, wastes from domestic animals and sewage from ships and boats. The amounts and proportions any water receives from these several sources differ in different situations and from time to time.

A few local studies have been made of contributions to receiving waters of nitrogen and phosphorus from several sources. Notable are the studies conducted at Madison, Wisconsin, at Oneida Lake, New York, at Lake Tahoe, California, and at Lake Washington at Seattle. At these sites, domestic wastes were found to be a major present or potential source of nutrients. Rather than cite figures for specific cases, it appears more meaningful to consider concentrations of nutrients in different kinds of source waters, recognizing that amounts of nutrients added to a specific receiving water depend upon the concentration of nutrients and the volume of water carrying them.

Drainage waters vary considerably in the concentrations of nutrients they carry. In one study, it was shown that urban street drainage and return flows from both surface and subsurface irrigation contained concentrations of nitrogen and phosphorus several times greater than that observed in streams of forested areas in the same region with little habitation and land use. Such urban drainage waters were also higher in nutrients than a quite fertile eutrophic lake (Green Lake, Seattle) and about as high as that for urban streams. It is apparent that the flows from irrigated lands and street drainage are sources of added nutrients to surface waters.

Sewage and sewage effluents, however, are a much more concentrated source of nutrients. Such concentrations are much greater than those of natural surface waters or those of drainage waters, except for the high nitrate levels in certain irrigation water returns. Investigations of the chemical composition of the effluents of sewage plants indicate that the phosphorus concentrations are considerably higher than was common in sewage effluents 20 years ago. This increase is attributed to detergents.

In the past two decades, detergent use has become widespread, and presently about 4 billion pounds of detergent products are used annually in the United States. Both non-biodegradable and biodegradable types have phosphate as a base or builder. Usually polyphosphates are used, and these are rapidly changed to orthophosphate, a form which is available for plant growth. Domestic and liquid detergents usually contain 20 to 30 percent polyphosphate, but some products contain as much as 50 percent. At some locations, as much as half the phosphorus in sewage effluents comes from detergents.

Although it has been stated by some that prospects for the replacement of readily hydrolyzable phosphorus compounds in detergents are bleak, others claim that compounds probably can be found which have the desirable charasteristics of the phosphate builders in the detergents, yet present little problem in terms of eutrophication. Whether or not such compounds are chemically and economically feasible or biologically desirable in waters remains to be seen.

Studies on the increase in the concentration of nutrients in sewage effluents, above that in source waters, indicate that concentrations of nitrate-nitrogen are increased by 1 to 20 ppm, ammonia 2 to 20 ppm, and phosphate-phosphorus 3 to 16 ppm. When it is considered that the amount of phosphate-phosphorus in uncontaminated source waters usually does not exceed 0.1 ppm and nitrate-nitrogen 0.5 ppm, the magnitude of the increase is immediately apparent.

The nutrient contributions from several sources can also be expressed in terms of population equivalents, *i.e.* as fractions or multiples of the average amounts contributed annually by one person. By such a calculation, the nitrogen of treated domestic sewage from one person for a year has been estimated in one study to be equivalent to that released by runoff from 0.16 to 0.24 acres of corn land with a 20 percent slope, or runoff from about twice the acreage of corn land with an 8 percent slope, or by drainage from .03 to 3.7 acres of irrigated diversified farmland. In terms of phosphorus, treated sewage from one person is equivalent to phosphorus received from 1.7 acres of corn land with a 20 percent slope, or 6 acres of corn land with an 8 percent slope, or 0.8 to 3.3 acres of irrigated diversified farmland.

The amounts of nitrogen and phosphorus reaching waters that can be attributed to the fertization of agricultural lands are as yet largely unknown. However, agricultural experts are of the opinion that most of the phosphate applied to soils is tightly bound and stays in place unless the soil is eroded away. Nitrates, however, leach through the soil and can more easily reach ground and drainage waters. Although the data are sparse, many observers are of the opinion that chemical fertilizers contribute to the enrichment of waters. There is little definitive information and further investigation is required.

Manure from cattle concentrated in feed lots is an important source of the nitrogen entering ground waters. Hog, chicken, and duck manures are also potential sources of nutrients. Small domesticated animals and pigeons in urban areas may add to the problem.

The contribution of nutrients to waters from industrial wastes, other than phosphorus attributable to detergents, is sporadic in the nation-wide picture, but it may be locally severe. In a few instances, the release of phosphoric acid wastes, or nitrogen in the form of ammonia, or organic nitrogen, may contribute to water enrichment. Waste water from fertilizer manufacturing plants is also a present and potential source, major contributions here usually being the result of poor plant management.

POSSIBLE USES OF AND NEEDS FOR CONSERVING NUTRIENTS IN WASTES

Addition of manufactured fertilizers and manures to fish ponds to increase yields has long been an established practice, and it is likely that the addition of nitrate, phosphate and other nutrients to other bodies of waters also increases fish production, provided only a reasonable amount is added. Excessive amounts are not desirable and result in making waters unsuitable for fish, or in production of rough rather than more valuable game fishes. Waterfowl may also benefit from some fertilization of waters. Enriched waters in Minnesota have been shown to produce more ducks and to have greater waterfowl use during migration than non-fertilized waters. Sewage effluents can also be used for watering crop or park lands if applied in reasonable amounts.

A proportion of the nutrients in sewage is removed by common methods of sewage treatment and is accumulated in sludge. Such sludge, when dried, is usually too poor in nutrients to be of commercial value as a fertilizer. Sludge produced by activated sludge plants is higher in nutrients, and some has a commercial use, but this is usually a marginal or non-profit making operation. Lime can be employed for removal of phosphate from sewage effluents; the resulting material could be put to use. Sewage nutrients could also be used for the commercial production of algae, which might possibly serve as a poultry feed or as a source of biochemicals of economic value.

REMEDIAL AND CORRECTIVE ACTIONS

Any discussion of control techniques applicable to the problem of eutrophication must necessarily be founded on a basic understanding of the cause, or causes, of the phenomenon. Such a basic understanding is not currently available. Accordingly, all recommendations for the development of treatment and control techniques for inorganic nutrient material (nitrates and phosphates) are based on the assumption that these nutrient materials do, in fact, contribute significantly to the eutrophication problem. Specific recommendations for control must be based on the various sources of the nutrients and the relative amounts from each of those sources. In general, it may be stated that the nutrients may come from point sources, including domestic wastes, industrial wastes, boats and ships, and urban runoff which is carried to receiving waters by separate or combined sewers; and non-point sources, including land drainage affected by man's activities, garbage and refuse dumps, nitrogen fixation, excrement from wild animals and fowl, natural land drainage, and precipitation.

Control at the source.—Consideration should be given to the substitution of products or processes which do not contribute inorganic pollution resulting in eutrophication. As examples, if phosphate from detergent products is a major contribution to the problem, a non-phosphate additive should be sought. Substitutes for industrial processes which result in the discharge of phosphates or nitrogen compounds could be developed. Industrial operations could be modified to minimize the amount of nutrients being discharged in waste to streams. Products might be developed, such as fertilizers with controlled nutrient release, which would minimize the amount of nutrients reaching streams, lakes and coastal waters. Wild fowl and other refuges could be planned and operated to minimize nutrient contamination of particular bodies of water.

Treatment of waste streams.—Bodies of water receiving nitrogen or phosphorus in the waste of an industry or municipality can be subjected to treatment for the purpose of removal of the undesirable substances. There are very few municipal plants which are being operated to minimize the nitrogen and phosphorus content in the effluent stream. In conventional biological treatment plants, organic nitrogen, urea, and ammonia nitrogen are converted to protein (in bacterial cells), ammonia and nitrates in the effluents. Further nitrogen removal from the effluent may be accomplished by algal ponds which convert more of the soluble nitrogen to algal cells. At some laboratory and pilot installations, the nitrified sewage is subjected to anaerobic conditions and the nitrogen converted to gaseous nitrogen with subsequent release to the atmosphere. Passing of sewage plant effluent through selected soils has resulted in nitrogen removal, possibly through denitrification. Chemical means for removal of nitrogen have not progressed beyond the laboratory research phase. Suggestions have been heard regarding the removal of nitrogen through ion exchange, but no quantitative data are available. The application of current treatment technology can result in the removal of approximately 50 percent of nitrogen in domestic wastes. The nitrogen removed in the form of bacterial or algal protein can be used as soil additive and potentially as animal feed supplements. The conversion of the nitrogen to a valuable product could make it more attractive to remove nitrogen from wastes.

Phosphorus removal is only accomplished to a very limited extent currently in biological treatment plants. Any removal that does occur is from the precipitation of phosphates and the removal of phosphorus in the excess biological mass developed. In conventional municipal waste treatment facilities, the inorganic nitrogen and phosphorus levels in the effluent generally exceed the level in the inflow.

Removal of phosphate can be accomplished by chemical coagulation, and plants, such as the one at Lake Tahoe, are now under construction to accomplish this. Chemical coagulation can reduce the concentration of all forms of phosphorus compounds, ortho, complex, and organic. Lime, alum, ferric salts, and polyelectrolytes are being used, and reduction of greater than 90 percent has been accomplished. Some of the proposals call for the recovery of chemicals which might provide for a more attractive economic situation. Work on the effectiveness of biological removal of phosphates by bacteria has not yet been substantiated by field or full scale plant operation. Removal of phosphates by algae in ponds can be accomplished, but there is limited information on the percentage reduction that is achieved.

Treatment of industrial wastes containing nitrogen and phosphorus follows the same trends as indicated for municipal treatment. Some industrial wastes, high in nitrogen, show a substantial reduction in nitrogen during treatment, but still result in high levels going to receiving bodies of water.

Techniques of waste treatment being developed under the waste treatment research program of the Department of Health, Education, and Welfare are aimed at complete removal of nitrogen and phosphorus from waste streams. Those processes, including adsorption, foaming, electrodialysis, ion exchange, precipitation, evaporation, and reverse osmosis show promise of complete removal of all contaminants from waste streams.

Wastes from boats or ships can be either treated aboard the vessel or else stored and discharged to an acceptable system.

Nutrients from land drainage.—Nitrogen and phosphorus currently entering streams in the form of land drainage from farm animal wastes can be treated by the installation of suitable facilities. Improved agricultural practices could reduce the amount of nutrients lost into receiving waters. In critical situations, land drainage can be intercepted and treated for removal of undesirable elements, or diverted to a disposal point where objectionable conditions would not be created, or stored for controlled release.

Control of eutrophication in receiving bodies of water.—If nitrogen and phosphorus enter receiving bodies of water, eutrophication may still be prevented. Since the concentration of the nutrients is a major consideration, efforts can be made to reduce the concentration of nitrogen and phosphorus in the stream by providing proper means for dispersion of wastes, or possibly by regulation through dilution by low flow augmentation.

It may be possible to make the nitrogen or phosphorus unavailable as nutrients by the addition of appropriate chemical chelating or complexing agents. If it develops that phosphorus is important to algal development, concerted effort could be directed to controlling this aspect. It should be noted that the current approach dealing with non-point sources of nitrates and phosphates, and the non-removable fraction from waste treatment plants, is sometimes by low flow augmentation.

Problems arising from eutrophication can be controlled by preventing the excessive development of undesirable plant growths. Chemical control, which has not proven particularly effective, or biological controls, such as through algal viruses and the biochemical or biological modification of a receiving body of water, should be considered as possibilities of preventing eutrophication.

Once critical nutrient levels are reached and eutrophication takes place, the natural sequence is self-perpetuating through the death and decay of the algae with the subsequent release of nutrients. To solve adequately the problem of eutrophication in certain locations, not only must the addition of nutrients be curtailed, but the nutrients already present in the lake must be removed, reduced in concentration, or made unavailable. A number of solutions for removing nitrogen and phosphorus by the harvesting of algae, rooted plants, and the fish population have been suggested. The role played by sludge deposits in lakes, their composition and what effect they have on the release of nutrients is still to be determined. Large scale engineering projects aimed at modifying oxygen gradients, temperature gradients, sludge dredging, and construction of physical barriers in lakes may be effective in solving the problem of eutrophication.

On the basis of exploratory experiments it would seem that controlled removal of nutrients by algae, followed by algal harvesting, should warrant more attention.

RESEARCH NEEDS

Eutrophication may not yet be an issue of catastrophic proportions, but problems associated with the increasing enrichment of waters merit immediate study not only to minimize present but also to avoid future degradation of the nation's water resources. Furthermore, research aimed at ascertaining the causes of problems resulting from the over-enrichment of water resources is urgently needed, and corrective measures must be established for specific bodies of water which continuously or seasonally no longer meet present and potential use requirements because of eutrophication. Consideration should be given both to personnel and funds needed to obtain the knowledge required.

Research needs may be listed within three major fields of endeavor.

(a) Studies of ecosystems:

(1) Establishing the conditions which permit the flourishing of unwanted aquatic plants in specific environmental situations. These factors include the amounts and kinds of nutrients, temperature ranges and other variables in the environment.

(2) Determining the cycles and fates of the forms of nitrogen and phosphorus in various bodies of water.

(3) Establishing the factors which initiate, promote, and terminate algal blooms and heavy growths of other rooted or floating aquatic plants. Such investigations should involve nutritional and physiological studies of the problem species as related to limiting or potentially controlling essential elements in their environments.

(4) Defining the mechanisms and magnitude of nutrient regeneration from bottom sediments. Information should also be obtained on the role that fish play in the cycling of nutrients.

(5) Ascertaining the alterations in ratio of nutrients, such as nitrogen and phosphous, and needed changes in the chemistry and ecology of receiving bodies of water, which would permit the nutrients to be used by efficient food sources (diatoms and certain small green flagellates) rather than by undesirable blue-green algae.

(6) Determining the possibilities for using shallow bodies of water which receive effluents for the production of fish and wildfowl.

(b) Studies of the relative contribution of nutrients from various sources especially nitrogen and phosphorus but also including other nutrients that may influence growth of algae and other aquatic plants. Specific sources may include municipal and domestic wastes, phosphate builders in detergents, industrial wastes, agricultural wastes including manure, nitrogen from commercial fertilizers, storm water runoff from urban and rural areas, sediment from land erosion, algal fixation of N_2, inorganic nitrogen precipitated from the atmosphere in rainfall, and fish and wild animals.

(c) Studies of means for the effective control of over-enrichment of water resources with plant nutrients and means for the control of the organisms causing problems. Methods for physical, biological and chemical control of nutrients and organisms should be evaluated with consideration given to the present and potential uses of particular bodies of water. Among the more profitable areas of investigation, the following may be cited:

(1) Establishing means to prevent, terminate or minimize the adverse effects of algal blooms. Such studies should be centered upon denial of the nutrient at source, removal or alteration of one or more critical nutrients before release of the effluent, reclaiming or rendering biologically unavailable the substances in the receiving waters, or minimizing the recycling of nutrients by storing them in bottom sediments.

(2) Investigating procedures for the long-term disposal of the critical nutrients denied to or removed from bodies of water.

(3) Developing technologies and the requisite "hardware" for the holding, removal or rendering innocuous of locally undesired compounds of nitrogen, phosphorus and other nutrients. Private industry should be encouraged to participate in these endeavors.

(4) Seeking expanded or new uses of the fertilizing nutrients and developing non-pollutional methods for the disposal or banking of these substances.

(5) Devising alternatives to the readily available phosphates in detergents, and means for holding nitrogen better on the land, should phosphorus from detergents and nitrogen from agricultural fertilizers be found to contribute significantly to eutrophication.

FINDINGS

Enrichment of our water resources, ground as well as surface, is now being observed almost country-wide. The resulting problems are increasing in extent and severity with the continuing expansion of population and industry and the intensification of agriculture. Compounds of nitrogen and phosphorus are frequent contributors to the over-enrichment of waters, although they may not be the only nutrients causing blooms of algae and undesirable growths of other aquatic plants. These nutrients which are released into waters may come from urban, natural, agricultural, industrial, or other sources, but the relative contribution of these various sources to the initiation or promotion of aquatic blooms is often unknown.

(1) Additional funds should be made available for study of the biology and chemistry of the aquatic environment, the relative contribution of various sources of nutrient elements, and means for the effective control of over-enrichment and of the aquatic plants that flourish in these enriched waters.

(2) More complete analytical data should be obtained about nitrogen and phosphorus compounds. The gathering of such data is currently a function of the Geological Survey and the Public Health Service. The scope of the analyses should be expanded for the present to include more complete monitoring of phosphate, total phosphorus, nitrate, total nitrogen and ammonia.

(3) Funds should be made available for research on new and improved methods of waste treatment for nutrient removal, including funds for pilot plant studies and field evaluations in representative locations.

(4) Means should be sought for attracting additional qualified personnel to conduct research on problems of eutrophication and methods for the control of the problems arising from enrichment of the nation's water resources.

(5) A single group or agency should be assigned coordination and information responsibility for the program.

APPENDIX Y10

Effects of Pollutants on Living Organisms Other Than Man

DAVID PIMENTEL, *Chairman*
DON W. HAYNE
LOUIS A. KRUMHOLZ
JOHN T. MIDDLETON
LIONEL A. WALFORD
JOHN L. BUCKLEY, *Staff*

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Section I. SIGNIFICANCE AND EFFECTS OF POLLUTANTS ON LIVING ORGANISMS

INTRODUCTION

Pollution of land, air and water is a universal problem closely associated with growth of the human population and the advancement of technology. Since waste products are produced in enormous quantities, they must be removed. Since they are of almost infinite variety, the means of removing them are varied. Some are trucked beyond the edge of cities and spread over unused land, some are dumped into rivers to be carried downstream, some are barged out to sea, others are released into the atmosphere to be diffused by air currents. The intent is to get the unwanted material out of the way and out of sight, but the effect is to disseminate it, and its influence, far and wide. Other pollutants, which may be toxic in small quantities, come from normal wear, are released as by-products of combustion processes, or escape from the places where we have tried to keep them.

In studying a large mass of published and unpublished evidence about pollution, we have attempted to assess, in terms of how it affects human welfare, the damage which pollution does to other kinds of living things. There is no doubt that pollution impoverishes our flora and fauna, deranges natural communities, blemishes the beauty of the landscape, even sterilizes a few habitats. There is no doubt that its invasion impairs the health of all kinds of plants and animals and threatens to destroy a few species. Granted all this, what differences does it make to man's health, comfort, happiness and prosperity?

Oviously man cannot live alone in a biological desert. He depends directly on many species of plants and animals, both for subsistence and for embellishment of his life. Scientific agriculture and husbandry are based on a simple principle: If the environment is kept favorable, these living resources will renew themselves. Yet the conditions making environment favorable are often exceedingly critical, differing from one species to another.

Man must reckon with the fact that, just as he depends on an assortment of renewable resources which are directly useful to him, so also do all other species depend on their own assortments. Accordingly, the species of plants and animals which man depends upon indirectly are very many times more numerous than those which he uses directly.

They include bacteria breaking down detritus into the inorganic nutrients that crop plants can utilize. They include invertebrates reducing dead animals and plants to detritus. They include invertebrate animals which are essential foods to birds, to insect-eating mammals, to fishes. They include insects that pollinate flowering fruit and other trees. Altogether they constitute man's living environment. No one is independent of this, not only if he lives on a farm in the country, but even if he spends his entire life in a city of concrete and glass and buys all his food at the corner supermarket. Any one of us is likely to be more or less affected when pollution defiles a habitat, even one we have never seen.

There are many kinds of pollutants, differing in their effects on living organisms: Materials which are inherently toxic to life, such as chemicals from industrial wastes, poisonous gases and particles in the atmosphere. Organic substances, such as domestic sewage, which in moderate amounts can have beneficial fertilizing effects. Heat pollution, mostly from industrial cooling and manufacturing processes. Radioactive pollution, from weapons testing, from accidental releases by industrial and bio-medical users, and from contaminants in phosphate fertilizers. Inert pollutants, such as the fibrous wastes of paper mills.

So, too, are there many kinds of organisms differing in their ability to move, and hence in the kinds of pollutants to which they are subjected. Plants, soil microorganisms, and some other animals such as clams, oysters and earthworms, are fixed in location or able to move only very short distances; they are affected by whatever pollutants reach them, for as long as the pollutants remain. Most larger animals are capable of moving at least short distances, and thus, if they recognize a substance as deleterious, may be able to escape from it; they also can repopulate areas temporarily made uninhabitable by pollutants. Still other wider ranging animals, such as migratory birds and fishes, pass through many areas and are subject to the pollution burden of each; migratory forms, too, can repopulate areas.

Pollution damages plants in many ways. In the air, pollution is an expanding problem which prevents the satisfactory culture of some fruits and vegetables, flowers, forest trees, and ornamental plants, reduces production, results in contaminated food supplies. Water carrying too high a burden of certain pollutants is useless for irrigating crops. Plants absorb certain air pollutants in their leaves, some to be degraded by physiological processes in the plant tissues; others to join the soil when the leaves fall. The vast leafy surfaces of greenbelts, parks and forests play a role in the removal of some atmospheric pollutants. However, when air pollution becomes excessive, it damages the plants and so reduces or even terminates these beneficial activities.

Damage to vertebrate animals has been widespread and varied. Considerable care is taken to protect domesticated animals in order to keep our meat and dairy products free of toxicants. At times, however, inadvertent contamination of animal feeds has been a problem. Careless use of pesticides has killed not only domestic animals, but in several areas large numbers of wild birds, mammals and fishes. Subtle deleterious effects of chronic pollution are even more serious because they tend to go unnoticed for long times, perhaps until populations of the vulnerable species have been reduced to dangerously low levels.

Populations of invertebrate animals in many areas are seriously jeopardized by pollution, especially from use of pesticides. Although pesticide programs are directed mainly against undesired invertebrates, they may be equally destructive to beneficial species; for these, being similar physiologically and anatomically, are often as sensitive to the applied poisons as are the pests against which they are directed. The consequent damage to the structure of the invertebrate communities, exemplified by a loss of as many as half of all the species present, frequently leads to explosive increases in numbers for some of the remaining species. In some cases, such outbreaks have produced new and serious pest problems, demanding new external controls and causing the use of more or different pesticides, with more and different unpredicted and harmful consequences.

Changes in the relative numbers of the various species reflect not only the reactions of the organisms to the poisons but the interactions among species. For example, applications of insecticides, because of the incidental elimination of the insect predators that normally had controlled its numbers, often result in a relatively minor form becoming a pest. Poisons often seem to have a selective effect against predators. This can happen if the predators are particularly sensitive to the poison; or if they feed on tolerant organisms containing higher concentrations of the poison; or if some essential food supply is eliminated by the poison. Organisms feeding upon other organisms take unto themselves the chemical constitutents of their food. If these chemicals resist degradation and elimination, they tend to accumulate at the far end of this chain of food and feeding.

Many pollutants, such as the organo-chlorine pesticides, are stored in fat because they are both fat soluble and resistant to metabolic processes. As a result they are subject to many stages of biological amplification, with the lowest link in the food chain containing somewhat higher concentrations than its environment, and each successive link still higher concentrations. If the concentration becomes high enough in any link, it will be eliminated, and drastic effects will reach on up the chain. To generalize, storage levels are lowest in plants, higher in herbivorous animals, higher still in carnivores.

But this statement over-simplifies what is generally a vastly more complex and only partially understood mechanism. Predation is only one of many influences affecting the composition of animal communities. Others are competition within and between species; quality and quantity of food and nutrients; and physical factors such as temperature, rainfall and chemical composition of soil or water. All animal populations, including those free of man's interference, fluctuate continuously in response to these processes. Man's exploitation, as in timber harvesting, hunting and fishing, also influences both abundance and species composition. Rates of exploitation change continually with prosperity and growth of the human population.

Most of the recognized and observed effects of environmental pollution have concerned specific, single pollutants. In reality, however, any organism responds to the totality of pollution to which it is subjected. Effects of different substances of the mixture in any locality may be additive, enhancing, or antagonistic. The biochemistry of such interactions among contaminants absorbed or accumulated in tissues of organisms has been neglected in pollution research, leaving a serious gap in our knowledge.

A major obstruction to progress in the study of pollution is our inability to measure the influence of specific pollutants, individually and in combination, and to distinguish these effects from those of all the many other varying components of the environment and from the effects of exploitation. Information on both the normal range of variation in plant and animal populations in the less polluted parts of each of the habitats with which we are concerned, and on the levels of pollution to which the more polluted parts of these habitats are subjected, is a first essential.

To deal with the effects of pollution adequately means doing many things which we have left undone. To begin with, we must enlarge our concept of biological resources to recognize the integrity of our living environment and the importance of its diversity. Our habit has been to attack conservation problems piece-meal, as though the only species worthy of attention were those that are most valuable economically, or most interesting as curiosities, or most obviously in danger of extinction. We have tended to treat each species as an entity more or less independent of other species; each question as a subject for separate action; each geographical area as though it were an island. Pressures from groups of people with special interests, usually with biases about what should be done, where it should be done, who should do it—and what segments of the public should benefit—have helped to form this habit, to divide government agencies with "conservation" functions into more or less independent specialized compartments. Once thus fragmented, how can they deal effectively with complex problems involving large geographical areas, with the interactions of many diverse groups of organisms composing natural communities, and with the influence of physical factors of environment and of man's multifarious activities such as exploitation, land development and pollution? It is largely because of this fragmentation that the most elementary need of all who strive to effect scientific conservation remains unfulfilled. This need is for nationwide records, of statistically acceptable quality, of the numbers and distribution of animals and plants and of changes in the physical components of their environments. These records should represent the full scale of ecological situations, and within each situation all levels of community structure.

The few widely-accepted generalizations that we can make regarding the effects of pollution on organisms other than man are based upon repeated observations in a few places. Although these may not represent the full range of ecological situations, it is clear that pollution by poisonous substances affects different species in different ways. Generally it is most destructive to those at the top of the food pyramid. As populations of the more sensitive species become reduced or even extinguished, those of the more resistant ones grow explosively as a result of release from competition and predation. The structures of plant and animal communities, which are normally maintained in a state of dynamic equilibrium by exquisite systems of checks and balances, alter greatly and may even be destroyed.

It is also clear that not all environments are subjected to the same intensity of pollution. For example, pollutants that reach the land may have an effect where they are, but the land serves also as a reservoir from which these materials may be taken up by plants or animals, carried away on windstorm dust, or washed into waters. Our inland waters in turn are burdened with the wastes we deliberately place in them, and may receive some of those removed from the soil. The complexity of the pollutant mixture increases as one stream adds its burden to another, as one river joins another, and finally, as they discharge into the sea. Pollution in the coastal zone is further aggravated by the nature of the estuary itself, by the unusually large pollution load that originates at the seacoast, and, especially, by the low rate of flushing of the estuarine water into the sea.

Our coastal zones receive the heaviest impact from water-borne pollution. Air pollution, too, is intense in these coastal zones. And these same zones are also subject to nearly irreversible forms of pollution, such as filling for housing or industrial sites, draining or impounding for mosquito control, or drainage malformation by highway right-of-ways. Yet our coastal lowlands are an irreplaceable resource essential to the existence of more than half of our commercial fish and shellfish, and of a host of other living things.

The widespread occurrence of environmental pollution and the ease of conveyance of pollutants—by air, by water, by migratory birds, by

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fishes and other animals—emphasizes the necessity of coping with pollution problems on an appropriately large geographical scale. Pollutants entering a stream in one locality affect localities downstream. Poured into estuarine or shore waters, they may be carried out to sea and transported long distances in currents. Released to the air in one community, they affect other communities as the polluted air flows along the airshed. People everywhere bear an inescapable responsibility to people in neighboring cities, states and countries that share their airsheds and river basins. Concern for protecting the quality of the environment must go beyond local political boundaries, must often become interstate or international in scope.

It can be argued that the damage which pollution does to man's living environment is the price of civilization. This may be true in some instances. More often, there are choices; pollution can be avoided at a cost that is not too great. Our choices must ultimately be made by familiar political processes. For them to be wise and well-founded, science must provide knowledge of the basic effects of environmental pollution, of the alternate actions possible, and of the costs of each action compared with the cost of inaction. Only then are enlightened decisions possible.

TO SUMMARIZE:

1. Man is a part of the living world, dominant over all other forms, yet dependent upon them. Thus, a healthy, properly functioning environment is essential to the well-being of man.

2. Pollutants can affect living organisms through effects on individuals, populations and communities. Some kinds of effects, such as death of individuals or changes in communities by elimination of species are relatively obvious. Other effects are so subtle as to almost escape detection. Pollutants may impair the health of organisms, lower their fecundity, reduce viability of the young and shorten the life-span.

3. Pollution is geographically widespread; the movement of pollutants is not retarded by political boundaries. Pollutants become dispersed by air, water and migratory animals far from their points of origin and affect populations of organisms which are widely distributed. Solutions to pollutional problems will involve matters of jurisdiction within the Federal government, between the Federal government and the states, between states, and between political subdivisions within and among states.

4. Pollution episodes have been responsible for the deaths of many kinds of living organisms; in some cases pollution has altered the composition of the plant and animal communities. In a few cases, more subtle effects of pollution have been observed.

Circumstantial evidence strongly suggests that birds, mammals, amphibians, reptiles, and microorganisms are being influenced significantly by pollution, but it is with the fishes and insects that these deleterious effects have been most clearly documented. Fish have been seriously affected by pollution from sewage, industrial wastes, and other types of pollutants. The effects recorded have ranged from the replacement of sport fish (like trout) with non-sport fish (like carp) to the complete extermination of fish populations in some waters.

Insect species have been reduced by 50% following pesticide applications to some habitats. Changes in the structure and physiology of invertebrate communities have frequently been followed by explosive increases in numbers, limited to certain unwanted species. In some cases the outbreaks have led to disastrous pest problems such as mite damage in orchards. Then the additional man-devised controls which are employed usually bring still more pesticides into the habitat.

From these and other examples, we can make certain generalizations concerning the changes pollution brings about in natural communities (these are very closely the same as for the effects of other kinds of stresses):

a. The number of species making up the natural community is usually reduced in a way depending upon the kind and intensity of pollution. It may range from the loss of a single species to extensive destruction of the fauna and flora of the habitat.

b. Reduction in number of species and resulting changes in structure of the community often leads to population and community instability. The amplitude of population fluctuations in a polluted community is generally greater than those in natural unpolluted habitats. Portions of the habitat (such as species of plants which serve as food for animals) may be destroyed, further disrupting the stability of the community. Generally, most of the "outbreak" species are in the lower part of the food chain (the herbivorous or plant feeding type) rather than in the higher part (the predaceous or parasitic types).

c. Organisms in the lower portion of the food chain may accumulate pollutants and pass them on to the predators and parasites in the upper part of the food chain. Sometimes as pollutants are passed up the chain their concentration in living organisms increases. In this way, large predators like birds and fishes may be exposed to greater concentrations than were initially applied.

d. Because predators and parasites at the top of the food chain are dependent on several lower links of their food chains, they usually are more seriously affected than species at the bottom of the food chain. A deleterious effect in the lower part of the food chain is likely to multiply its effects as it moves up the links. Thus, predators and parasites at the top of the food chain appear to be more sensitive to pollution stress than herbivores at the bottom of the food chain.

5. We do not yet have objective measurements of the extent of damage by pollution. We do know that pollution causes damages, that pollution is increasing, and that damages are almost certain to increase.

6. Present methods of study of the effects of pollution are not adequate to determine the extent of the effects. Better means of measuring populations and changes in populations are an urgent necessity.

7. Coastal lowlands, including estuaries, marshes, and lagoons, are under increasingly severe pollution stress. These areas are of great value to all aspects of man's life, especially for sea food production and recreation. The lowlands of our coastline deserve concerted efforts for protection against destruction; unless relief is immediately forthcoming they may be irreparably damaged.

8. Agencies responsible for control of pollutants have not always exerted sufficient effort to assure that available facts are considered in making decisions affecting distribution of pollutants.

9. Investigation of the effects of pollution on living organisms other than man or his crops and domestic birds and animals are not the clear responsibility of any Federal agency. The result has been concentration of investigations on species that were rare, or curiosities, or economically valuable, with little or no effort devoted to others. Preoccupation with these few species has kept us from dealing effectively with complex problems involving large geographic areas, interactions of diverse groups of organisms in natural communities, and the influence of physical factors and man's activities.

FINDINGS

1. In their contacts with the public, especially those through education and extension systems, all organizations and agencies concerned with pollution should emphasize that man is part of the natural system and cannot stand alone; that other organisms are essential for many aspects of human life aside from recreation and food production; and that uncontrolled environmental pollution, as a threat to other organisms, is a threat to man himself.

2. Standards for pollution control, and incentives for pollution abatement, should take account of effects of pollution on plant and animal life as well as its direct effects on man.

3. The investigation and control of pollution requires a deeper understanding of the functioning ecological system and man's place in this system. This will mean study of both the species structure and the dynamic interactions of organisms as well as the influence of the physical environment.

a. The Department of Health, Education, and Welfare should direct more of its resources to the study of such problems, in government and in the universities, with particular reference to environments closely associated with human health, or greatly affected by human and industrial wastes.

b. The Department of Agriculture should expand and broaden its studies concerned with such problems, and should greatly expand its support of university research in these problem areas, with particular attention to environments used in, or greatly affected by, agriculture and forestry.

c. The Department of the Interior should expand its studies concerned with such problems, and should increase its support of university research in this area. In this connection, a Bureau of Biology should be established in the Department of the Interior, with special responsibility for both basic and applied studies.

4. Funds for intramural and extramural research should be increased to provide for:

a. Intensified studies of the species structure of plant and animal communities, the interactions among species and between organisms which make up plant and animal communities, and the influence of physical and biological factors, singly and in the aggregate, that impinge on these communities.

b. The development of techniques which will enable more accurate sampling of organisms in the natural environment.

c. An increase in taxonomic investigations which are basic to studies of the biological environment. Identification and reference services, similar to the Smithsonian's Oceanographic Sorting Center, should be extended to cover organisms of a much wider group of habitats.

d. An investigation of the role our coastal lowlands (estuaries, marshes, and lagoons) play in the life histories of many important fishes and shellfishes and how they are affected by accumulated river pollution and related man-made alterations.

e. The development of more objective techniques to measure the tolerance levels of different organisms to pollutants and to identify and assess the changes in abundance and distribution of organisms making up natural and man-controlled biological communities under pollution stress. Such studies should include pollutants in air, soil and water, and should include agricultural, urban and suburban areas as well as less intensively used forest, range and wetlands.

f. The construction of quantitative baseline measurements by systematic sampling of certain natural populations in diverse relatively unpolluted habitats to establish a basis for comparison with populations under pollution stress.

g. The role of living organisms in removing pollutants from the environment.

5. Before Federal decisions are made that affect use or release of pollutants, special care should be taken to consider knowledge, wherever available, concerning all probable effects on various kinds of organisms and on the physical environment.

6. The Federal government can and should take a variety of actions which will contribute to reducing or eliminating pollution of estuaries, lagoons and salt marshes and to preservation of their biological, recreational and other resource values.

a. Funds should be made available to acquire, either directly or through the states, title to important coastal marshes, lagoons and estuaries which could then serve incidentally, as national and state parks, national monuments, wildlife refuges and public recreational areas. Among other sources, a portion of the funds received under the Land and Water Conservation Act could be used for this purpose.

b. In the Federal-state highway program, the government should require that bridges and causeways be constructed so as not to impair natural drainage channels or access routes.

c. Properly designed public works such as improved drainage channels can often minimize pollution in lagoons and estuaries. Federal agencies such as the Corps of Engineers, which are involved in modifying coastal water bodies and shore lines, should develop comprehensive plans for multiple uses of United States shores, including preservation of some natural areas as well as changes in others to allow intensified recreational and other uses.

d. The Federal Government, working in cooperation with the states, should encourage formation of unified authorities for planning and carrying out the optimum development of areas threatened by destructive encroachment or severe pollution. San Francisco Bay is an example of such an area. Rational planning for the Bay as a whole has been greatly impeded by the separateness of numerous local government jurisdictions along its shores.

e. Many marshes and estuaries lie at the mouths of large river systems or are measurably influenced by the effluents from such systems. Prevention of pollution and other destructive changes in these water bodies should be one of the most important elements in Federal-state river basin development. Compacts and agreements for such developments should extend to cover such estuaries and marshes. Although their importance as breeding grounds for fish and shellfish is less obvious, similar considerations apply to the estuaries, lagoons, and marshes of the Great Lakes.

Section II. SELECTED EXAMPLES OF THE INFLUENCE OF POLLUTANTS ON LIVING ORGANISMS

PLANTS

Air pollution.—The adverse effects of air pollution on vegetation were recognized over a century ago. Interest in its effects on animals developed much later, largely as a corollary to concern with effects on human health. As a result, much more, and more conclusive, knowledge is available about damage to plants and trees than about harm to livestock and other animals.

The principal pollutants first recognized as harmful to vegetation were sulfur dioxide, ethylene, and fluorides. Much more recently, increasing importance has been attached to photochemical air pollution; its typical toxic components are oxidants resulting from the photolytic reaction of nitrogen oxides and hydrocarbons in the presence of sunlight, especially ozone and peroxyacetyl nitrate or PAN. New and important types of crop damage are thought to be resulting from emissions from motor vehicles, from air pollution associated with our expanding urban development, and from stack gases from new industrial processes and older ones which use fossil fuels at rates far beyond those of 15 years ago. There are also several other gases, such as ammonia, chlorine and hydrogen sulfide, which become important in this connection only when they are released in accidental spills. Particulates as well as gases can be harmful to vegetation, too.

Plants damaged by sulfur dioxide include important forage, forest, fiber, and cereal crops, although many vegetables and flower crops are also adversely affected. Species highly sensitive to fluoride pollution include corn and many fruits and flowers; damage to citrus fruits and to gladioli has been especially notable. The most spectacular damage by ethylene from industrial sources has been to cotton, and by ethylene from motor vehicle exhausts to orchids. Cotton, grapes, and tobacco are especially sensitive to ozone, although damage to cereal crops, ornamentals, vegetables, and indigenous vegetation is also indicated. PAN affects especially citrus, forage, salad crops, and ornamentals. Oxidant damage is also considered partly responsible for destroying ponderosa pine in the mountains of the west and white pine in the east. Many fruit and shade trees, especially in and near cities, are damaged by air pollutants.

Air pollution's effects on a plant are held to be "damage" when they impair its economic value, the quality or quantity of the yield, or its external appearance. The visible symptoms on the leaves include leaf tissue collapse, chlorosis or other color changes, and growth alterations. Ozone injures primarily the upper surface of plant leaves, while PAN causes a silvering, glazing, or bronzing of their lower surface. "Weather fleck" in tobacco, emergence tipburn in white pine, and tipblight of ponderosa pine have been attributed to ozone toxicity. The effect of fluoride absorption by citrus varies from minor reduction in yield to complete defoliation of trees, and complete fruit drop. Leaf blight and defoliation of pine, and whole fields of dead gladioli are alleged to have been caused in a short period of time by fluorine-containing gases. Sulfur dioxide from stack gases is probably involved in the slow and chronic damage to plants and trees which has been increasingly noted of late in, and over a wide radius around, most cities and smaller industrial areas, especially those using coal and oil as fuels.

The occurrence and significance of adverse effects were first those dramatic ones caused by pollutants emitted from smelters, of which sulfur dioxide was the major effluent. In three well-known instances—Ducktown, Tennessee, Anaconda, Montana, and Sudbury, Ontario—almost total destruction of vegetation in the vicinity of smelters was noted. Ethylene was first identified as a major air pollutant from studies of damage to cotton and other crops growing in the vicinity of an industrial polyethlene plant located on the Gulf Coast of Texas; here fields of cotton downwind and within a mile of the emanating source had almost 100 percent loss of yield. Fluorides have become a serious toxicant to vegetation only with the industrial expansion of the last few decades; the industries mainly responsible are aluminum reduction, smelting of iron and nonferrous ores, ceramics, and phosphate reduction and phosphate fertilizer manufacture. The last is now centered largely in southern Florida, where the effects of its fluoride effluents on citrus fruits, vegetable and flower crops, and on cattle have been most damaging.

Photochemical air pollution, first noted in the nation in southern California in 1944, is increasing rapidly in frequency, severity, and geographical spread. Typical oxidant and ozone injury to plants has been found in most of the major metropolitan areas of the United States. Its manifestations have now been reported in urban and adjacent rural areas in 27 states, the District of Columbia, Canada, and Mexico. The entire coastal area from Washington, D.C. to Boston has come to rival southern California for extent, severity, and economic loss to agriculture because of photochemical smog.

Urban pollution has also had significant effects upon native vegetation about cities and many miles from them in causing damage and changing the nature of the flora itself. Especially noticeable is the disappearance of some lichens near cities, as well as change in the kinds of lichens further away, and the poor growth of normally occurring species still more distant from pollution sources. Other changes are shifts in dominance of susceptible plants and their replacement by resistant species, thus altering the very nature of the vegetation cover.

The use of lead alkyls in antiknock gasolines since 1923 has contributed enough lead to contaminate the surface of the northern hemisphere to the extent of about 10 mg per square meter. Some of this airborne lead, amounting to 1.6 μg per kilogram, has been found in rural snow in Lassen Volcanic National Park. Contamination of surface soils resulting from soil erosion from runoff water has contributed to abnormal lead levels in vegetation as well as in surface ocean waters. The average air concentration of lead in Cincinnati was 1.4 μg per cubic meter, in Philadelphia 1.6, and in Los Angeles 2.5. Atmospheric lead has also contributed to unusual burdens in plants growing near major highways and roadways as shown by measurements in three widely separated areas, Denver, Colorado, Canandaigua, New York, and Washington County, Maryland. Pasture grasses collected at the intersection of two U.S. highways near Denver contained 3000 ppm lead, while grasses next to a lesser roadway contained 700 ppm; grasses collected 50 to 1000 feet away yielded 5 to 50 ppm. Vegetables from Canandaigua gardens located about 50 feet from streets averaged 115 ppm lead, while vegetables collected 25 feet from roadways in Washington County, Maryland, averaged 80 ppm.

The total economic loss throughout the country due to crop damage caused by air pollution has been estimated to range from $150 to $500 million a year. Estimates of economic damage to agricultural and forest crops are impressive both as to the sums involved and the evidence of continuing increase in yearly losses.

From 1949 through 1953, for example, crop damage from air pollution in Los Angeles County alone was reported at more than $500,000 a year. According to a 1956 report, damage to 11 crops in the Los Angeles area had exceeded $3 million a year since 1953. For 1957, the estimates had risen to $5 million for the Los Angeles area and over $1,100,000 in the San Francisco area. One 1961 estimate raised the California figure to $8 million a year, while now it exceeds $12 million a year. The additional damage due to retarded growth, reduced yields, and impoverished quality costs many more millions each year. In Utah, Florida, and Idaho, legal claims for fluoride damage to crops in 1957 totaled nearly $3 million. Court cases nationwide in 1956 for all pollutants involved damage claims of $50 million. In 1959, ozone damage to shade tobacco in Connecticut was estimated at one-fourth the value of a $25 million crop. A 1961 report estimated annual crop damage on the Eastern seaboard, from Boston to Washington, at $18 million.

The economic losses which result from the effects of air pollution on growing vegetation are certainly substantial and they are, of course, the effects of primary concern to us. However, in the case of flowers and ornamentals, and shade and forest trees, esthetic considerations, too, are involved. And when the damage results in the destruction of entire crops or the compulsory relocation of a horticultural industry (as with the cultivation of orchids in parts of California), the sociological effects are also significant.

As our population grows, more and more of our land will be diverted to nonagricultural use—for urban dwellings, factories, roads, and parking lots. Yet more foodstuffs will be required to feed more people, and there will also be greater demand for recreation as well as fiber from our forests, for more parks, more greenbelts, more flowers. We can ill afford the losses we are already sustaining in agricultural crops, in trees, and in ornamentals because of air pollution and we shall be less able to sustain them economically and esthetically in the future.

Pesticides.—Pesticides are extensively used for the control of insects, nematodes, rodents, plant diseases, and weeds, while lesser amounts are used for regulating plant growth, foliation, and fruit development. Pesticides are used most extensively in agricultural production, land improvement, and vector control. The effects of the applied pesticides typically affect an area much larger than the site treated, because most of the chemical compounds are applied by aircraft and mobile surface equipment which allow the toxicants to be dispersed by air and extend beyond the area selected for treatment. Pesticides, unlike some recognized air contaminants from domestic and urban activities which typically increase the amount of specific chemical compounds already in the atmosphere, constitute an original pollution burden since they do not naturally occur in the atmosphere. The presence and persistence of the contaminating pesticide and its effect upon ambient air quality are functions of the chemical nature of the toxicant, its physical state, method of application, and atmospheric conditions. Usually soil applications of nematocides, surface placement of rodenticides, and directed use of growth regulators preclude their general occurrence in air, while many insecticides, fungicides and herbicides applied aerially are potential air contaminants, and so drift and deposit on soil and vegetation. For example, parathion applied in apple orchards in Washington varied from 0 to 5.53 mg per m^3 near loading and mixing operations, while it varied from 0 to 0.02 mg at residences near the treated orchards, and from 0 to a trace at residences at some distances from the orchards. Another example of the potential drift is shown by the benzene hexachloride levels in ground-treated forests ranging from 2.6 to 12.5 mg per m^3 while they ranged from 4.1 to 53.7 mg for forests treated by aircraft. In the case of mosquito control it has been shown that malathion levels drop from 0.07 and 0.09 mg per m^3 to 0.04 and 0.03 after 1 hour. The distances that these materials travel depend upon meteorological conditions, the nature of the material, and its particle size.

The drift of organochlorine sprays applied by aircraft shows that under windy, turbulent conditions as much as 8.0 ppm residue occurred on alfalfa 100 feet downwind, while only 1.5 ppm occurred under good weather conditions when 1 pound of material was applied per acre on a 40 acre tract. The same treatment produced 0.01 ppm residue at about 20,000 feet downwind under windy conditions, and 0.01 ppm at 8,000 feet under good weather conditions. As the size of the tract is increased there is a concomitant increase in the amount of residue deposited. Under a 40 acre treatment 0.02 ppm was deposited on alfalfa 3,000 feet downwind, on an 80 acre tract 0.03 ppm was deposited, whereas on a 160 acre tract 0.06 ppm was deposited. The amount of residue is also directly proportional to the rate of active chemical applied, such that a drift from an application of ½ pound per acre may deposit 0.01 ppm at 3,000 feet while 1½ pounds will deposit about 0.04 ppm.

The importance of sedimentation and impaction is shown by the fact that spray droplets ranging from 10 to 50 microns in diameter typically produce the greatest ground contamination several miles from source, while droplets of 100 microns usually do not present any drift hazard unless winds are very high. About 80 percent of the particles are deposited within short downwind distances when they are larger than 200 microns, while very small droplets of less than 5 microns do not produce appreciable deposits and drift for many miles. Dusts released about 10 feet above ground in a 3 mile per hour wind with a particle size of 10 microns are carried about 1 mile, whereas those 2 microns in diameter are carried 21 miles; particles 50 microns in size under the same conditions are carried no further than 200 feet.

While organochlorine pesticides typically have no adverse effect directly upon vegetation to which they are applied, or are deposited upon, their presence on forage crops has a direct adverse effect upon the quality of animal products produced by ingestion of the contaminated forage and becomes especially limiting in the production of healthful milk and dairy products.

The direct effects of pesticides upon plants are shown by damage to plant growth, crop production, and product quality. (See Y1)

Another example of the direct adverse effect of pesticides upon plants is the damaging effect of herbicides upon vegetation at varying distances from the point of application. The adverse effects of certain phenoxy herbicides have been observed on sensitive crops such as cotton, grape, and tomato at distances as much as 15 miles from the site of application. Some kinds of herbicides applied to plants and soils have beneficial effects on specific crops but have serious adverse effects upon successive crops because of their residual toxicity.

The accepted and regular use of herbicides in the production of grain and some other economic crops has been responsible for the recurring damage to native vegetation in many states. Of particular interest is the control of weeds in wheat and barley in the western states by phenoxy herbicides and the problems of damage to a variety of trees and shrubs, especially box elders, and grapes due to the transport of toxic vapors into adjacent wildlands. Such herbicides, though providing beneficial effects in the agricultural regions, may produce serious adverse effects in natural communities, in state and national parks, and other areas dedicated to recreational purposes.

TERRESTRIAL VERTEBRATES

Air pollution.—When cattle eat forage contaminated by air-borne fluorides, the fluorides can cause a serious condition known as fluorosis, in which the animal's gums and teeth become soft and spongy, and the teeth fall out or wear very rapidly. There can also be an overgrowth of bone on the legs and ribs of the animals. Milk production and the reproductive process in dairy herds may be seriously affected.

Post-mortem examinations of cattle which died or were slaughtered following acute respiratory distress that developed during the great London smog of 1952 revealed acute bronchiolitis, emphysema and heart failure. In a study at the zoo in Philadelphia, there is a suggestion that increased urban air pollution is a causal factor in the increasing death rate from lung cancer in the zoo population. This study which spanned a 62 year period involved 1,702 mammals in the zoo including wolves, lions and others and 3,306 birds. Among those which died between 1901 and 1935, cancer was found in the lungs of three as against 20 among those which died between 1935 and 1963.

Laboratory experiments with animals have shown that certain irritants common in polluted air can slow down and even stop ciliary activity in the air passages, thereby increasing susceptibility to respiratory infections; induce bronchogenic cancer of the type which humans have; and increase the mortality rate and decrease the survival time of the exposed animals.

Heavy metals.—Waterfowl which ingest lead pellets that result from accumulations of shotgun pellets in areas that have been heavily hunted cause lead poisoning. Many deaths of swans, geese and ducks in the Coeur d'Alene River Valley of Idaho since 1924 have been attributed to poisoning by heavy metals including lead, zinc and copper carried in the water and deposited on or in the vegetation.

Pesticides.—Pesticides have been the most widely studied class of pollutants and relatively much information is available about effects of these on terrestrial vertebrates. Instances of poisoning in domestic animals and deaths in wild birds and mammals are not rare. In the case of domestic animals, most poisonings have been a result of accidents or misuse. In the case of wild birds and mammals deaths have also resulted from uses carried out as planned. Direct losses of this sort are avoidable and therefore not of particular concern in this presentation. However, two other types of phenomena exist that deserve further comment: accumulation of pesticides and sublethal individual effects.

Accumulation of pesticides.—The complexities of the web of food and feeding interrelationships are not fully known even for a single species. Variation between groups of organizisms in sensitivity to pesticides may result in the elimination of certain forms from the food chain. Conversely, resistant organisms which survive exposure may concentrate and store pesticides at levels higher than those found in the environment. Such biological magnification on the part of resistant species may result in damage to more sensitive organisms which are higher in the food chain. The most dramatic examples have been observed in aquatic environments; Clear Lake, California, is the best known. Here, waters containing 0.02 ppm or less of DDD produced plankton containing 5 ppm, which in turn produced fish with fat containing hundreds to thousands of ppm. Grebes that fed on the fish died, although they contained somewhat smaller residues than the fish.

Similar magnification of pesticides has been observed in terrestrial environments. Fallen autumn leaves from elm trees sprayed with DDT contained 20–28 ppm of chemical, and the soil beneath contained 11–18 ppm. Earthworms living in the soil and coming to the surface to eat the leaves accumulated 4–194 ppm in various body tissues, 403 ppm in crop and gizzard. Dead and dying robins from the same area, presumably feeding on the earthworms, most often had 50–70 ppm of residues in brain tissues, but some had up to 250 ppm of DDT or DDE.

Soil containing 0.1 to 0.2 ppm of heptachlor epoxide has yielded earthworms containing 2.1 to 4.1 ppm, a magnification of 10 to 40 fold.

When worms containing 2 to 3 ppm of heptachlor epoxide were fed to woodcock, the birds died containing an average of more than 10 ppm.

Ground fish containing 10 ppm of DDT produced levels of 135 ppm in bald eagles to which it was fed, a concentration of more than 10 fold.

This process of biological magnification has less impact on man because human food is produced by a two- or three-link chain in which the process, if recognized, can be controlled. For example, residues on animal feeds are permitted only in amounts that will not ultimately yield unacceptable levels in meat, in milk, or in other animal products. Thus, excessive levels of pesticide residues in domestically produced human food result only from accident or misuse, while damaging levels in the food of wild animals may be unwanted effects resulting from recommended practices.

Sublethal individual effects.—Wild animal populations are obviously affected differently by pesticides than are domestic animals and man. Unlike the latter, wild animals cannot be kept from treated areas long enough for the chemical residues to degrade or otherwise dissipate. Because birds and mammals are free to range over relatively large areas, they are exposed to a variety of different compounds. Insectivorous birds are likely to be attracted to areas with high insect populations and may be exposed when control chemicals are applied. Furthermore, birds reinvade depopulated areas very rapidly; thus, it is possible that areas heavily treated with persistent pesticides may act as poisonous traps which kill the successive waves of birds that move into them.

Pesticides can kill birds and other animals, affect their reproductive success, destroy or change their food supply, and alter their behavior and physiology. We do not know whether there are long term hazards such as carcinogenic or genetic changes.

The extent to which wild bird and mammal populations have been affected by pesticides is largely unknown except for the numerous obvious examples of mortality. The more basic and critical population changes that operate through a series of complex interrelationships over a period of time are difficult to recognize, more difficult to predict.

The first demonstration among vertebrate populations was the Clear Lake food-chain buildup of DDD through water, algae, and fish, ultimately to the destruction of nesting grebes.

In New York State more recently DDT treatments resulted in complete elimination of lake trout production in certain lakes, and great reduction in others. Fry died at the time of final absorption of the yolk sac, when the young fish were about ready to feed. Mortality occurred when residues of DDT were 2.9 ppm or higher; percentage mortality generally increased with increased concentration of DDT; no fry survived in lots containing as much as 5 ppm and nearly 100 percent mortality occurred in several lots containing considerably less.

As at Clear Lake, the dramatic demonstration brought remedial action—the Conservation Department discontinued use of DDT in its forest pest control programs and at State campsites in watersheds inhabited by lake trout.

In Great Britain, drastic reductions in numbers of birds of prey, particularly the kestrel, sparrow hawk, and peregrine have been associated with pesticide use (particularly in seed dressings). The recent drastic decline in reproductive success of Scottish golden eagles has been attributed to pesticides by strong circumstantial evidence.

A relatively great backlog of information is available on the toxicity of pesticides to laboratory and domestic mammals. There is much less information on toxicity to wild mammals and to birds. Bobwhite quail, mallard ducks, and ring-necked pheasants have been exposed to diets containing more than 60 of the most commonly used pesticides. In addition, diets contaminated with a few of these pesticides have been fed to cowbirds, starlings, red-winged blackbirds, grackles, Japanese quail, woodcock, and bald eagles. Findings confirm that many of these compounds, taken in minute amounts, cause death to the test animals, and that many of these pesticides at somewhat lower concentrations in the diet reduce the capacity of birds to reproduce.

These results are not laboratory artifacts. Tests using large pens in which the ground was treated, but in which the experimental birds received clean food and clean water, have produced mortalities comparable to those resulting from feeding contaminated diets. And field observations following many kinds of insect-control programs have demonstrated substantial mortalities among birds and other wildlife. Effects of pesticides on reproduction also have been observed in the field. Studies in California have shown differences in pheasant reproductive performance between an area treated with insecticides according to "good" agricultural practice and another, untreated area. Differences were small in fertility of the eggs, hatchability of the eggs, and capacity of the young birds to survive. Differences between the areas were statistically significant, however, when the total differences were compared.

TERRESTRIAL INVERTEBRATES

To understand the influence pesticide applications are having on terrestrial invertebrates (insects, mites, etc.), we need to examine the characteristics of this vast group of life. Of the 75,000 insect species found in the United States, only 1,000 are classified as pests. An estimated

50% of the insecticide applied is concentrated on controlling about 100 of the most destructive pest species. While the remaining pest species are problems, they do not account for the most serious economic losses to man or pose a serious threat to man's health.

The similarity in structure and physiology of all insects makes both the pest and beneficial species equally susceptible to insecticides. Furthermore, because there are so many different terrestrial invertebrates, it is only logical that the effects of insecticide applications, though concentrated on a few species, affect many.

Frequently, insecticide applications are followed by an increase in some new pest species, which is able to flourish in the absence of the original pest. The new pest is often as harmful as the original species. For example, when DDT (1 lb./acre) controlled the codling moth in apple orchards, mites became a serious pest because several species of predaceous beetles were destroyed along with the moth. Infrequently, insecticide applications have been followed by an increase in pest numbers. This happened when DDT was applied to control the potato aphid (¼ lb./acre), and also when dieldrin was used to control houseflies in privies.

To fully understand how pesticides influence terrestrial invertebrates, populations of all species in the community must be studied. Each natural community has a structure and physiology, and pesticides change both of these characteristics. Even if only a single species is affected, the overall physiology of the community will be influenced. The extent of the change depends upon the role and relative abundance of the particular invertebrate species. Few insecticide control studies have taken into consideration the hundreds or thousands of other species which make up many natural communities in addition to the destructive pests. These other species include beneficial predators and parasites, organisms which serve as food for many species at a higher level in the food chain, and organisms which play an important role in the decomposition of dead plant and animal material.

In one New York State study, the influence of pesticides on invertebrates was studied in the plant community associated with a mustard plant. For two years, the 210 species in the mustard plant community were followed weekly during the summer months. During the second year, three additional mustard communities were established and treated with different insecticides: a natural plant insecticide, rotenone (0.07 lb./acre, 7 treatments); DDT (¼ lb./acre, 6 treatments); and parathion and endrin (0.18+0.20 lb./acre, 4 treatments and malathion 0.64 lb./acre, 1 treatment).

The natural community had the largest number of species, and as a reference community, will be referred to as having 100% of the species. Following chemical treatment, the DDT-treated community had 90%

as many species as the natural community; the rotenone 80%; and the parathion community 50%. The number of plant-feeding pest species in the four communities did not differ significantly, although there was a difference in relative abundance. The significant species reduction which occurred in the insecticide-treated communities was in the parasitic and predaceous species. In the parathion-treated community especially, parasitic and predaceous species were almost totally eliminated.

In addition to changes in number of kinds of species there were also significant changes in the density of the various insect populations in the communities. With the exception of aphids in the DDT- and rotenone-treated communities, the density of the various species of plant-feeding populations decreased from 10 to 90% as compared with the natural community. This varied response reflected the diverse susceptibility of each species to the insecticide treatments.

Aphids in the DDT- and rotenone-treated communities were about 10 times more abundant than in the natural community. Along with this aphid increase, the associated parasite populations increased to a level more than 10 times that of the natural community. The increase in parasite populations was due to the superabundance of aphid-hosts available and also to the fact that parasitic types were relatively tolerant of DDT and rotenone.

Although the aphids and their parasites were relatively tolerant of the DDT and rotenone used, their predators were sensitive; in the absence of the predator pressure, the aphids increased. Assuming predator density in the natural community to be 100%, predator density was 85% in the DDT-treated community, 35% in the rotenone-treated community, and 5% in the parathion-treated community. Had the experimental plots been sufficiently large the apparent survival of predators would have been even less. In these small plots, set in homogeneous communities, predators from untreated parts of the communities moved in rapidly to feed on the tremendous numbers of aphids.

Each season, orchard litter is exposed to great quantities of pesticides. For this reason, a study was made of the influence of pesticides on the invertebrates of the leaf litter community in a New York orchard. This orchard had been repeatedly sprayed for the past 50 years with many different pesticides. The number of years any one pesticide was used varied, but the following named pesticides and amounts per acre were employed each year for several years: DDT at 5 lbs; dinitrobutylphenol 318 at 3 lbs; dieldrin at 1¼ lbs; mercury at ⅝ lb; lime at 2 oz. to 7½ lbs; lead sulfate at 7¼ lbs; glyodin at 2.4 to 4.8 lbs; forband at 2½ lbs; captan at 5 lbs; diazinon at 2½ lbs; TEPP at 2.4 lbs; DDD at 25 lbs; lead arsenate at 6 lbs; dinitrobutylphenol 289 at 1½ lbs and dinitrocyclohexyphenol at 3 lbs. The control community consisted of natural litter, vegetation and other conditions similar to the orchard.

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The diversity of species in the orchard was only about 60 percent that of the control community. Interestingly enough, there were more individuals present per unit area in the orchard than in the control community—28,000 per square meter compared with only 7,000 per square meter in the natural community. The invertebrates in the orchard consisted principally of the small Collembola and mites, whereas those in the natural community consisted principally of the larger insect types.

The imbalance created by pesticides was evident when weights of plant feeders and predaceous species were compared in the two communities. The plant-feeding types present weighed about 60 grams per square meter in both communities. However, the predaceous species weighed significantly less, about 0.3 grams, in the pesticide community, compared to 1.2 grams in the natural community.

How all these changes influence the breakdown of leaf litter was not evaluated but we suspect that important modifications did take place.

At best, present information on the effects of pesticides on terrestrial invertebrates is spotty. We do know that each species can be expected to react individually to a pesticide. Mortality may range from 0 to 100 percent, and will change the structure and physiology of the total community. Because of the complexity of effects, it has not been possible to predict how a natural community would react to a pesticide application.

Diversity of species, which is typical of natural communities and which functions to give them stability, is reduced by pesticides. The balance between species in a community develops slowly as the members of the community adjust to each other's feeding pressures. When species are removed or new ones introduced the balances in communities are changed, and in the process often create new problems for man to solve.

The complexity of the terrestrial invertebrate communities is such that intensive research is necessary to understand the effects of pesticides on these communities. Until the complexities of the problem are systematically studied, and better understood on a community-wide basis, man should be cautious of all insecticide programs and strive to develop programs which do not cause useless destruction of the countless beneficial species of invertebrates which exist in nature.

FRESH WATERS

The importance of fresh water to mankind is well known: it is used in almost every aspect of our daily living. As the human population in the United States continues to increase, we will need more and more water of high quality. It is readily apparent that all fresh water must be used over and over for domestic and industrial purposes. After each use, it must be restored to some semblance of its original quality before it can be used again. Impure water is a deterrent to our physical well-being as well as to our peace of mind. In addition to domestic and industrial uses, one of the most important things we need from our waters is the quality of being clean and pleasing to the senses, something we can enjoy and use for relaxation and recreation. Very frequently, polluted waters are dirty and evil smelling and serve as ideal places for the multiplication of noxious microorganisms.

We cannot consider pollution in any absolute sense. It must be considered in the light of what we want in amenity and usability of the water. Individual sources of pollution may in themselves be quite innocuous, but the sum total of all such "innocuous" sources may be so great that much of the life of the stream is killed and the amenity of the water is lost. Because there are so many different kinds of pollutants, any assessment of pollution must vary with time and place, and no single set of criteria or standards can be applied to all situations.

Broadly speaking, pollutants may be grouped in seven different principal categories, but there is considerable overlap among these categories because some arise from domestic or industrial uses or both, and the various pollutants may have an additive, a synergistic, or an inhibitory effect on each other: (1) poisons, (2) organic materials, (3) suspended solids, (4) heat, (5) nontoxic salts, (6) pesticides, and (7) radioactive isotopes.

Poisons, such as metallic ions, may be present in industrial effluents from steel and chemical plants and may be poisonous to aquatic organisms at very low levels (lead, 0.3 ppm; copper, 1–3 ppm); or they may be present in the seepages from mines (zinc, 0.2–0.7 ppm); there may be toxic materials such as oils in the bilge waters from ships; or there may be secondary alteration of the original toxicants through chemical or physical actions (changes in temperature, oxygen content, etc.). Frequently, temperature has a direct influence on toxicity; a rise of 10° C may halve the survival time. Organic material, usually sewage, but also from many industrial processes such as the preparation of foodstuffs and the manufacture of papers and synthetic fibers, may be fairly toxic (phenols, 5–10 ppm); may cover the bottom of the stream bed with inert materials so that the bottom fauna will be smothered (wood pulp); or may enrich the water (phosphates and nitrates from primary treated sewage, see also Y9) to a point at which algal growth becomes objectionable and difficult to control, or the biochemical oxygen demand (B.O.D.) may become so great that the concentration of dissolved oxygen is so depleted that most animals cannot inhabit the area (milk and food processing). Suspended solids usually accompany organic materials from domestic and industrial sources, but may also arise from mining and quarrying operations, poor control of erosion on agricultural lands, or through milling processes and construction. Increases in temperature usually result from the use of large quantities of water for cooling industrial plants, such as generating plants powered either by steam or by nuclear energy. Non-toxic salts are waste products from some kinds of mining and industry, from oil drilling, or from irrigated agriculture, and may increase the salt content to quite high levels (100–500 or more parts per thousand). Pesticides used in the control of plants or animals in orchards and other agricultural enterprises may be washed into waterways following heavy rains, where they may be highly toxic and frequently are cumulative. Some pesticides used for weed control in waterways are toxic to animals (at less than 1.0 ppm) as well as to the plants. Radionuclides from industrial reactors are a potential source of pollution, especially in the event of accidents, and will become more so as more power reactors are placed in operation.

The amounts of heavy metals and the levels of dissolved gases toxic to aquatic organisms are generally well known and can easily be measured by rather simple chemical procedures, and simple detection devices can reveal the amounts of radioactivity known to be harmful to man. However, in many instances, the effects of pollution may be so subtle that they cannot be detected until some parts of the biota have been eliminated. A substance that may be toxic to one organism may aid in the growth of another organism in the same community. Similarly, the different salts of a particular metal may have quite different effects on the same kind of organism.

An accurate analysis of the bottom fauna and flora is perhaps the best method for determining the extent of pollution. These organisms live on the bottom and usually are fixed or can move only very slowly so that they are exposed to pollutants for relatively long periods of time. If they are unable to withstand the effects of the pollutants, they will be eliminated. If those organisms serve as a principal food for other organisms in the community, those consumers will suffer because of the loss of food. Motile organisms, on the other hand, are capable of moving away from the polluted area provided they are capable of detecting the pollutants before a lethal dose is received. Also, if a portion of their diet is eliminated, they are capable of foraging elsewhere. Conversely, if the source of pollution is eliminated, the motile organisms can reinvade the depauperate area quite rapidly from nearby areas, whereas the slow-moving or sessile organisms will require longer periods of time to re-establish healthy populations.

The insecticide endrin was probably directly responsible for the death of a great many fishes in the lower Mississippi River. There is much experimental evidence that many organic phosphates and chlorinated organic compounds used as insecticides are lethal to fishes and many other aquatic organisms in very small doses (DDT, 0.1–0.3 ppm; endrin, 0.01 ppm or less).

In fresh as well as in marine waters, inert pulp wastes from paper processing plants have been shown to cover the stream or ocean bottom to such an extent that the entire area was rendered unfit for the survival of bottom fauna. Much the same sort of condition is traceable to the accumulation of coal dust, and tailings from Portland cement plants.

In Texas and Oklahoma and other oil-producing states, there is abundant evidence that waste materials from oil wells render entire stream systems devoid of most aquatic life. Many such streams have high salt contents (up to 1500 ppm chlorides), in addition to phenols, sulfides, etc. Seepage from coal mines in West Virginia and Pennsylvania has resulted in almost complete acidification of the Monongahela River so that the usual hydrogen ion concentration, as indicated by pH, is less than 4 and causes constant corrosion of the metal hulls of barges and has resulted in a virtual elimination of aquatic life.

Synthetic detergents will reduce the efficiency of water treatment plants and also will interfere with certain types of bacterial activity.

Large doses of radioactivity from fission products or any other radioactive wastes will cause irreparable harm to all plants and animals, and there is a slowly accumulating body of evidence that long-term exposures to low levels of radioactivity may result in a shortened life span and/or reduced fecundity among aquatic as well as other organisms. In many instances, these radioactive isotopes are accumulated by organisms and are concentrated in vital organs, with ultimate deleterious effects.

Each of these pollutants has a primary effect on various organisms either by killing them directly or by so changing their physiological processes that the composition and dynamics of the aquatic community are drastically changed. Thus, it is evident that a thorough knowledge of the biota of the aquatic environment must be at hand to assess the effects of pollution. Adequate and accurate assessment of pollution and interpretation of the biological data are the tasks of the biologist. He must design the sampling program for each situation, and each situation must be appraised individually. Chemists and engineers can be most helpful in measuring pollutants and in recommending remedial measures for alleviating pollution. Still, it remains the responsibility of the biologist to assess the extent of pollution.

To properly assess pollution, research must disclose the species composition and requirements of healthy aquatic communities in all parts of the United States. Sampling methods must be improved and revised, and levels must be established that will indicate maximum permissible pollution. Such levels must take into consideration the health and welfare of the human population and the aquatic community and must assure that the amenity of the water is not lost.

BRACKISH AND SALT WATER ENVIRONMENTS

A river flowing to the sea ends in an estuary, and here interaction of river flow, tides and coastal currents and the shape of the coastline at that point, combine to direct the deposition of the sediments carried down by the river and of those washed up by the sea and to make of the estuary a trap for nutrients and pollutants. The suspended material begins to settle out as the river slows upon its entrance to the estuary. Thus, tidal mud or sand flats form along the fronts and margins of the delta and about the estuarine embayment. As they rise, they become colonized by algae and flowering plants which tolerate salt and brackish water. The plants catch sediments, and so build up higher ground on which other plants grow; and the whole area becomes channelled with meandering creeks which form designs like the branches of trees, whose trunks open into the estuary. This is the coastal salt marsh. This zone of interplay between the margins of the sea and the land is the environment for a remarkable assemblage of terrestrial and aquatic life. Large populations of birds, including such game species as ducks, geese, swans, rails, and snipe, concentrate in the water-logged lowlands—"wetlands"—associated with estuaries, bays, sounds and keys. Waterfowl come there chiefly during the winter to feed on the lush vegetation or on the brackish water invertebrate animals that abound in the zone.

Many of our most valued commercial and game species such as prawns, menhaden, bluefish, weakfish, croaker, mullet, and channel bass, spend their juvenile stages in the protected inside waters of the estuarine zone. Oysters, soft clams, blue crabs, and diamond back terrapins are all residents of estuaries. Fishes that divide their lives between fresh water and salt such as salmon, striped bass, shad, river herring, and eels, pause for a sojourn between coastal waters and their upstream or oceanic spawning grounds.

Several qualities combine to give peculiar biological value to the estuarine zone. To begin with, the salt marshes are extraordinarily fertile. The Sapelo marshes of Georgia, which are cited as an example only because they have been studied more than any others, produce nearly seven times as much organic matter per unit area as the water of the continental shelf, 20 times as much as that of the deep sea, six times as much as average wheat-producing land. It is no wonder that the creeks meandering through the marshes are superlatively rich feeding grounds for fish and wildlife. For this reason alone the estuarine waters are excellent nursery grounds for coastal fishes. Another reason is that the estuarine systems are capacious for the meandering marsh creeks add enormously to the area of the shallow water nurseries.

Over 90% of the total harvest of sea foods from waters off the United States are taken on the continental shelf. Nearly two thirds of that fraction are composed of species whose existence depends on the estuarine zone; or which must pass through the zone enroute to spawning grounds. These include resources which have singular values. To cite a few examples: the menhaden is the most abundant of all our commercial fishes, the cheapest source of animal protein, and the object of the largest fishery in North America. Southern shrimps, oysters, blue crabs and Pacific salmons are among our most valuable fishery resources. Striped bass, sea trouts, bluefish, tarpon, and bonefish rank among the most celebrated of marine food and game fishes.

In 1960 estuarine dependent sea food resources supported about 90,000 commercial fishermen to whom they yielded 2.8 billion pounds. This quantity was worth 59 million dollars on the wholesale market. The resources yielded an additional 900,000 pounds to about 1,600,000 anglers. It is hard to evaluate recreational fishing, but if the amount spent specifically for fishing expeditions over and above normal living costs be accepted as an index, the value of the sportsmen's catch of estuarine dependent fishes was about 163 million dollars.

North America is endowed with a remarkable variety and abundance of waterbirds, that is to say, birds which must obtain food largely in or about water. These include all the waterfowl (ducks, geese, brant and swan); and all those that live in marshes such as herons, egrets, ibises, rails, gallinules, and cranes; and shore birds, such as sandpipers, plovers and numerous other species that run along the beaches in search of food; and it includes a miscellaneous variety of fish-eaters such as cormorants, pelicans, grebes, loons. For most of these bird species, no economic value can be assigned. They are simply items in our nation's treasury of natural beauty, essential parts of what makes "country"; but even so unevaluable. Waterfowl, on the other hand, do have measurable dollars-and-cents value; for they are among our leading recreational assets. In 1960, nearly two million people hunted waterfowl and spent over 89 million dollars for this form of recreation.

Although the life habits of waterfowl vary from species to species, most of them nest during the summer in inland areas of the United States and Canada, some of them far north of the Arctic Circle. Their wintering grounds are characteristically in the marshes of the Atlantic, Gulf, and Pacific coasts; and for several species, extend south into Central America.

The fish and wildlife resources of the shore zone have value as food, as a basis of recreation and as objects of esthetic enjoyment. While tidal embayments are remarkably fertile, being traps for nutrients, they are also traps where pollutants can collect and concentrate. Although these pollutants may kill large numbers of birds and aquatic food animals from time to time, generally as a result of accidental large-scale discharge, they more frequently poison or suffocate the life over large areas and thus destroy feeding grounds. In addition some poisons may accumulate in the tissues of birds and fishes, and be transported hundreds of miles in the bodies of migratory species. Deleterious effects of these accumulated poisons on fecundity, on viability of the young, or on the health of predators are not likely to be diagnosed because the causes are so remote.

Pollutants can be carried long distances down rivers, and those that remain in solution or suspension and are not broken down by chemical or biological processes reach the estuarine zone. Moreover, a large part of the pollution load originates near our sea coasts. Close to 60% of the people in the United States live in a band about 250 miles wide bordering the coasts of the Atlantic, Gulf of Mexico, and Pacific. Two thirds of the factories making agricultural pesticides, two thirds of those making organic chemical products, 58% of those making inorganic chemicals, 52% of petroleum refining plants, and two thirds of the pulp mills are located in the coastal states.

Thus, an impressive body of evidence points to the lowlands bordering the sea coasts as an area where pollution problems merge and concentrate. In this area contamination which is deleterious to fish and wildlife resources is rarely if ever a purely local problem; for each locality, each bay, each estuary, each lagoon, each stretch of coast, is a segment supporting some fraction of a much larger population than that occurring there at any one time. The population size depends on the sum of available habitats. If one habitat is vitiated, the whole population becomes impoverished to that extent at least. It can be much more seriously affected when the damaged area is a necessary part of some sequential process.

Based on 1958 statistics, four major industries—paper, chemicals, primary metals, and petroleum—used and discharged into the environment 84% of all water used by U.S. industry for that year, including 91% of all brackish water. Only ¼ of all wastes discharged by these industries received any sort of treatment prior to discharge.

Each of the four major groups of industries is concentrated in different sections of our country. For example, paper and allied products are most abundant in the southeastern states, Alabama, Mississippi, and in the Pacific Northwest; chemical plants in Middle Atlantic and Gulf Coast states; primary metal industry plants in the Chesapeake region of the Middle Atlantic states and in Texas; petroleum industries in New Jersey, Louisiana, Texas, and California. Scientists have demonstrated clearly that wastes, both treated and untreated, from each of these four groups of industries are harmful to marine fishes and invertebrates.

Pulp mill wastes.—Pulp mill wastes dumped into various bays of British Columbia have been shown to deplete seriously the available dissolved oxygen and, in settling, blanket the bottom, thereby destroying the habitat for bottom-dwelling organisms which are necessary food for fishes. Oysters are about 500 times more sensitive to kraft mill effluents than are fish.

Chemical wastes.—Results of acute toxicity experiments to test the effects of common organic and inorganic pollutants, including pulp mill wastes, on Pacific salmon are summarized in Table 1. The results show that many chemicals and metals for example, are far more toxic to salmon than are pulp mill wastes.

Agricultural pesticides.—Controlled environment studies by the United States Fish and Wildlife Service with Atlantic and Gulf Coast animals demonstrate that agricultural pesticides are in general more toxic to marine life than any other group of chemicals (Tables 1 and 2). Since many of these pesticides are resistant to degradation and since they can inhibit productivity of phytoplankton and growth of mollusks, pesti-

TABLE 1.—Resumé of toxic effects of organic and inorganic pollutants on Pacific salmons in salt water (From: Toxic effects of Organic and Inorganic Pollutants on Young Salmon and Trout. State of Wash. Research Bull. No. 5, 1960. Table 110)

Pollutant	Days exposed	Tolerance [1] level in ppm
Synthesized kraft waste effluents (pulp mill wastes)	20	25,000
Kraft waste condensate (pulp mill wastes)	7	20,000
Kraft waste black liquor (pulp mill wastes)	7	<1,000
Actual kraft waste effluent (pulp mill wastes)	30	16,000
Chlorinated wash (bleach plant wastes)	7	80,000
Raffinate waste effluent (bleach plant wastes)	3	750
Acetylene supernatant liquor	3	>8,000
Refined cresylic acid	3	2
Detergents	3	25
Glues	3	>1,000
Naphthalene	3	2
Potassium phenylacetate	3	>10
Tannic acid	3	1
Ammonia	3	6
Arsenic trioxide	3	12
Arsenic trioxide	10	4
Residual chlorine	3	<1
Potassium chromate	5	24
Chromium sulfate	5	>50
Cupric nitrate	5	<1
Sodium sulfide	3	<2

[1] Tolerance level as used here is bounded by two concentrations, the lower of which did not cause a statistically significant kill. Where more than one observation was given in the citation, we have given an average.

TABLE 2.—Acute Toxicity of selected groups of chemicals to the mummichog, *Fundulus heteroclitus*, an estuarine teleost (From: Experiments conducted at Sandy Hook Marine Laboratory, unpublished)

Chemical group (number of compounds)	Approximate concentration, in ppm, of active ingredients that kills 50 percent in 96 hours
Ethylene imines (3) (insect sterilants)	4,000
Soaps (3)[1]	1,400
Synthetic detergents (1)[1]	23
Organophosphorous insecticides (3)	4
Organochloride insecticides (7)	0.0006–0.060

[1] Packaged product.

cides must be considered among the most harmful of all chemical wastes affecting marine organisms.

Metals.—Bioassays to test the effects of metallic salts on European and North American marines fishes showed that ions of various metals are relatively toxic. Those that killed fishes in less than 48 hours at low levels were cobalt (125 ppm), cadmium (17 ppm), copper (3.3 ppm), and mercury (0.3 ppm). Metals not causing death within 48 hours at concentrations of 200 ppm included sodium, calcium, strontium, magnesium, barium, and lithium. Little published information is available on acute toxic levels of common metals to marine and estuarine animals.

Petroleum byproducts.—Laboratory studies with Gulf Coast marine animals and chemicals used in oil well drilling off the Texas coast showed that many chemicals used in connection with oil well drilling, such as oil well cement, white lime, and caustic soda killed in the 70–450 ppm range within 24 hours. Other chemicals, such as hydrocyanic acid and lactonitrile, which are byproducts of petroleum operations in Texas, kill representative Gulf Coast fishes and invertebrates within 24 hours at levels below 0.3 ppm.

Land-fill and refuse.—Filling in of marshes to make real estate must be recognized as the most threatening danger to this environment. In Long Island, New York, for example, between 1954 and 1959, over 13% of the wetlands were destroyed by land-fill projects. This process is going on at various rates in all states endowed with coastal marshes. It makes the fraction of this environment that remains even more critical to the animal resources and adds to our responsibility to preserve its quality.

The waste product which is most difficult to hide is solid non-combustible refuse, such as old automobile bodies, worn out machinery, and scrap metal which is not reclaimed. Coastal cities such as New York, for example, find the nearby marshes a most convenient place to dump such rubbish. The biological productivity and natural beauty of thousands of acres of marshes are thus destroyed. It is ironical that this metal could be made to have an opposite effect by dumping it into the sea in appropriate places off shore, thereby creating new habitats for fishes, and hence artificial fishing reefs.

Sewage.—Sewage, the seepage of septic tanks, and the wastes of poultry farms provide excessive organic enrichment of estuarine waters just as they do of fresh water. The results are tremendous increases in the growth of phytoplankton with consequent oxygen depletion of the water and impoverishment of the fauna. Perhaps because the effects are particularly obvious and offensive to people this problem has been studied more than industrial wastes.

Case histories.—The following three case histories illustrate pollution problems in estuaries. The first is cited because it is among the first and most thoroughly studied and documented case of pollution by organic enrichment from duck farms and sewage; the second because it is an example of pollution by both domestic and industrial wates in a densly populated area; the third because it is an example of a pollution problem which is not yet fully diagnosed.

1. *Great South Bay and Moriches Bay, Long Island, N.Y.: Agricultural and domestic sewage pollution.*—A serious pollution problem which caused the failure of a once prosperous shellfish industry and lessened the recreational use and esthetic value of Great South, Moriches, and Shinnecock bays prompted the towns of Islip and Brookhaven (Suffolk Co., N.Y.) to commission Woods Hole Oceanographic Institution (W.H.O.I.) to conduct an analytical survey toward finding the causative agents and their necessary remedial measures. W.H.O.I. has conducted this survey since 1950.

Using phosphorous concentration as an index of pollution, W.H.O.I. investigators traced the source of pollution to duck farms in Great South and Moriches Bay. Studies of the bay's hydrography showed that the low flushing rates of the bays were responsible for holding the pollutants long enough to permit massive proliferations of minute algae which were deleterious to oysters. Dredging Moriches inlet open served to increase the flushing rate and consequently pollution was substantially reduced. It did not recur until the inlet silted in sufficiently to lower the flushing rate. Conclusions from this study were that low salinity and low flushing rates augment ill effects of these pollutants (in this case the organic nitrogen compounds from duck-farm waste) and that remedial measures are any that will raise salinity and flush out nitrogenous wastes. These generalizations appear to have held true during the period of the investigation.

Biologists studying this problem conclude that until such a time as the pollution is stopped at its source or the inlets to Moriches and Great South Bay are appreciably widened and stabilized, the shellfish industry and the recreational interests in the area will be at the mercy of unpredictable and uncontrollable meterological conditions.

In 1964 residents of Brookhaven and adjacent towns complained again of foul smells emanating from Great South Bay. In spite of a decline in the duck farming industry, pollution was great enough to hamper recreational use of parts of the Bay, and bubbles of H_2S and methane belching from bottom potholes discolored paint of houses near the water. It was then found that dredged areas along the shore served as traps for large multicellular algae which underwent anaerobic degradation, producing the unpleasant gases. Much of the rotting material came from abnormally expanding *Zostera* beds in shallow areas of the Bay. It appears now that pollution from the duck farm wastes is now being augmented by an increasing human population along the bay shore and that septic tank wastes may have become the major source of algal nutrient. No study of these new developments is in progress as of this date.

2. *Raritan Bay, N.J.: Mixed sewage and industrial pollution.*—Longtime residents of the south shore of Raritan Bay, N.J. report that as recently as forty years ago these waters were used for bathing beaches, surf fishing, and commercial clamming. A ferry service from New York City carried urbanites to shore resort hotels and marinas in Keyport, where a thriving resort economy provided access to seaside recreation less than an hour's trip from the city. Today, Raritan Bay and its adjacent waters are unsuitable for bathing or sport fishing. A previously profitable shellfishery is prohibited and the few remaining commercially valuable fishes taken from its waters are unmarketable because of an unpalatable taste which the polluted environment imparts to their flesh. Old timers in the Keyport area say that some resort business survived until the 1940's, but now even the charter fishing boats have their ports south of the Raritan. Its once clean waters which contained large numbers of harvestable shellfishes and many other species of invertebrates were transformed by the pressures of industrialization and the resulting population expansion into a septic, despoiled environment, murky with domestic and industrial wastes and the peculiar, undesirable flora for which they select.

Although the Raritan River watershed, some 1200 square miles, is the main source of bay pollution, a strong current of polluted water from

New York City drainage passes the south shore of Staten Island to enter the northern mouth of Raritan Bay and circulates counterclockwise, leaving via the south bay past Sandy Hook. During and after World War II, heavy industralization of the Raritan valley changed the character of effluent pollutants from its watershed from small amounts of human and domestic animal wastes to hundreds of thousands of tons of sewage annually plus high concentrations of industrial chemicals. A 1951 analysis gave the following figures for industrial chemical concentrations in the water: phenols, 1,087 ppm; formaldehyde, 1,960 ppm; copper, 5.8 ppm; and arsenic, 375 ppm. More pollutants entered Raritan Bay from the New York current and from a second intruding current coming from the Arthur Kill, carrying sewage waste and oil refinery effluents respectively. A series of biological and geochemical studies of the Raritan Bay gave quantitative assessments of the degree of pollution in relation to N, P, N/P ratios, plankton production, dissolved 0_2, coliform bacterial counts, phytoplankton and benthic fauna analyses, and bay hydrography. Over all but the mouth of the bay, the surface waters contained only phytoplankton during spring, summer, and autumn. Near the mouth of the bay only 17 benthic species remained of the original diverse invertebrate fauna and these were forms resistant to organic pollution. By diverse methods, each study indicated that the primary cause of this floral and faunal despoilage was an imbalance of organic nutrients carried into the bay as sewage.

An incompletely successful attempt at pollution abatement was begun in January, 1958, with the operation of a large trunk sewer system, which poured chlorinated liquid industrial and domestic wastes into the head of the Raritan Bay near the river mouth. Solid wastes were taken to sea by barges. A four year (1957–1960) extensive study of benthic invertebrate repopulation of the bay showed a trend toward several of the original resident species establishing niches in the bay and other species penetrating farther toward the river's mouth. However, an abnormally high population of primary food organisms, phytoplankton in the form of surface diatoms and flagellates and subsurface photosynthetic microflagellates persisted, choking out complete repopulation by a normal bay flora and fauna, and attesting to the continuation of highly debilitating levels of pollution in Raritan Bay. Public alarm about the failure of the trunk sewers to restore the living resources of the bay resulted in establishment of a Raritan bay project by the U.S. Public Health Service which is charged with monitoring and investigating bay pollution.

3. *Barnegat Bay, N.J.: Sewage.*—Proliferation of a sudden Red-Tide in Barnegat Bay during August, 1964 generated considerable controversy which centered on the role of a small chemical company whose effluents enter the bay via a tidal estuary. Barnegat Bay on the central New

Jersey coast, is over 20 miles long, about 2 miles wide, and has a single direct inlet toward its southern end. It is shallow, highly productive, and its northern shores are densely populated with many miles of small summer cottages in rows of 10–20 perpendicular to the bay.

The red tide with its associated fish kill was due to two dinoflagellates, *Polykirkos kofoidi* and *Cochlodinium* sp. Unlike most dinoflagellates, both organisms have an absolute requirement for organic molecules as fuel. There is an emerging body of evidence that they best extract their organic nutrient requirements from living bacterial cells. Barnegat bloom waters contained a large proportion of small bacilli and cocci along with the dinoflagellates. Although there is conflicting information about the nature of the chemical effluent entering the bay, most informants agree that there were inorganic acids and traces of azo dyes present. Most bay residents assumed that the bloom water discoloration and fish kill were due to the chemical company's dye effluent, although actually the bloom species does not utilize this kind of molecule. Organic nitrate and phosphate sources and bacteria which *Polykrikos* do utilize and which most probably caused their massive proliferation are the result of sewage and septic tank wastes—wastes from cottages of persons who populated Barnegat's shores to enjoy their recreational resources. Like all algal blooms, some chemical or physical factor became limiting, the cells settled to the bottom and most were flushed out with the tides.

Although inorganic acids from the chemical plant effluent might have supplied enough phosphates and nitrates to cause an algal bloom of some other species, five million cells of *Polykrikos* per liter cannot be attributed to any nutrients except rich organic substrates and bacteria. Thus, knowledge of the nutritional requirements of the bloom species gives circumstantial evidence that the source of pollution which supported the red tide was primarily sewage that had leached into the bay. A repetition of this occurrence in coming summers will undoubtedly damage the shore resort economy of several towns along Barnegat's banks.

APPENDIX Y11

Improved Pest Control Practices

DAVID PIMENTEL, *Chairman*
DONALD CHANT
ARTHUR KELMAN
ROBERT L. METCALF
L. D. NEWSOM
CARROLL SMITH, *Staff*

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BIOENVIRONMENTAL CONTROL OF PESTS

> Definition: Bionvironmental control of pests involves reducing pest populations to low density levels, which are both economic and effective for man's health, welfare, and crop production by manipulation of the pest's environment and ecology or altering the pest's physiology, genetics, and behavior or employing various combinations of these.

Scientists responsible for pest control research are struggling to protect man's crops and health under rising pressures of an increasing population and a public demanding high-quality foods. Under these kinds of pressures and with a shortage of manpower, research workers have had to devise empirical control measures until more permanent and economical controls could be found. Great reliance upon the persistent broad-spectrum pesticides followed the initial success of certain new organic pesticides and development of efficient application techniques after World War II.

About ten years ago evidence began to accumulate indicating the seriousness and complexity of pesticide problems, in particular residue and pollution hazards, destruction of beneficial organisms, insect resistance to certain insecticides, and the creation of new pest problems. The general use of pesticides is continually increasing as pressures rise for maintaining productivity on reduced acreages. As a consequence, residues of certain chemicals are increasing in our soils and water supplies. Some types of pesticide chemicals have thus become important environmental pollutants. At the same time, narrowing profit margins also have stimulated a search for more economical pest control and have resulted in work on new approaches, including bioenvironmental methods.

For certain pests there are no immediate prospects for development of effective bioenvironmental methods. Certain conventional pesticides are indispensable for maintaining current food and fiber production and the health of man and animals. Furthermore, it should not be assumed that all pesticides have adverse effects, are persistent, and have a high toxicity to man or warm-blooded animals in general.

Reduction in problems associated with the large scale use of chemical toxicants can be achieved by the development of well-coordinated diversified control programs. Several major avenues of research and development can be followed to reduce pollution hazards without sacrifice of agricultural productivity.

Although there is continued need for chemicals in controlling certain pests, bioenvironmental controls are often inherently better weapons in pest control because an effective method once devised is likely to be useful for longer periods of time with less adverse side effects than methods involving use of pesticides. Furthermore, annual costs to the grower are minimized or may in some instances be eliminated.

It is estimated that thorough application of our present knowledge of pest suppression through integrated control programs could result in certain cases in an immediate reduction of pesticide pollution to about one half of existing levels. A further major reduction in pollution can be made through the development of bioenvironmental methods for the 100 major pests of plants and animals in the United States. These developments would free the grower from the costly "routine-treatment schedule" and place him on a "treat-when-necessary" basis. However, as this report will emphasize, additional investments in trained scientists and research facilities, and a further redirection in existing research programs will be required to initiate sound integrated control programs which utilize bioenvironmental controls and rapidly degradable selective pesticides.

In our study of methods by which pesticide pollution can be minimized or avoided, we will consider and evaluate the following:

1. The present scientific effort in the United States directed toward bioenvironmental pest control.
2. The various methods for pest control.
3. A comparison of bioenvironmental and pesticidal pest controls relative to effectiveness, economics and safety.
4. Potential for improvement in the use of pesticides.
5. Discussion of an integrated pest control program.
6. Recommendations for training and research programs to develop species-specific controls for pests.

I. RESEARCH EFFORT ON BIOENVIRONMENTAL CONTROL OF PESTS IN THE UNITED STATES TODAY

The subpanel experienced major difficulties in documenting the division of the national research effort with respect to bioenvironmental and other controls. There is no one central source for such statistics, the categories are inherently overlapping and indistinct, and assignment to the categories is probably colored by current trends and professional climates. The information on division of research efforts that the subpanel has been able to obtain indicates that a total of about 1400 man-years is being devoted to bioenvironmental control methods in all pertinent disciplines (research on the more efficient use of pesticides has not been included except as they might be used in conjunction with other methods). Only the time of research scientists who spend at least 25% of their time in the subject areas has been included. There are more than 5000 scientists in these disciplines (entomology, plant pathology, nematology, weeds, and vertebrates with reference to agriculture and forestry). However, not more than 3000 man-years are spent on research in pest control of any kind; the remainder is devoted primarily to teaching and non-control oriented research. Of this 3000, about 45% is devoted to research on bioenvironmental controls.

The relative divisions of research effort for the major disciplines are:

[In percent]

	Entomology	Plant pathology and nematology	Weeds
Bioenvironmental	41	86	40
Other controls	59	14	60

The relative divisions of research effort between various aspects of bioenvironmental control are:

Research areas	Federal		State		Private	
	Percent	Number	Percent	Number	Percent	Number
Host resistance	12	169	43	625	1.0	13
Biological control	7	96	7	93	1.0	15
Cultural, etc	6	87	10	143	1.0	10
Sexual sterility [1]	3	44	1	23	.2	3
Attractants, etc.[1]	4	58	3	52	.2	3
Total	32	....	64	....	4.0	....

[1] Not for plants.

The relative research efforts by major disciplines between various aspects of bioenvironmental control are:

1. Entomology

(In percent)

Research area	Federal		State		Private	
	Percent	Number	Percent	Number	Percent	Number
Host resistance	13	56	13	53	......	....
Biological control	13	58	18	80	4	15
Cultural, etc	4	17	7	31	......	....
Sexual sterility	7	39	4	18	1	3
Attractants, etc	7	36	7	37	1	3
Total	44	206	49	219	6	21

2. Plant pathogens

(In percent)

Research area	Federal		State		Private	
	Percent	Number	Percent	Number	Percent	Number
Resistance	12	104	67	572	1	13
Natural enemies	2	25	1	6	......	....
Environmental manipulations	4	37	10	87	1	10
Total	18	166	78	665	2	23

II. DISCUSSION OF VARIOUS BIOENVIRONMENTAL METHODS OF PEST CONTROL

A. Insects, Mites, and Other Invertebrates

The economic losses and human suffering caused by insects and other invertebrates are too well known to require elaboration here. We need only recall that there are thousands of insect problems, and that the pests concerned occupy the entire range of survivable habitats and conditions. Their developmental requirements and behavioral patterns are so varied that they are adapted to participate in every phase of our existence. Obviously no single control method or type of method will be satisfactory for dealing with all the species in such a diverse group. In recent years we have placed great dependence on pesticidal organic chemicals to control the most injurious species. For many of these species bioenvironmental methods may be more efficient than pesticides. To control any significant number of such species, however, the range of our methods will have to be as varied as the habits of the pests themselves. Fortunately, a wide range of bioenvironmental methods is in fact available. In this section of our report we will discuss each one briefly, with special reference to its potential effectiveness as a control weapon if it could be fully exploited through adequate research.

1. Parasites and predators

Parasites and predators are among the most important of the many factors that cause mortality in animal populations. The deliberate use of these natural enemies (and also pathogens) to reduce the numbers of undesirable animal species is known as biological control.

All species of insects and other invertebrate pests are attacked by parasites and/or predators. Most are kept at a density level acceptable to man by the combined action of natural enemies and other factors. A few species (less than 1% of the total) manage to exceed this and become pests. The great value of natural enemies often is not fully appreciated. They sometimes are destroyed by the nonselective use of pesticides or in other ways, which results in adding a new candidate to the ranks of pests themselves.

Man was slow to recognize the importance of natural enemies in regulating potentially harmful insects at tolerable levels, and it was not until late in the 19th century that deliberate attempts were made to reduce the balance of pest species either by assisting their natural enemies to become more numerous and hence effective, or by introducing new forms of natural enemies to the environment of the pest to increase mortality. Early efforts were crude but remarkably successful; for example, the Vedalia beetle was introduced to California in 1888–89 and quickly provided complete control of the cottony-cushion scale, for which no other effective control was known, thereby saving the California citrus industry from extinction. This control continues unabated today, 76 years later. The number of successes is well over 110 in all parts of the world, but especially numerous in California (18 successes) and Canada (15 successes) where the use of parasites and predators has received much more attention than elsewhere. Clearly, success with this method of controlling pests is a function of the emphasis it receives.

The advantages of biological control are: (1) that once effected it is relatively permanent; (2) it has no undesirable side effects such as toxicity, or environmental pollution; and (3) its cost in relation to the savings it effects is low (as shown below in the section on Economics).

Modern biological control is often defined as the direct and indirect use of living organisms to control pests and reduce damage below economic levels. There are three basic kinds of biological control:

a. *Conservation.*—The use of natural enemies, either introduced or native, through changing their environment to increase their effectiveness. In its simplest form, this involves modification of pesticide programs to permit more of the beneficial forms to survive. In a more complex form, the method may require intensive, quantitative research on the complex of environmental factors acting to reduce or regulate the abundance of the natural enemies and studies on how best to minimize the effects of the more critical factors.

b. *Introduction.*—The search for new kinds of natural enemies in foreign countries, their introduction to the area where the pest is of concern, their rearing, and their release. The theory behind this is that many pests were accidentally introduced without their natural enemies. By going to another part of the world where the pest or a close relative occurs, some of these may be found and reassociated with the pest.

This method requires intensive research on the native natural enemies that have adapted to the pest in its new home, so that during foreign exploration a rational attempt can be made to discover natural enemies that will fill gaps in the total complex with a minimum of conflict with the acquired native species. It also requires research on the principles of predation and parasitism so that we can better understand the attributes required in a successful natural enemy and thereby waste less time and effort on importing species with a low potential and of little value in pest control.

c. *Inundation.*—The mass rearing and periodic release of vast quantities of a natural enemy. Releases are made on the basis of relatively small areas and the object is to flood an area with parasites or predators at times when the pest in question is most vulnerable to them. In some ways, inundation resembles a conventional pesticide program except that living organisms are substituted for an inert chemical—and undesirable effects are minimized.

In spite of some intensive efforts, the inundation method has not proved widely successful. Too often it has centered on natural enemies of limited or dubious value. It might well be of greater value with natural enemies of demonstrated importance and deserves more research effort to test this possibility.

Most experts on biological control concede that some pests may lack natural enemies that will regulate the pests at acceptable economic levels. However, more often they feel that failure merely reflects inadequate knowledge on the dynamics of the pests themselves and on the principles governing the action and effectiveness of natural enemies.

2. *Pathogens*

Diseases of insects have been known and recognized for centuries (e.g., honeybee and silkworm diseases) but it is only in the last two or three decades that there has been an appreciable research effort to use pathogens in pest control.

There have been several outstanding examples of insect pest control by microorganisms—the Japanese beetle (milky disease), and the European spruce sawfly (virus disease). *Bacillus thuringiensis* has shown promise against a variety of pests. The milky disease of the Japanese beetle is caused by a bacterium, and infection occurs when the beetle grub ingests the bacteria. The mechanical dissemination, mainly on turf, of commercially produced spore dusts of this bacterium throughout the northeastern part of the United States, has resulted in permanent control within three years.

Microbial control of insects is widespread in nature. The manipulation of microorganisms to bring about reductions in pests at will has become a major goal of insect pathologists. Microbial control has advanced by adopting not only the principles of biological control but also those of chemical control. The most successful applications of insect-infesting microorganisms in the future probably will be made in conjunction with these other agents of control. This does not mean, however, that microbial control should be directed solely to use as chemical insecticides; many insect pathogens appear to be adaptable to development along with other living organisms and the principles governing the use of parasites and predators may apply here as well.

The disadvantages of microbial control are: the need for precise timing of the application of the pathogen with respect to the incubation period of the disease; the need to maintain the pathogen in a viable condition until the pest is contacted; the difficulty of producing some pathogens in large quantities and inexpensively; and the requirement of some pathogens for favorable climatic conditions to infect the pest species.

The advantages are: the generally harmless and nontoxic nature of insect pathogens for mamals; the high degree of specificity of most pathogens, which tends to protect beneficial insects and mites; the compatibility of many pathogens with many pesticides so that the two may be used concurrently and in some cases synergistically; the high versatility of pathogens in so far as methods of application are concerned (colonization may be permanent, for example).

To realize the potential value of insect diseases, however, a greatly increased research effort will be required in the immediate future. Perhaps the area of study that demands the greatest immediate research effort is that of the process of infectivity and of how to create outbreaks of diseases in pest populations. At present we are often unable to fully utilize microorganisms whose virulence has been demonstrated in the laboratory because we do not know how to manipulate important environmental factors to produce conditions conducive to epizootics.

3. Plant and animal resistance

Plant resistance is one of the best means for pest control without insecticides. Although plant resistance to more than one hundred pest species is known, this method of control has not found widespread use. This probably is because several years of research are necessary before a selection can be made, and then it takes additional years to breed the genetic-resistant characters into a commercial variety. Once a variety is developed, however, it costs no more to grow a resistant one than a susceptible one. Furthermore, in using the plant resistance method, only the pest population with its immediate parasites and predators is affected. The successful programs with the Hessian fly and spotted alfalfa aphid are discussed in detail later in the report. The European corn borer program is also an excellent example of pest control by resistance, and we estimate the use of resistant corn varieties has saved about one hundred million dollars a year in the United States alone.

The development of varieties with even partial resistance could be helpful; the application of insecticides could be drastically reduced, parasites and predators would therefore be less inhibited, and there would be a reduced increase rate of the pest population.

Resistance has also proven successful in controlling pests of domestic animals. Differences in susceptibility to ticks have been found among breeds of cattle, and differences in resistance to strike by blowflies have been found among sire families of Australian sheep. The characteristics associated with strike resistance have been identified.

4. Environmental manipulations

All pest problems are created by environmental conditions which favor the pest. Altering the environment to make it less favorable may control the pests, or at least reduce their rates of increase. Environmental manipulation for pest control includes plant spacing, species diversity, timing, crop rotation, plant hormones, water management, fertilizers, soil preparation, and sanitation.

a. *Plant spacing.*—Preliminary research suggests that insect damage to crops and forests can sometimes be reduced through changes in the spacing of the plants. The relative rate of growth of a plant and its pest population per unit time and the behavior of the pest in searching for food may be affected. When plants are closely spaced, the productivity of the plant population per unit time may be increased within limits. Placing the plants close together may add to the effectiveness of natural enemies and result in greater control of pest populations. Diseases of pests may also be enhanced by manipulating spatial patterns. With other plant species, the alternative of spacing plants far apart may hinder pests in finding their host plant. Various combinations of plant spacing, use of fertilizers, water management, and timing offer possibilities for pest control and need investigation.

b. *Species diversity.*—Preliminary experimentation supports the hypothesis that pest populations will reach outbreak levels more frequently on crops and forests under monoculture than those cultured in a habitat with diversity of plant species. Greater plant diversity supports greater animal diversity in both host and prey species and provides alternate food for parasites and predators. Ultimately, this gives greater stability to these population systems, and there is less chance for one species to dominate and destroy. Diversity in parasites and predators feeding on one species of pest also aids in greater stability in the population interactions, because each natural enemy has a different level of efficiency related to the density of the pest population. The use of the diversity technique has limitations with many crops because of the need for monoculture, but in forests the technique might be more effectively used. Certainly further research is needed in this area.

c. *Timing.*—Some pests may be controlled successfully by growing the crop when the pest is not present, or injury may be reduced by planting so as to cause the most susceptible stage of crop development to coincide with a low ebb in seasonal abundance of the pest. Planting wheat on safe planting dates provides reasonably good control of the Hessian fly. The pickleworm is controlled in pickling cucumbers by growing the crop in the spring before the annual invasion of the pest from areas along the Gulf Coast where it is endemic. The clover midge is controlled on red clover by spring grazing or clipping to delay formation of heads when adults of the first brood are present. This allows seed to set and mature before the second brood appears. The planting of all cotton within a given area during a short period of time prevents extension of the fruiting period which is favorable for population buildups of the boll weevil and pink bollworm. Use of this technique alone can reduce the populations of these pests by one generation each year. Planting during the earliest favorable period for an area makes early stalk destruction possible, thus reducing overwintering populations.

d. *Crop rotation.*—Rotation of crops is a useful technique for controlling insects that become established in one season, overwinter in an immature stage, and damage the succeeding crop if it is susceptible, or where sequences of resistant or immune crops can follow susceptible crops in the cropping system. An excellent example is provided by the northern and western corn rootworms. Eggs of these species are laid in the soil during summer and late fall, and hatch about the time the corn emerges the following spring. Both are controlled reasonably well by not having corn follow corn for more than two consecutive years. In many cases, some injury occurs the second year. A rotation in which oats or some leguminous crop follows corn provides food plants that are unsatisfactory to the hatching larvae and they starve.

Rotation of crops is a good farm practice with a number of benefits in addition to its usefulness in insect control. However, its potential usefulness is limited by the economics of crop production. Moreover, a rotation practice which may be highly desirable from an agronomic standpoint, may actually create insect problems. For example, in some of the rice-growing areas of the South it is desirable to include lespedeza in the rotation. However, this crop is an excellent host of the grape colaspis, whose larvae may seriously damage the succeeding rice crop. It is controlled satisfactorily by rotating rice with weed fallow or pasture mixtures which do not include lespedeza.

e. *Plant hormones.*—The judicious use of plant hormones might alter plant growth or other plant characteristics to make the plant less appealing to the pest while not adversely affecting production qualities. Several hormones are in use to change the characteristics of plants, yet to our knowledge no one has investigated the influence of these hormones on plant growth as it relates to resistance to insect populations. This may prove to be a profitable area for investigation.

f. *Water management.*—Insect pests, especially mosquitoes, whose larval stages are spent in water are effectively controlled in many cases by making small changes in the water level of an impoundment to allow for more effective predation by fish such as *Gambusia.* Moderate adjustments in the time schedule of flooding and draining irrigated pastures or rice fields can reduce mosquito breeding greatly by rendering oviposition sites unsatisfactory.

Fungus epizootics in the spotted alfalfa aphid and the pea aphid are often aided by properly timed irrigation of alfalfa fields.

Water seeding of rice controls grape colaspis on this crop. Draining rice fields at the proper time and withholding further irrigation water until the soil has dried to a point beyond which the crop would suffer from water stress has been used successfully for more than 40 years as the only method for control of rice water weevil.

Winter irrigation of fields in arid areas where cotton debris has been plowed under for pink bollworm control eliminates diapause in overwintering larvae and causes suicidal emergence of adults. Strict irrigation schedules on cotton are recommended as necessary for successful biological control of the tobacco budworm in Peru. A minimum of water is applied during the growing period to prevent succulent growth of leaves and stems which are highly attractive to ovipositing moths. This procedure prevents inhibition of activity by the principal predator, an anthocorid bug, which lacks the capacity to work actively in the humid microclimate of a heavily irrigated cotton field.

g. *Fertilizers.*—Host plant nutrition affects the longevity and fecundity of a substantial number of species of insects and spider mites. However, there seems to have been relatively little effort devoted to exploring the possibilities of pest control by varying the amounts and ratios of mineral fertilizers provided their hosts.

Increased levels of nitrogen have most often been associated with significant increases in population growth. This has been demonstrated for the cabbage aphid, apple grain aphid, pea aphid, and greenbug. The application of optimum amounts of fertilizer to cotton extends the fruiting period so that one generation more of the boll weevil is produced than on plants inadequately fertilized. Host plant nutrition influences spider mites. Longevity and fecundity of spider mites grown on plants in nutrient solutions deficient in nitrogen, phosphorus, or potassium are adversely affected when compared to that of animals on plants in full nutrient solutions.

On the other hand, some species have exhibited negative responses to increased fertilization of crops. Also, resistance of sorghum to the chinch bug has been reported to vary with fertility, increasing as phosphorus levels were increased and decreasing with increased levels of nitrogen.

h. *Soil preparation.*—Soil preparation offers a frequently neglected means of controlling pests which is highly effective in cases where it can be timed to coincide with susceptible stages in their life histories. It is especially useful for controlling species whose pupal stages are spent in the soil at depths which are disturbed by plowing. For example, it has been shown that 98% of overwintering pupae of the corn earworm is destroyed by breaking and land forming practices. It also contributes to the control of species which are buried at depths from which they are unable to emerge such as the pink bollworm, sugarcane borer, and southwestern corn borer.

Wireworm populations of species with two-year cycles or longer can be reduced by plowing infested fields in summer. Mechanical injury and exposure to summer heat and low humidities account for most of the mortality.

Clean fallowing is useful to control weed hosts on which insects develop to attack subsequent crops after they are planted. The southern corn rootworm develops on weeds during the winter and early spring in the Gulf Coast States. Populations consisting of all larval stages damage corn planted in fields soon after fitting for planting. This species may be controlled satisfactorily by clean fallowing for two or three weeks before planting. This allows the larvae present to starve and the bare soil is unattractive for oviposition. The variegated cutworm is controlled by plowing under weed or cover crop hosts in time for all plant residues to decay before planting the subsequent crop.

i. *Sanitation.*—Good sanitation is a technique of insect control which has been used successfully for the control of a number of important pests. Probably no pest illustrates the necessity for such practices more than the house fly. This pest is not controlled satisfactorily by even the most effective insecticides if disposal of moist organic matter, which serves as a source of larval food, is not carried out scrupulously and carefully.

The southwestern corn borer is controlled adequately in early planted corn if the nearby stubble of the previous corn crop has been plowed out of the soil in the fall so that low winter temperatures kill the overwintering larvae. In areas where winter temperatures are not low enough to kill larvae, plowing stalks under several inches of soil prevents adults from emerging. Destruction of sweet potato crop residues by plowing under during the winter to expose roots and vines to freezing temperatures, thorough cleaning of storage facilities, and destroying infested material prior to storage are important techniques for control of the sweet potato weevil. Cleaning storage facilities, and destroying infested grain prior to storage of a new crop is an indispensable measure for control of stored grain pests.

Although none of these techniques provide satisfactory pest control when used alone, they do significantly reduce the potential of many pests. Frequently their use is consistent with good production practices, aside from effects on pest populations. The possibility of improving these techniques seems to justify more work on them.

5. *Induced sexual sterility*

Insects for release may be sterilized by gamma radiation, or by the application of chemosterilants. Each method has advantages for certain species.

The sterile insect release method provides a new principle of insect control that could change our whole concept of ways to deal with major insect problems. The system of releasing sterile insects to compete with other insects for mates, and thereby destroying the reproductive capacity of the insect with which they mate or attempt to mate, provides a method of reversing the law of diminishing returns when integrated with other control systems that depend on insecticides, cultural measures, and other conventional methods of control. With naturally low populations or when integrated with other methods of control when populations are high, the sterile insect release method could play a major role in the control or eradication of all of the species of tropical fruit flies, codling moth, pink bollworm, boll weevil, tobacco hornworm, sugarcane borer, oriental fruit moth, sweet potato weevil, and other important insect pests. We need to explore the potential of the method for maintaining continuous control for such widespread major pests as the corn earworm, the tobacco budworm, and the cabbage looper after populations have been reduced to manageable levels by other means. The practical possibility of releasing sterile insects in terms of billions each year to maintain complete population control in areas covering half the nation, if necessary, should not be overlooked. The feasibility of this approach depends on the relative merit, both economic and otherwise, of the various available alternative methods. Certainly the methods employed today leave much to be desired for such widespread and broad spectrum feeders as the three Lepidopterous insects mentioned. The sterile insect release method on a regional basis for dealing with the hornworm problem appears to offer a more economical and a more desirable method than those currently used.

Research on the sterility principle is complex and it is costly. However, the reward can be great. It is difficult to estimate how much research support would be justified on the various ways that the sterility principle might be employed. Current research permits exploration on ways to rear insects and on ways to produce sterility. These are fundamental requirements. However, there is need for information that is equally as important but much more difficult to obtain. We need to know more about the natural population density of the insects, their overwintering areas and when and how far they fly. Much additional information is needed on ecology and behavior of the insects.

Another potential method of inducing sterility is the release of males of a cytoplasmically incompatible strain, or a strain that will produce sterile hybrids.

However, many species of insects cannot readily be reared and released in overwhelming numbers. Some species are not adaptable to laboratory rearing. With others, the numbers required to overwhelm the normal population would be too enormous. With still others, the released insects would themselves be dangerous, destructive or annoying. For control or eradication of such species, the chemical induction of sterility in a large proportion of the existing natural population would be highly advantageous, especially if the sterile males were then able to mate with, and thus render infertile, the females that escaped the sterilizing chemical. This can best be done by means of baits or other attractants containing or treated with chemosterilants.

6. Physical environmental factors

Research has demonstrated that electromagnetic energy in some ranges is attractive to insects while in others it is destructive, and that it is potentially useful for controlling insects. The research on the attractiveness of ultraviolet and visible electromagnetic radiation has been most promising, especially in connection with the use of light traps.

Laboratory tests have shown that the radiant energy produced by an electronic flash can interrupt diapause in the imported cabbage worm. Application of such a stimulus may induce diapausing insects to emerge at times that may not be favorable for their survival.

Electromagnetic energy in the radio frequency (RF) range has been used to kill insects by instantaneously raising their body temperature.

Control methods utilizing this principle have already been used to kill stored grain pests in both grain and burlap bags.

Very little research has been conducted on the response of insects to infrared energy. However, with the development of infrared equipment and expanded research in this area other possible methods of control may arise. Insects are known to respond to sound stimuli, but there has not been any demonstration that sound can be used in insect control. Tests have shown that male *Aedes aegypti* are attracted to sound recordings of the female's wing beat in the laboratory, but not in the field. Other research has shown that some noctuid moths detect the sound produced by bats and in turn make an avoidance movement. The status of research in this area at the present is more in the nature of determining the potential rather than development to practical usefulness.

7. Attraction and repellency

a. *Attractants.*—The behavior of insects is governed by their internal physiological condition and their responses to external stimuli. Physical and chemical stimuli play dominant roles in three important aspects of their behavior—those associated with feeding, mating, and ovipositing.

The behavior of an insect in finding a mate, once it has attained the necessary physiological condition, and in copulating after the mate has been selected, is regulated by natural specific chemicals, sounds, various electromagnetic radiations, or a combination of such stimuli. Natural chemical attractants and mating stimulants have been shown to occur in a wide range of economic insects. They have been identified chemically and synthesized in a few cases. The materials studied are known to be extremely active in minute amounts and almost completely specific.

Research on specific sex attractants should offer effective and desirable solutions to many of our major insect problems. A greatly intesified research effort is needed on insect pheromones. This effort will require research by chemists trained in various fields, as well as biologists who must investigate the behavioral aspects and develop practical ways to employ the pheromones. In considering the role that sex pheromones might play in insect control, the possibility of employing the living insects themselves must not be overlooked. Research has progressed sufficiently on the tobacco hornworn moth to suggest that the use of living virgin females in conjunction with light traps, or perhaps the living insects alone, could offer practical ways for effective control.

Much research has been done on the attractants that guide certain species to their plant and animal hosts, and on the arrestants and feeding stimulants that regulate their feeding behavior. Promising leads are available in a few species, but many of the most important pests have only been casually observed. Such research is difficult and costly, but the approach offers much promise.

Attractants, arrestants, and feeding stimulants can be used to trap insects, to poison them, to sterilize them, or to infect them with pathogens. They provide highly specific methods for attacking the pest species with the least disturbance of the environment.

An outstanding example of the practical application of attractants in insect control is found in the recent eradication of the Mediterranean fruit fly from Florida. A serious and widespread infestation of this pest was eradicated within a few months after its discovery. The principal method used was the distribution of a protein hydrolysate bait containing malathion. In this instance the distribution of the bait was widespread, by airplane, but the attractiveness of the bait made possible the use of a non-persistent insecticide and provided eradication with a much smaller quantity of insecticide than would otherwise have been possible.

In a much smaller experiment a more specific bait was used to eradicate the Oriental fruit fly from the Island of Rota. The baits were again distributed by airplane, but in this instance they consisted of fiberboard squares treated with an attractant, methyl eugenol, containing 3% of an insecticide, naled. This lure is highly attractive to male oriental fruit flies, which feed on it ravenously, but unattractive to the females. Even though only one sex fed on the lure, 15 biweekly drops resulted in the eradication of the species from the island. At the most recent survey, a year later, the island was still free. Only 3.5 grams of naled per acre were needed with this highly specific lure.

It is our view that research on insect attractants per se will not yield highly fruitful practical results unless scientists also fully appreciate and accept the concept of area-wide population control in using insect attractants. Attractants offer no protective coating to the individual host plant or animal as do insecticides. Adequate protection will come about only by reducing the population level in the area to a point where the number of insects remaining cannot damage the host or the fruit. For many insects this will require virtual elimination of the population during the growing season. Since in most cases we are dealing with highly mobile insects, we must also accept the fact that attractants for many insects can be practical only if they are highly effective and are used against the total population in an area large enough to keep infiltrating forms to levels of no economic significance.

b. *Repellents.*—The use of substances such as dimethyl phthalate, 2-ethyl-1,3-hexanediol, and *N,N*-diethyl-*m*-toluamide to repel mosquitoes, flies, and other biting arthropods has become a successful pest control operation for the sportsman and outdoorsman, in military operations, and for the protection of domestic animals. Benzyl benzoate and *N*-butylacetanilide are successfully used to impregnate clothing to ward off attacks by chiggers and ticks, respectively.

Woolens and other fabrics are routinely "mothproofed" by a variety of substances: by complex "colorless dyes", by dieldrin and DDT, and by sodium fluosilicate. All of these have a mixture of repellant and toxic properties.

However, in the protection of plants against insect attack, the use of repellents has not been as successful. The only large scale use of such a repellent is Bordeaux mixture, a complex of tetra- and penta-cupric sulfates, which for many years has been widely employed as a fungicide and to protect plants against attack by flea beetles, leafhoppers, and the potato psyllid. Tetramethyl thiuram disulfide has been described as very repellent to the Japanese beetle. A newer repellant is 4′-(dimethyltriazene)-acetanilide which is described as an anti-feeding compound. In actual practice many well known insecticides such as the pyrethroids, DDT, and the aryl carbamates cause pronounced repellency during the early stages of poisoning.

Repellents for plant-eating insects do not appear to offer any especial advantage over conventional insecticides. They require the same exhaustive study and development in order to prove their toxicological safety and have the same inherent problems as to application and confinement to the treatment area. For pest species they only serve to spread the problem to neighboring untreated areas. However, if satisfactory repellents could be developed to deter honey bees and valuable natural enemies away from crops during regularly scheduled spray periods, these might have some practical importance.

Very few studies have been conducted on the nature of the repellent process to insects, apart from the converse of studying the requirements for attraction, which in mosquitoes, for example, seems to be warmth and CO_2. Careful physiological investigations of both of these processes for important insect pests may provide the background for better insect control measures.

8. Genetic manipulation of pest populations

Through the manipulation of the genetic make-up of certain pest populations, their growth rates may be limited to levels satisfactory for control. Lethals may be maintained in the population through the use of pest-plant gene complexes, and also be released as lethal genes in the pest population. Genes causing an obligatory resting stage, thus limiting the pest to one generation per year, could be substituted in insect populations. Because mass rearing of insects is feasible for more and more species, such genetic manipulations can be used more widely.

The sterile-male technique mentioned earlier is not included in this section because complete sterility cannot be inherited in the pest population, whereas lethals and similar deleterious genes can be under certain conditions.

a. *Lethal genes.*—The release of individuals carrying lethal genes into a pest population could drastically reduce the numbers of the pest pop-

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ulation, especially if the individuals carrying the lethal genes were released periodically. The advantage of this procedure over the sterile-male technique, to which it is related, is that heterozygous individuals carrying the lethal genes continue to breed in the population for some time after introduction. Ideally, this lethal gene in the heterozygous state should be tied to some characteristic which has survival value to the animal in the field. The lethal gene would persist under these conditions, but in this state it would remove at most 25% of the pest population. This procedure, perhaps in combination with some other, might make the difference between a successful or unsuccessful control program. A great many lethals exist which could be utilized for control.

b. *Male producing genes.*—Genes which result in the production of a preponderance of males have been found in mosquitoes, and these might be bred into a pest population. These male-producing genes have been found to have a relatively good survival value in laboratory populations. More research, especially in field trials, is needed in this area to evaluate the potential of this technique.

c. *Plant-pest gene complexes.*—Using plant-pest gene complexes, it may be possible to achieve permanent control for pest species. For example, control might be possible if two alleles were lethal when either was homozygous. To keep the alleles in the pest population, we would only need to make the heterozygous pair be necessary for survival. Each allele in single doses has survival value because of a two-gene complex in the plant host. This model would result in a 50% reduction in the pest population each generation and might provide an effective permanent control. The control technique, however, might be made more efficient using a complex polygenic system. The main point to be made is that this area deserves investigation.

d. *Insecticide-unfavorable gene complexes.*—The locations on the chromosomes of genes for resistance and susceptibility to certain insecticides have been determined for a few species. With adequate research, chromosome maps could be developed for a number of the more important economic pests. If genes unfavorable for survival in nature are found to be associated with genes for resistance either because of very close proximity on the chromosomes or, preferably, because of physiological interaction, strains carrying the combination could be released to spread the combination through the natural population. The pressures of insecticide selection and other elements in natural selection would then tend to be counterbalanced, with the result that neither insecticide resistance nor total insect populations should reach high levels, since the portion of the population surviving insecticide treatment would be the portion otherwise genetically inferior.

B. Bioenvironmental control of plant diseases

Losses from plant diseases in the United States are estimated to exceed 3 billion dollars a year. In the case of forest trees it is now recognized that diseases take a toll which is greater than the damage caused by either fire or insects. Over 1,500 different diseases caused by adverse environmental relations, viruses, bacteria, fungi, nematodes, and parasitic seed plants may cause economic loss to crop plants and forest trees in the United States.

Research in plant pathology has in the past, and presently continues to have, a pronounced orientation toward development of resistant varieties and cultural practices in coordinated programs for reducing crop losses. A high degree of control of many destructive plant diseases and nematodes has been achieved by genetic and cultural manipulation of crop plants without involving chemical control.

For control of certain soil-borne organisms with very broad host ranges, for many orchard and perennial crops under attack by a wide range of different pathogens, and for many diseases for which no available sources of resistance are currently available, fungicides and nematocides still provide the primary means of minimizing losses and maintaining crop productivity. The continued need for chemical controls also provides the basis for supporting research on the nature of action of toxicants, development of improved fungicides, bactericides, and nematocides, evaluation of chemotherapeutants particularly for systemic diseases and improved methods of application.

In this connection it should be emphasized that the bulk of the chemicals used in control of plant diseases are non-persistent and have a relatively low toxicity to man, or warm-blooded animals. The need remains to develop methods to reduce the use of those compounds that do affect warm-blooded animals and to seek improved alternate methods of control.

For certain orchard crops such as apples, peaches and citrus there are many diseases and nematodes which affect quality or yields for which there are no effective bioenvironmental controls as yet. For example, the program of breeding for apple scab resistance is making excellent progress, but if scab resistant varieties were available chemical controls would still be requisite for other diseases, such as powdery mildew, cedar-apple rust, black rot, and bitter rot. The number and type of sprays would certainly be modified and costs reduced if scab resistant varieties were available but there would not be an immediate prospect of eliminating the need for fungicides completely. With more knowledge of the ecology of these other pathogens, there is no question that certain cultural practices and improved methods of application of fungicides and nematocides could reduce total requirements for chemicals. Similar examples could be cited for other orchard crops.

Because of relatively low cost and economic returns, most farmers recognize without question the need for treatment of seeds with fungicides to prevent or minimize infection by seed-borne pathogens and damping-off fungi during the early stages of seedling development. Because of the nature of the attacking organisms, the environmental conditions during inital growth and development, and the relatively small amounts of chemicals required, it is unlikely that there would be significant gain in emphasizing intensive research on new bioenvironmental control methods to reduce the use of seed-treatment chemicals. There would be advantages to development of less toxic materials or of new compounds that would provide protection to the plant for longer periods of time.

Other examples may be cited of the use of fungicides for control of a foliage disease for which no effective alternative controls are available, and progress in development of resistant varieties has been slow. In the peanut producing area of North Carolina major losses are attributable to two fungus leafspot diseases. Based on production figures for 1959 these diseases cost North Carolina peanut growers approximately $2,500,000. Peanut leafspot can be controlled by dusting with sulfur at an average cost of $1.75 per acre or with sulfur plus 4% copper averaging $3.50 per acre. The increased net value due to either treatment is worth over 12 times the cost of the dust (average 1949–1951 prices). Of 130,000 acres dusted in 1959 based on average yield increase of 362 pounds per acre, growers realized an increase of 47 million pounds, worth approximately 5 million dollars. Similar examples could be cited for vegetable, fruit, sugar and other crops where over one million acres are treated with nematocides each year.

The application of nematocides for control of a broad range of nematode pests has had wide acceptance by the tobacco grower in the south. Treated acreage in North Carolina rose from a few hundred acres in 1949 to 200,000 acres in 1956. On an average basis the relative increase in value of the crop may range from 4 to 8 times the cost of application if proper application methods are utilized. However, it is estimated that the acreage requiring soil fumigation could be reduced by ⅔ or more with the use of a proper cropping sequence involving crops that prevent increases in populations of nematodes pathogenic to tobacco and plowing out tobacco roots immediately after harvest to reduce survival of nematode populations. In many areas the use of nematocides will be reduced even further as soon as nematode resistant varieties currently in advanced stages of development are released to growers.

In considering needs for reducing the introduction of toxic chemicals into the environment by man, it should also be recognized that many microorganisms growing in plant residues or in feed may introduce compounds with biological potency to warm-blooded animals that far exceed that of man-made chemicals. The potential toxicity of a microbial toxin is best illustrated by the botulinus toxin: one milligram of this toxin is reputedly sufficient to kill 1,000 tons of guinea pigs. Examples from the past involving plant pathogens would include ergot of rye which over a period of hundreds of years brought agonizing death to thousands of persons in Europe. Recently it has been demonstrated that harmful effects on poultry, particularly following ingestion of peanut meal, were attributable to toxins formed by a common mold *Aspergillus flavus*. This toxin is injurious at levels of a few parts per billion. Other powerful mycotoxins affecting animals in diverse ways are formed apparently in feeds by a variety of other microorganisms including many saprophytic mold fungi and certain plant pathogens. Recognition of these problems adds a new dimension to our appraisals of pollution problems and enhances our need to develop bioenvironmental controls to reduce dangers from mycotoxins in feeds.

1. Disease resistance

Of the wide variety of plant disease and nematode controls that have been developed usually the most effective, economical, and easiest to use by the agriculturist is that of disease resistance. In 1900 in the United States less than 1% of the total acreage in agricultural production utilized varieties that were specifically developed by man for resistance to specific plant pathogens. In 1965 more than ¾ of the total acreage in production is being planted to varieties which did not exist prior to 1900. Most of these varieties incorporate varying degrees of resistance to one or more important diseases. Without the development of varieties with characteristics for high yield and quality and with resistance to certain destructive pathogens, commercial production of certain crops would have literally ceased in many areas of this country. For certain crops such as small grains, 95–98% of the vast acreage involved is planted with resistant varieties that have been developed in the last 20 years. Varieties of alfalfa resistant to one or more diseases occupy approximately 95% of the total acreage planted to this crop. At present all efforts to improve varieties of crops for agronomic or horticultural characteristics also involve attempts to increase resistance to one or more diseases.

Examples of success in these areas would include Fusarium wilt resistance in a wide range of crops, particularly cotton, tomato, cabbage, and watermelon. In areas where the Fusarium wilt pathogen specific to a certain host is present 100% of the commercial production is devoted to varieties resistant to Fusarium wilt. In these areas farmers will no longer plant a variety unless it has resistance to this type of soil-borne pathogen. The entire flue-cured tobacco program has been dependent on the successful incorporation of resistance to the two most destructive diseases of this crop, namely bacterial wilt and black shank. The continued production of sugar crops in this country reflects the remarkable success of the program of breeding for disease resistance in sugar cane and sugar beet to specific virus diseases such as mosaic and curly top, respectively. For many field and forage crops which have a low value per acre the use of resistance will continue to serve as the major means for reducing disease losses in the most economic manner.

The history of breeding for resistance to plant pathogens has not been a series of uninterrupted successes, however. Tremendous efforts have been expended in the development of cereal grains with resistance to rust pathogens. In recent years unfortunately, these have in essence developed into delaying actions because of the rapidity with which new races and strains of rust fungi in particular have arisen to frustrate the efforts to maintain stable high levels of resistance. It has been necessary to reshift genetic factors continuously in order to maintain a degree of stability in production. The outbreak of Victoria blight on oats exemplified the destructive potential of a disease when large scale plantings were made of varieties which lacked resistance to this previously unrecognized disease. Through the combined efforts of plant breeders and plant pathologists it has been possible both in the case of the rusts and Victoria blight to introduce new and different combinations of resistance and to maintain high productivity with the new varieties.

Research effort has not been as extensive in breeding for nematode resistance as in the search for resistance to fungus pathogens. Resistance to certain species of root-knot nematodes, the most important pathogenic nematodes, has been successfully incorporated into available varieties for only a few of the major field and vegetable crops. Resistance has been developed, however, for the stem nematode on two varieties of alfalfa, for sugar beet nematode on selections of sugar beets, and recently for the soybean cyst nematode on selections of soybeans. More frequently than not, crop plants grown in the same area are attacked by more than one nematode species, but resistance in present varieties is for only a single nematode type. Multiple nematode resistance is needed in many areas.

For a large number of diseases sources of resistance have either not been detected or it has been extremely difficult to incorporate such resistance into commercially acceptable varieties. Examples of diseases for which resistance has been sought without much success include southern stem rot on peanuts and other hosts caused by *Sclerotium rolfsii*, *Phymatotrichum* root rot and Verticillium wilt of cotton, Fusarium root rots of beans and peas, and pasmo of flax.

In contrast to the situation in the area of breeding of annual crops for disease resistance, progress in the development of resistant varieties in orchard crops and forest and shade trees has been relatively slow. Progress is being made now in the development of scab resistant apple trees. Mimosa clones with resistance to Fusarium wilt are available and elm selections with levels of resistance to Dutch Elm disease and phloem necrosis of elm have been developed. Encouraging progress is being made in research on resistance to white pine blister rust and fusiform rust. Breeding has been underway for several decades for resistance to the destructive blight disease that virtually eliminated the valuable and extensive stands of the American chestnut. Hybrids with moderate resistance may soon be available. However, re-establishment of the chestnut as it originally existed from Maine to Georgia is, of course, not possible now.

The difficulties inherent in breeding for resistance to one disease are magnified, of course, as efforts are made to add factors for resistance to additional diseases. That these problems are not insurmountable, however, is evident from the progress being made. Barley varieties with resistance to 5 diseases are now available in certain areas. As another example, in 1965 growers of flue-cured tobacco will be able to plant a variety which combines factors for resistance to the following 6 diseases: black shank, bacterial wilt, Fusarium wilt, black root rot, root knot, and brown spot.

An area warranting intensive additional research would be in the field of insect resistance. The process of screening large populations of plants as a part of disease resistance programs could be geared to coordinated insect resistance studies. With the possible development of resistance to insects such as leaf-hoppers or aphids in many major crops will come the bonus of reduced losses from certain viruses which are currently not readily controlled except by vector control. The very recent rapid spread of two damaging corn virus diseases into the corn belt focuses attention on the potential gains to be obtained from research which combines efforts of plant pathologists, entomologists and plant breeders.

One of the most challenging areas for future research emphasis is the determination of the biochemical basis for resistance to diseases and nematodes. For certain types of diseases in which multiple and complex genetic factors are involved resolution of this problem in the immediate future may be extremely difficult. A study in depth of diseases in which there is clear evidence for a more simple mode of transfer of resistance could provide keys to help unlock the more complex relationships. With new analytical tools and advanced procedures in biochemistry and organic chemistry it is now possible to identify and rapidly characterize micro-amounts of relatively complex organic compounds. In view of the intensive effort currently being expended in the development and screening programs for resistance to plant pathogens on major crops and certain forest trees, it is appropriate that there be a significant increase in the attempts to characterize more exactly and directly the specific objectives of the search.

2. Reduction of losses by manipulation of plants and pathogens

For a wide range of plant diseases and nematodes it is possible to reduce or minimize losses by the judicious application of properly coordinated cultural practices. This would include all practices of management, cultivation, harvesting, or handling exclusive of the use of chemicals and resistant varieties. These approaches to control are designed (1) to exclude or prevent introduction of pathogens by the use of disease- and nematode-free propagative material, (2) to reduce or eliminate sources of inoculum under field or storage conditions, or (3) to minimize or prevent infection and subsequent development of pathogens.

3. Control of plant pathogens by natural enemies

Soil-borne plant pathogens are extremely difficult to control and major unresolved disease control problems lie in this area. The possibility of direct biological control of soil-borne fungi, bacteria, or nematodes has long been an attractive but unrealized prospect. It has been clearly demonstrated that certain soil organisms may be suppressed or destroyed by the action of other soil-inhabiting saprophytes or predators.

It has been attractive to consider the possibility of increasing the numbers of these soil organisms that will parasitize, poison, antagonize, or out-compete plant pathogens. However, in contrast to recent developments in biological control of insects, direct use of hyperparasites or antagonists for the control of plant pathogenic fungi or bacteria has not been explored intensively in crop plants and in limited experiments control has not been consistent. It has also been difficult to obtain direct evidence that parasitic forms studied in culture actually work in the soil as they do under laboratory conditions.

In the case of plant pathogenic nematodes, a large number of bacteria, viruses, nematode-trapping fungi, predatory nematodes and invertebrate enemies, some of which can destroy large numbers of other free-living forms have been described. No large scale system of land management, however, has been developed which will maintain a balance of these fungi or predatory nematodes adequate to insure predictable and effective control.

Direct efforts for control by utilization of predatory, antagonistic, or competitive organisms have in general been limited in scope with primary emphasis on small experiments. The control obtained by certain management practices, however, particularly against soil-invading pathogens in contrast to soil-inhabiting organisms does in many cases reflect significant alterations of the antagonistic microflora.

If effective, the use of cultural practices such as crop rotation or adding organic material to soil as a means of disease and nematode control has many advantages. The costs of such control, however, are borne entirely by the grower in contrast to control involving the use of a resistant variety. There is obviously a need for coordinated programs that will study the ecology of cropping and land management practices. These efforts would involve team approaches including plant pathologists, nematologists, ecologists, mycologists, soil microbiologists, soil scientists, agronomists, and entomologists. It is apparent that computer procedures will be essential to bring some pattern of order into the great mass of data now accumulating in this area.

A good level of control has been obtained for several diseases by the use of certain soil amendments or of crop rotations which provide residues with high carbon: nitrogen ratios. This is exemplified by (a) the control of potato scab by incorporation of soybean residues into soil which prevents increase of scab severity and (b) control of Fusarium root rot of beans by a rotation with barley and incorporation of barley straw into the soil.

In the case of forest trees the regeneration of stands faces many serious problems associated in part with the need to control soil-borne pathogens and the inability to use cultural practices that are applicable to annual crops. It is in this area that the need and potential for development of bioenvironmental controls is of particular importance.

4. *Eradication*

Attempted eradication of a microorganism would only have a possibility in those cases in which the pathogen was introduced into a well-defined localized area and the means of dissemination of the pathogen was very limited. In only one case where such an approach was used was success achieved. This was in the case of citrus canker in Florida in the early 1920's. However, certain notorious failures would include chestnut blight and the Dutch elm disease. In these cases attempts were made without full understanding of the biology of the pathogen and the means of dissemination.

For certain rust diseases involving two hosts, eradication of the alternate host has been attempted with varying degrees of success. The intensive barberry eradication program with initial high promise for control of black stem rust of wheat is now considered to have value mainly in reducing to some degree the rapidity with which new races and strains develop. A high degree of success was obtained in the case of white pine blister rust in those areas where eradication of *Ribes* was feasible under environmental and terrain conditions. In other areas *Ribes* eradication has been so costly and often ineffective that other approaches to control are sought.

5. *Disease- and nematode-free seed and propagating material*

The importance of the use of disease- and nematode-free material in any agricultural enterprise should need no emphasis or elaboration. A variety of techniques has been developed including the use of heat-therapy for elimination of certain fungi, viruses and nematodes in planting material, use of meristem culture, indexing on diagnostic hosts, growing seed crops in arid regions to avoid seed infection by bacterial pathogens, and rigid supervision and propagation of disease- and nematode-free planting material particularly for grapes, greenhouse crops such as chrysanthemums, seed beds of various types and ornamental and orchard nurseries. For plant material propagated vegetatively these procedures have become well-organized functions of a wide range of state and private organizations.

6. Crop rotation and soil management

The value of crop rotation is directly correlated with the nature of the primary pathogens involved in a specific area with a given crop. Approximately 24 diseases on 17 different important crops may be controlled relatively effectively by properly managed rotation sequences.

For many nematodes with specialized or restricted host ranges cropping sequences combined with other cultural practices can hold populations below levels causing economic loss. In the case of the wheat gall nematode in the southeastern United States rotation with non-susceptible crops has virtually eliminated this pathogen as a cause of economic loss. Resistant varieties, trap crops, and non-host crops such as crotalaria, beggarweed, and marigolds, may reduce nematodes in soil.

Rotation with crops that are not susceptible to the specific pathogen involved has also been effective in reduction of losses from organisms that are soil invaders and cannot compete with the saprophytic microflora in plant debris or the soil. Examples of diseases that can be reduced by rotation would include bean anthracnose, cabbage blackrot, and various bacterial blights of vegetable crops. Such control must be coordinated with the methods that prevent reintroduction of the pathogens on seed or planting material. For many soil-borne pathogens that are well adapted to long-term survival in soil, such as damping-off fungi, various species of Fusarium causing wilt diseases, and the potato scab organism, crop rotation by itself has dubious merit.

Many nematodes and plant diseases may be controlled by soil management. Spacing of crops, flooding, alternating wetting and drying cycles, clean fallow, and plowing may control certain nematodes and plant diseases. Deep plowing and burying of surface litter has controlled white mold (*Sclerotium rolfsii*) of peanuts. These methods of control have never been fully investigated or exploited.

7. Destruction of inoculum sources

Sanitation has been helpful in reducing disease severity for certain diseases but rarely serves by itself as a sole means of control under field conditions. Simple removal of diseased plant material from a field may be a waste of effort unless it is based on specific knowledge of the pathogen involved.

Experience has shown that proper cleaning of vehicles, equipment, and tools prevents spread of certain nematodes. Destruction of infected plant parts by burning, plowing out of roots, and harrowing reduces root-knot nematode infestation. Timely harvesting of peanuts reduces soil infestations of root-lesion and root-knot nematodes. Sterilization of peanut shell mulches prevents spread of root-lesion nematodes and several plant diseases.

In the case of late blight, however, potato cull piles have been shown to provide a source of inoculum for early development of several diseases including late blight, blacklegs, and aphid-borne viruses.

In storage and transit facilities sanitation becomes a more critical factor since elimination of crop debris that may harbor pathogens is often essential in minimizing losses.

8. Vector control

An area in which plant pathologists and entomologists share a common interest is in the control of vectors of bacterial, virus, and fungus diseases. With a few exceptions, control of virus diseases solely by control of insect vectors by insecticides has not had many successes.

In the case of the Dutch Elm disease the effective control has been dependent upon application of rigorous sanitation coupled with careful spraying with insecticides to control the elm bark beetles that carry the spores. New developments with systemic insecticides to control Dutch Elm disease have recently been announced but testing under rigorous field conditions will be requisite prior to large scale application.

9. Nematode attractants and repellents

Many crop and non-crop plants are known to be immune to nematodes, possibly because they contain repellent chemicals. Other plants probably produce substances that attract nematodes, as larvae are attracted to and penetrate localized areas of plant roots. Marigolds and asparagus root contain chemicals that are toxic to nematodes. Discovery of new methods of controlling nematodes may depend on precise knowledge of the attractants and repellents found in plants.

C. Internal Animal Parasites

1. Animal resistance

There is evidence that animal resistance can be used to control a wide variety of pests. West African Shorthorns are more resistant to trypanosomes than other breeds and their resistance is to trypanosomes in general, not just to those of the area where the West African Shorthorns are bred. Similarly, the N'Dama cattle of French Guinea are conspicuously resistant to trypanosomiasis, and in Northern Nigeria these N'Damas had superior resistance to two species of trypanosomes. They were found to be actually resistant to the trypanosomes, and not just able to escape the disease by repelling the vector.

Resistance of fowls to the coccidium, *Eimeria tenella,* following deliberate exposure to measured standard doses of that parasite was significantly raised during several generations of selection.

After nine years of artificial selection for resistance to the worm, *Haemonchus contortus,* resistance in sheep and goats significantly increased. In the latter species, resistant sires were able to transmit a high degree of resistance to their progeny from unselected females.

2. Parasites and predators

Intermediate hosts of various disease organisms have been controlled using parasites and predators. For example, a small viviparous fish, *Gambusia,* has proved an effective control agent for mosquitoes in some drainage areas in North America. The fish swarm through streams and canals consuming mosquito larvae.

Researchers have discovered a small fly whose larvae feed on aquatic snails. These flies are being investigated as possible controls for the snails which act as the intermediate host of human schistosomiasis. In Hawaii and California, the sciomyzid flies have been introduced for control of another aquatic snail which serves as the intermediate host of liver fluke disease in cattle.

There are many other parasitic and predaceous species of animals which could be utilized for the biological control of animal parasites and these deserve intensive investigation.

3. Environmental manipulation

Parasites of both man and animals have been controlled by altering the environment to make it unsuitable for the intermediate host of the parasite. The best known is the control of mosquitoes in some regions through the judicious draining of marshes and related mosquito-breeding areas.

A snail, *Marisa,* is being experimentally introduced into water areas in Puerto Rico of eliminate the pest snail which serves as the intermediate host of schistosomiasis. The introduced snail destroys the food supply and incidentally the eggs of the pest snail and thus eliminates the pest.

In Africa, control of one species of the tsetse fly, which transmits sleeping sickness, has been achieved simply by removing certain types of brush which the flies occupy for shelter.

D. Bird, Mammal, and Other Vertebrate Pests

Birds and mammals sometimes compete with man for his food, crops and livestock, carry diseases transmissable to man or domestic animals, interfere with his transportation systems or in other ways impinge adversely on human desires. The problem is not uniform in distribution, and may be locally severe. Estimates of crop losses caused by birds in the U.S. run into tens of millions of dollars per year. Damage to aircraft from collisions with birds may be considerable, and sometimes causes loss of life. Predatory mammals kill some livestock, and at times may cause substantial loss. Commensal rodents damage stored products and are a reservoir of disease in most cities and many other places.

Because of the relatively scattered nature of the problems, environmental pollution from attempts at control has been comparatively small. At the same time, the ill considered use of some very persistent poisons, such as sodium fluoroacetate (1080), has led to secondary poisoning of desirable birds and wild and domestic mammals.

Control of rough fish, using chemicals, is rather widespread. Some programs have had unforeseen and unwanted effects. Clearly more discriminating means of fish population control will be an increasing need in the future.

1. Noise and physical repellents

Noise, light, moving objects and electrical shocking devices have been used with varying success to exclude birds from certain areas. The effectiveness of the approach depends largely upon proper selection of the devices and manner of application. Experience has shown that combinations of devices and frequent shifting of devices are often important in obtaining effective exclusion. Noise generated by automatic exploders, exploding shotgun shells, pyrotechnics, and recorded distress calls has been used most widely. It is a fair statement that many bird problems could be alleviated through the use of these devices in the hands of a perceptive observer who picks and chooses among the devices as the bird reactions suggest.

Repellents of this sort have been less effective against mammals than against birds. Electrical shocking devices have been used with considerable success in preventing fish from entering irrigation ditches, etc., where their presence was not desired.

2. Chemosterilants

Chemosterilants have not been extensively used in control of bird or mammal populations but a number of small-scale field investigations suggests the utility of this approach. The problem of safe application of the chemosterilants so as to affect only the species intended, and the discovery of chemical substances with appropriate characteristics has so far prevented large-scale successes.

The method holds special promise for long-lived species that are limited in population levels by the availability of nesting sites, or species where present population levels are acceptable but increases are not wanted. The first of these cases is well exemplified by the Herring Gull in the Northeast; here nesting islands are fully occupied, and the large gull populations are a problem at Boston's Logan Airport. A chemical treatment that would permit nesting but not hatching of eggs would prevent other individual Herring Gulls, or gulls of other species, from utilizing the nesting islands. A gradual decline in gull population would follow. Populations of short-lived species, like most other birds, would decline more rapidly.

The second case is typified by big game populations in many National Parks where hunting is not permitted and animal populations are so large that they damage the range. Present practices of population control by slaughter are distasteful to many people; chemosterilants would be a welcome substitute.

3. Chemical repellents

Many chemicals are being used with varying degrees of effectiveness in repelling certain rodents such as rats, mice, and squirrels. Repellents are also available for use in preventing damage by deer and rabbits. While repellents generally give satisfactory results, there is no assurance that they will give complete protection nor can they be applied to food crops because of residue problems.

The two major bird control methods available in this category are (1) chemical coating to prevent roosting; and (2) seed protectants. The roost repellents are being used with fairly good success. The main complaints are that they are usually expensive and messy to handle. However, future use of this method looks good. Some protectants are designed to repel birds from eating seeds, but materials thus far tested have not been very successful.

4. Trapping and shooting

The technique of shooting nuisance birds and mammals is an old one. It is time consuming and has limited use. Where law permits, this method is successful in taking individual animals but is not practicable for use in the control of large populations.

The use of traps is increasing, especially for the control of nuisance birds. Success depends much on proper trap design and placement. The method is selective and safe in areas of high human populations. However, it is usually a slow and expensive technique for controlling large numbers of offending animals.

Soporific compounds are included in this category. These have been used to a limited degree in the control of both birds and mammals. The results with one compound, avertin, in controlling birds have been erratic. Another is currently being applied in conjunction with traps.

When used in this manner, the drug helps to prevent an animal from damaging itself while in a trap.

5. Behavior

Recorded distress calls or other sounds that elicit responses have been mentioned under noise and other repellents. So called anti-flying compounds which stimulate erratic behavior of the drugged birds often serve to frighten others of the same kind away. Results of experiments to date are erratic but the principle is worth further investigation. Decoys to attract birds are used in conjunction with large enclosure traps and certainly increase the effectiveness of these traps.

Comparatively little imaginative investigation of the use of behaviorial stimulants has been performed and the methodology deserves further work.

6. Environmental manipulation

Habitat manipulation in those circumstances where it is applicable, offers permanent relief from bird problems. Unfortunately, relatively few bird problems lend themselves to this sort of solution. In the northeastern United States many communities own watersheds surrounding their water supplies. Many of these areas were open land, and were reforested with coniferous trees. These plantations are often extremely dense, and evidently are ideal roosting sites for blackbirds. For example, a winter roost that may have contained as many as five million birds, including starlings, redwinged blackbirds, cowbirds, and grackles, was present in the Hanover, Pennsylvania, watershed for several years. The local people are proud of the plantations, and are very disturbed that the winter roosts result in extensive damage to the trees. There is also the problem of possible contamination of the water supply. An obvious solution is the clearing of the tree growth and conversion of the site to low-growing vegetation unsuitable for roosting. Experimental work elsewhere has demonstrated that water yields are as high or higher with low-growing vegetation as with conifers. The solution is obvious biologically, even though unpalatable locally. Similar situations are not rare.

A second example is the modification of Logan Airport in Boston, Massachusetts. Here a stand of giant reed grass harbored a roost of about 8000 starlings. A flock of these starlings enroute to the roost collided with an aircraft and caused it to crash, with the loss of 62 lives. Cutting the reed grass removed the roost; other steps also have been taken to make the airport less attractive to birds. The general principle of making airports unattractive to birds will not eliminate bird-aircraft collisions, but it will markedly reduce the frequency of such collisions, particularly at the critical period of take-off.

A third kind of habitat modification, though not undertaken specifically for bird control, results from the smooth exterior surfaces of our modern buildings. Without arguing the esthetics of modern architecture, we have certainly gained in elimination of bird roosting sites.

Control of fish populations has at times been accomplished through the manipulation of water levels in reservoirs to make the habitat less favorable for the reproduction of non-game species. In other situations, excess populations of undesirable species have been controlled by the mass stocking of predatory species.

7. Exclusion

Excluding birds is usually a costly process initially, and is suitable only for high-value limited areas. For example, a number of buildings in the city of Washington have been "bird proofed." In some cases this has been done by the installation of hardware cloth or other barriers; in some cases by placing sharp wires in such a fashion as to make the areas unsuitable for roosting; and in other cases by installation of low-voltage electrical systems that shock the birds when they attempt to land on the ledges. Physical exclusion of this sort is comparatively permanent, although initial costs may be high.

With some high value crops, such as berries, it is possible to exclude birds by the use of netting. Disposable paper netting has been used with some success in parts of New England. Unfortunately, installation of netting sufficiently tightly to exclude birds is not easy; and poorly installed, the netting simply acts as a cage to confine the birds that do manage to work their way in. The use of hardware cloth on telephone poles to prevent damage by woodpeckers is another example.

E. Weeds

The losses caused by weeds and the cost of weed control constitute important problems in agricultural production and technology. Weeds cause damage in many ways. Yields of crops and livestock are impaired. The prevalence of certain weeds may limit the choice of crops that can be produced. They increase production and harvesting costs and impede production mechanization. They impair the quality of agricultural products by contaminating them with noxious odors, seeds, or pathogens. Aquatic weeds interfere with efficient water management.

Until the advent of selective herbicides, the methods available for weed control were largely tillage, mechanical, and cultural practices. Some weeds are still controlled by these methods which involve hand weeding and hand hoeing. Because of the scarcity of hand labor and need to increase production efficiency and mechanization, old traditional methods of weed control no longer are satisfactory as the sole methods of weed control. Chemical weed control provides many advantages, but other approaches have been neglected and need to be developed. More basic information on the reproduction and growth requirements of weeds will provide new clues to their control. The application of current knowledge and technology provides promising opportunities unknown a few years ago; these should be exploited to develop alternate nonherbicidal measures. Some weed problems for which there is now no solution can be attacked with promise of success by exploring new approaches. To exploit fully the opportunities provided to develop alternate bioenvironmental control measures for weeds would require marked expansion in current research effort, along the lines discussed in this section.

1. Insects and other herbivores

In 1944, two species of leaf-feeding beetles were introduced as a means of suppressing Klamath weed, a rapidly spreading weed of foreign origin. By the time the bettles became effective, about 2,300,000 acres of farm and rangeland in California had become infested by the weed and there were less serious, but increasing infestations on 2,000,000 acres in neighboring states. In a relatively few years, these bettles were successful in checking further spread of the weed and, in California at least, unaided by supplementary means, reduced Klamath weed to the status of economic insignificance. It is estimated that the investment to effect the degree of control now enjoyed is in the neighborhood of two or three hundred thousand dollars. Considering the number of years since successful control, the cessation of applications of herbicides, and the increase in land values as a result of killing the weed, the benefits from the program must now be conservatively calculated at several million dollars.

During the last ten years, insects that attack gorse, puncturevine, tansy ragwort, Scotch broom, and alligatorweed have been imported and released in the United States. Some promise for the control of gorse, Scotch broom, puncturevine, and ragwort is already evident but the importations are too recent to show striking results. Spectacular increases in population of a weevil on gorse and of a seed weevil on puncturevine have taken place.

The effectiveness of certain snails, e.g. a *Marisa* and fish such as tilapias, for control of certain aquatic weeds has been demonstrated in exploratory studies. Work needs to be intensified to exploit the full potentialities of these biological agents to control the weeds that infest ponds, reservoirs, lakes, streams, canals, and waterways.

The degree of success given by biological control of weeds in various parts of the world has been impressive, and in several instances outstanding. It is now recognized that a high degree of host specificity is shown by vast numbers of plant-feeding insects and that there are encouraging possibilities in the deliberate and broad extension of geographic ranges of insects which can modify the abundance of undesirable plant species.

The concept of suppressing (but not eradicating) weeds has been proved useful, and there is adequate justification for significant expansion of this type of work. The justification is based on the following points:

1. It seems likely that the majority of flowering plants have associated insects that are intrinsically capable of greatly reducing the abundance of their host plants.

2. The host specificity of plant-feeding insects, potentially useful as biological control agents, must be carefully tested.

3. Although earlier successes were obtained only against perennial weeds, recent work with *Emex spinosa,* an annual weed, in Hawaii and with a *Tribulus,* also an annual, in the United States and Hawaii, indicates that annuals may be controlled biologically.

4. Insects available for control of a native or introduced weed are not limited to those attacking it in its native habitat, but include insects that attack related plants in other areas.

We have given most consideration to control of weeds that infest non-cultivated areas, i.e., rangelands. Weeds in areas where truck-crops are grown, i.e., fields, subject to repeated mechanical disturbance, are not the best candidates for control by insects (except that infestations on margins of fields might be reduced), but weeds in crops that are sown (hay, small grains) would be susceptible to suppression by insects.

2. Diseases

Intensive search is needed to discover phytopathogens that may be introduced to control important weed species. Devastation of native plants by phytopathogens such as involved in phloem necrosis and Dutch Elm disease, chestnut blight and others indicate the possibility of this approach. Safeguards and adequate evaluation before release of such pathogens is essential.

Studies are also needed of means of using phytopathogens already present for controlling weeds. Many native and introduced weeds are attacked by disease organisms that prevent seed formation and frequently death of these plants. The epidemiology of these diseases is not understood and has not been studied. Investigations are needed to gain an understanding of the life cycles and behavior of these phytopathogens so as to develop means of multiplying, dispersing and causing them to attack important weed species.

3. Environmental manipulation

Weed problems are created by man-made changes in the environment such as disturbance of native vegetation and soil, overgrazing, incidence of fire, poor drainage, planting of weed infested crop seeds, improper land preparation and cultivation, growing of poorly adapted plants, and silting up of streams, lakes and ponds. Environmental manipulations to control weeds include choice of variety, seedbed preparation, method of seeding or planting, seeding rates and row spacing, fertilization, cultivation, irrigation and water management, erosion control, design of irrigation and drainage canals, and managed grazing and sanitation.

a. *Choice of variety.*—Some crop plants develop quickly and provide heavy shade and competiton against weed growth. The use of selected varieties of soybean and sugarcane shows promise for suppression of certain annual weeds that emerge in late spring and summer. Another example of an effective competitive variety to suppress weeds is zoysia, a lawn grass, that is adapted to some climatic zones where other lawn species are poorly adapted. Further study and evaluation of crop varieties and their rotation offer good potentials to reduce weed problems.

b. *Seedbed preparation.*—Thorough and proper tillage to prepare seedbeds for crop plantings are good practices for controlling certain perennial weeds and for reducing the reservoir of weed seeds occurring in the soil. In addition, preparation of seedbeds to provide good drainage prevents development of weeds in low places in fields where tillage operations are inefficient. Several properly timed cultivations prior to planting have been effective in reducing infestations of pernicious perennials such as Johnson grass and bindweed, and in killing annual weeds during germination. Life history studies of weeds, including the nature of seed and bud dormancy, are needed to control weed growth by manipulating plant communities through properly performed cultural practices. One such study of downy brome determined critical factors governing germination of its seed and the longevity of seed in the soil. The information facilitated the development of cultural and cropping practices for the practical elimination of downy brome from fields in two years.

c. *Method of seeding or planting.*—The planting of seeds with minimum disturbance of the soil has been shown to reduce development of annual weed problems in a number of crops. For example, sugar beets can be planted on well prepared seedbeds which have been previously treated by flaming; such a practice reduces need for chemical weed control. The seeding of rice into flooded fields has shown promise for control of troublesome grass weeds. Further study of the requirements for weed seed germination in relation to crop seeds can provide new opportunities to develop planting methods to alleviate problems caused by annual weeds.

d. *Seeding rates and row spacing.*—The development of a quick and heavy cover of cultivated fields with crop plants is known to provide control of many weed species. For example, the planting of soybeans in close-spaced rows at high plant population per acre suppresses growth of weeds particularly when soil is properly fertilized and drained and planting is done on the proper date. More critical study of seeding rates and row spacing in combination with other management practices offers opportunities for the practical control of weeds in many crops.

e. *Fertilization.*—The application and placement of fertilizer at the proper rate and time will encourage growth of crop plants without significant benefit to weeds. The resultant stimulation in crop growth tends to suppress weed growth. Fertilizer can be placed in the soil so it is absorbed by crop roots and not by many weeds. Also the application of fertilizer can be made when growth of crop plants will be encouraged but weeds will not. Fertilization of ponds can induce growth of plankton which reduces penetration of light into the water and in turn reduces aquatic weed growth. Further careful study of fertilization practices should be conducted to develop improvements in weed control methods.

f. *Cultivation.*—Although cultivation has been practiced for centuries to control weed growth, too little attention has been given to cultivation practices in relation to the physiology and reproduction of weeds. Certain tillage practices are known to aerate the soil and promote germination of weed seeds. In other cases light-sensitive weed seeds tend to germinate when exposed to light by cultivations. Detailed studies on the germination requirements of weed seeds can provide opportunities to employ cultivations more effectively to deplete the soil of weed seeds. Study should be made of timing of cultivations to promote vegetative growth of perennial weeds so as to cause death by freezing or drying.

g. *Irrigation and water management.*—Some of the critical weed problems occurring in irrigated crops of the western states develop because of the irrigation practices used. In many cases, crop roots can be irrigated without wetting the soil surface. If the soil surface on top of rows is maintained in a dry state no annual weeds emerge; weeds which emerge in the middles between the rows can be controlled by cultivations. Properly timed flooding of rice fields is known to suppress certain weeds that usually become established during early growth of rice plants. Studies on the management of irrigation water, including the removal of weed seeds from the water, offer good potentials for alleviating critical weed problems in many areas.

h. *Erosion control.*—Cultivated fields and grazing lands which become eroded of top soil usually become infested with weeds and brush. Such infestations then spread to other areas by movement of seeds in water, wind, and by other means. Silt moved from fields into waterways, ponds and lakes cause aquatic weed problems to develop which in turn cause flooding, poor drainage and other problems. Studies to improve water and soil conservation practices can help prevent weed problems from developing.

i. *Design of irrigation and drainage canals and ponds.*—Submerged aquatic weeds tend to develop in sites where light penetrates the water to an appreciable extent. Studies in Florida on the light requirements of certain aquatic weeds permitted the design of drainage canals with proper depth and bank slope to prevent the penetration of adequate light to promote aquatic weed growth. Further studies on the life history, physiology, and growth requirements of aquatic weeds in relation to design of waterways and ponds offer excellent opportunities to avoid aquatic weed problems.

j. *Managed grazing.*—Some of the most serious weed and brush problems occurring on grazing lands have evolved because of poor grazing management. Further research to develop criteria for proper grazing management should greatly aid development of methods of alleviating weed problems on uninfested ranges and pastures.

k. *Sanitation.*—Many weed problems are created by distributing weed seeds in manure, hay, and other feeds. In addition, weed seeds and viable weed fragments occuring as contaminants in farm seeds and plants are planted on farms each year. Studies to develop methods to avoid such distribution of weeds onto farm lands offer potentials to reduce the spread and incidence of weed problems on farm lands of the nation. Special methods need to be developed to control the weeds in non-cropland sites such as fence rows, ditchbanks, and rights-of-way to prevent reinvasion of agricultural lands by weeds.

4. Natural stimulants and inhibitors

The germination of some seeds is regulated by light. Chemical substances produced by plants and other organisms are known to promote or retard seed germination. For example, witchweed seeds germinate only in the presence of stimulants exuded by the roots of corn and certain other plants. Knowledge of the nature and identity of these substances would offer opportunities to develop cropping sequences or synthetic substances to deplete soils of the tremendous reservoirs of weed seeds and thereby avoid necessity for annual and repeated application of control measures. To adequately explore this promising approach to the control of weeds requires research effort by plant physiologists, microbiologists, chemists, and biochemists.

5. Plant competition

Toxins and antitoxins produced in the soil by certain plants exclude other plants from growing in association with them. For instance, some work currently underway in Wisconsin shows that seed of a particular species could not only inhibit the germination of the seeds of several crops and weed species, but the inhibition was species specific. Germination of some were only mildly affected while for others the inhibition was complete. Some plants produce stimulants that promote germination and growth of other plants. A better understanding of the phenomena involved offers excellent opportunities to develop new principles and approaches to the control of weeds.

Nature of growth requirements and competition between weeds and other plants for light, moisture, and nutrients should be better understood to develop better methods to (1) utilize competing forage plants in the control of grazing land weeds; (2) devise planting and cultural schemes for cultivated crops that would suppress weeds; (3) find and develop non-weed type vegetation to control aquatic and ditchbank weeds of irrigation and drainage systems; and (4) utilize smother and catch crops to suppress weed growth.

6. Revegetation of weed- and brush-infested grazing lands

In the arid Southwest over 100 million acres of rangeland are brush-infested. In the humid eastern U.S. a similar sized area infested with weeds and brush is found. Progress has been made in brush control by cabling, fire, chemical and cultural methods. In the absence of of prompt and successful artificial revegetation, this land soon reverts again to brush and weeds. Research indicates that a team effort by range scientists, agronomists, and plant physiologists is needed to develop effective methods for establishing desirable forage species on land cleared of brush and weeds. Restoration of brush land to grass in the arid Southwest has defied conventional seeding methods. High soil temperature and rapid drying after storms are major difficulties. Recent research suggests that adapted grasses can be established by seeding in pits or in furrows that are shaded with dead brush. This keeps the soil cooler and retains moisture longer enabling seeds to germinate and the seedlings to become established.

7. Breeding highly competitive forage species

Throughout the United States revegetation of grazing lands has contributed greatly to stabilization of soil and water resources, to the production of meat and other animal products, and to the current rapid expansion of outdoor recreation, hunting, and fishing. To be most effective, this program requires forage species possessing superior competitive ability against brush and weeds. For example, grass species are being evaluated artificially in controlled environmental chambers for salt and drought tolerance in order to compete with weeds and brush. Also hybridization is being attempted between quackgrass and other species of agropyrons to obtain range species with wider adaptation and competitive capacity against cheatgrass and brush species. Teams of plant breeders and agronomists are needed in each major area of the country to develop forage species that are highly competitive against such brush and weed species as halogeton, medusahead or chamise in the west; mesquite, creosotebush, or cactus in the Southwest; cheatgrass in the intermountain region; tarweed on mountain ranges; palmetto in the south; and Canada thistle, and such other weeds as broomsedge, sporobolus, nimblewill, etc., in the east. Teams of scientists involving plant breeders and agronomists are required to initiate these needed approaches to the control of weeds and brush on grazing lands.

III. ECONOMICS OF BIOENVIRONMENTAL AND PESTICIDAL CONTROL OF PESTS

Attempts to compare relative effectiveness and costs of bioenvironmental and pesticide chemical control programs in forestry and agriculture are difficult because detailed and comparable statistics are not generally available. Specifically, detailed information on sales and uses of pesticides and the costs of applying bioenvironmental control measures have not been assembled regularly. Moreover, there are relatively few satisfactory statistics on the value of the crop saved. Although there are many statistics that show the presumed loss of the crop without control, or the loss of the crop in spite of control, there are almost no valid comparisons. In some countries, notably England, the gathering and analysis of these statistics has the status of a major research project; however, in the United States we lag behind.

Because of the difficulties in preparing cost analyses on a national basis, this subpanel elected to narrow the scope of its analysis to a smaller area in which research is known to be intensive and where it was hoped sophisticated records of costs might be available. California was judged suitable for this purpose and the figures for this state are used below to compare the contrasting approaches to pest control. California is not typical in that it invests more in research on biological control than any other state, almost as much as the other states combined. In addition, several important pests were selected as examples of the comparative economics of control of individual species.

A. Economics in an Exemplary Area

The subpanel wished to present a more precise cost analysis than could be done even for the state of California as a whole. For this purpose, it selected the Fillmore Citrus Protective District in California for an analysis in depth. This analysis is presented below also.

1. California statewide

California has an intensive agricultural industry: cash farm receipts in 1963 were about $3.5 billion. To this can be added the value of timber harvested, $270 million (1958 figure, no others available), which gives a total of about $3.7 billion per year for agriculture and forestry at the primary producer level. This is the basic figure used throughout the following analysis. It does not, of course, reflect the fact that more than a third of California's population is involved at some level with agriculture and forestry and their subsidiary industries.

The number of major pests in California forestry and agriculture against which control programs were aimed in 1963–64 was:

Insects, mites, and other arthropods	107
Weeds	61
Plant diseases	30
Total	198

More than 13 million acre-treatments were made with pesticides (about 6 million acres in agriculture and forestry were treated an average of about 2.2 times). The research and application costs of this effort may be analyzed as follows:

Type of control	Research and development costs	Retail and application costs
Biological control (parasites, predators, and disease)	$800,000	$300,000
Other bioenvironmental controls	325,000	2,337,000
Pesticidal controls	[1] 13,250,000	230,000,000
Total	14,375,000	232,637,000

[1] Breakdown: University and other State agencies, $1,250,000; industry, $12,000,000 (gross estimate).

Research costs in biological and other bioenvironmental controls are paid mostly by the state and Federal governments, and therefore are directly supported by the taxpayers. The University of California Agricultural Experiment Station and other state agencies administer these funds. The application costs of other bioenvironmental controls are borne mostly by the California Department of Agriculture and used mostly on quarantine activities. The remaining costs in the right-hand column were borne mostly by the agricultural and forestry producers, and by local agencies such as mosquito abatement districts.

The savings derived from these expenses are estimated as follows:

a. *Biological control.*—Savings derived by any bioenvironmental control are especially difficult to assess because they are hidden in the estimates for total savings from all control activities. However, biological control specialists in California recently estimated that imported natural enemies saved the economy of the state $115 million from 1923 to 1959. This figure did not attempt to assess the value of programs that were only partly successful and the real value was not less than $125 million for those 36 years (probably much higher). During that period, about $4.3 million was invested in research and application. Therefore, there was a return of about $30 for every dollar invested. This figure would be substantially higher today because benefits continue to accumulate from the earlier activities without further investment, and new successes have been added since 1959.

About 20 insect and weed pests have been controlled biologically in California since 1923. More than 30 insects, mites, and weeds are the targets of current studies on biological control.

b. *Other bioenvironmental controls.*—No estimates available.

c. *Pesticidal control.*—(1) One source estimated that pesticides save California agriculture and forestry $700 million per year. This would be a saving of about $3.00 for every dollar invested.

(2) The nationally accepted figure for the savings derived from pesticide use is about $5.00 for every dollar invested.

(3) Another source estimated that 50% of the agricultural and forestry crops in California would be destroyed without pesticides. The present loss, in spite of pesticides, is about 21% ($800 million). The difference is 29%, or $1.07 billion. This represents a saving of about $4.30 per dollar invested.

A reasonably accurate figure, taking into consideration all the above estimates, would be between $4 and $5 returned for every dollar invested in research, purchase, and application of pesticides.

The cost of research is low in terms of value received with pesticides. But retail and application costs are higher and the result is that pesticidal control as an economic proposition without consideration of possible undesirable effects is only about 1/6 as attractive as biological control. It should be borne clearly in mind, however, that biological control is now being used against all pests for which natural enemies are known, and the present level of pesticide use is necessary in many instances. Before pest control costs can be reduced and the drawbacks of pesticide use, including environmental pollution, avoided, further research support for biological and other bioenvironmental control will be required.

This analysis focused attention on a truly remarkable example of the savings derived from biological control. In the 1880's, the cottony cushion scale was devastating the citrus industry of California. Shortly thereafter, at a total cost of less than $5,000, the Vedalia beetle was introduced from Australia. It achieved complete control of the scale immediately and thereby saved the citrus industry from extinction. This control continues at the same high level today and the total savings to California agriculture in the intervening 80 years is incalculable, certainly many millions of dollars. The value of the citrus industry in 1963–64 was $174 million at the primary level.

2. Fillmore Citrus Protective District, California

The Fillmore Citrus Protective District was initiated in 1922; a number of citrus growers banded together to eradicate the California red scale by chemical methods. From 1922 until the early '50's fumigation with cyanide, and oil sprays were used. A parathion program was continued until 1961, when the District switched to a total program of biological control. Parasites and predators were reared in the District's private insectary by an entomologist and technician on the District's payroll. In 1964, this insectary reared and released 10 million *Metaphycus helvolus* against the black scale and 13 million *Aphytis melinus* against the red scale.

In 1964 the District had 331 growers with about 8,000 acres of citrus. The assessment to members was $24 per acre in 1960, the last year of the chemical program. In 1961, the figure fell dramatically to $6 per acre and in 1962 and 1963, to $8 per acre. The annual savings derived from the biological control program are estimated at $300,000 for the District, or about $40 per acre. The average cost of citrus pest control in the District was about $20 per acre in 1963–64, including the assessment. In other areas this figure was as high as $150 per acre for mites alone, and probably averaged $80–100 statewide.

The acreages in the District that were treated with pesticides for the red scale in recent years are:

1959	1,150
1960	2,035
1961 (1st year of biological control)	150
1962	0
1963	0
1964	0

B. Economics in Selected Species

1. Tobacco diseases

A bacterial disease known as Granville wilt became a limiting factor in flue-cured tobacco producing counties in North Carolina following the turn of the century. Growers frequently lost 20–40% of their crop in severely affected fields. All attempts to obtain practical controls failed. Losses during the period from 1920–1940 in Granville County, one of the key tobacco growing areas, were estimated to total 30–40 million dollars.

Intensive efforts to develop a wilt resistant tobacco were initiated in 1935. This effort culminated in the release in 1944 of a tobacco variety with acceptable quality. In 1947 over 80,000 acres were planted in the new variety, returning to productivity land that was unproductive and increasing land values. The total cost for producing this variety, including salaries and other expenses, was approximately $150,000. In 1948 the value of the resistant variety for the tobacco farmers in the areas where Granville wilt occurred was estimated at $2,000,000. This did not consider the increased value of the land. It is obviously difficult to estimate the total value of this contribution to the region. It should also be emphasized that research on development of resistance in tobacco to bacterial wilt provided the guidelines for similar investigations on the same bacterial disease which affects other major crops such as tomato and Irish potato.

In 1964, 416,000 acres were devoted to the tobacco crop in North Carolina; the value of the crop to the grower was $520,000,000. Approximately 95% of this acreage was planted to varieties which not only incorporated resistance to Granville wilt but also to black shank. The highly destructive black shank fungus had spread through the tobacco growing area with spectacular rapidity in the mid-1950's. Fortunately it was possible to combine black shank and bacterial wilt resistance. The project involving the development of black shank resistance was estimated to cost $250,000 for salaries and other related expenditures. In 1964 it was no longer considered safe to plant a variety susceptible to black shank in any of the tobacco growing counties in North Carolina. If resistant varieties were not available and only susceptible varieties were grown in a given year it is estimated that no tobacco would be harvested on 120,000 acres and yield would be reduced approximately one-fourth on the remaining 290,000 acres in North Carolina alone. Such a loss could not be estimated on a dollar value basis since crop prices would increase if such a drastic reduction in yield occurred. Recognizing that such an adjustment would result, the loss to growers would still be measured in terms of hundreds of millions of dollars based on average yields of 2,200 pounds per acre and a price of $58.53 per pound in 1964. These statistics need to be considered as examples of the gain to agriculture which can be realized by the investment in research on a bioenvironmental approach to control on any given crop.

Since the two major diseases involved are caused by soil-borne pathogens, it should also be recognized that no effective or practical chemical controls would have been available to control these diseases and that the effectiveness or practicality of other approaches, including rotation and related cultural practices, would have been limited by various factors.

2. Curly top in sugar beets

The losses to sugar beet growers caused by the curly top virus caused drastic reductions in yields and threatened the extinction of the sugar beet industry in the western United States. The curly top virus is transmitted by the beet leafhopper and causes severe dwarfing or premature death of infected sugar beet plants.

The uncertainty of sugar beet production for processing in years of crop failure during the mid 1920's made the enterprise unprofitable to the sugar companies. For example, the per acre yield of roots in Idaho was 12.7, 6.0, and 12.8 tons; and in Utah, 15.4, 8.1, and 12.1 tons for 1925, 1926, and 1927, respectively. This illustrates the low productivity for the "curly top year" of 1926. In this same 3-year period the per acre yields in California were 6.4, 9.0, and 8.0 tons, or an average of 7.8 tons for the State. These yields are based on harvested acreage and do not reflect the losses due to abandonment of many acres not worth the cost of harvest.

Breeding for curly top resistance was begun in 1925 and gave rise to US 1, the first distinctive American variety of sugar beets. In 1934, sufficient seed of US 1 was available to plant 35,000 acres. US 1, which had about 25% tolerant plants, was soon followed by US 33 and US 34 with 40 to 50 percent resistant plants in their populations. Further improvement in the 1940's gave US 22 and US 22/3 (3rd selection) that had approximately 85% and 95% resistant plants, respectively. These varieties were good in root production and acceptable in quality.

The estimated cost of initial development of the sugar beet varieties with resistance to curly top was $750,000. The estimated cost of the research included funds expended from 1918–39 and involved salaries for 15 investigators, both full time and part time, from 1929–39. During the 1940's and 1950's, as resistant varieties became available the staff devoted to curly top investigations was reduced and manpower and funds diverted to other projects.

Currently the staff on curly top investigations consists of a full-time employee who is screening new breeding material for curly top resistance and a full-time plant pathologist who keeps abreast with the occurrence of new strains of the virus. In addition, four employees devote part time to breeding for resistance and other activities related to curly top. The estimated current effort on curly top research is 3 professional man-years per year at a cost of approximately $100,000 annually.

Maintaining curly top resistance in established varieties of sugar beets is an insignificant cost. In the 8-State region where curly top is a serious hazard, the sugar beet acreage planted in 1964 was roughly 720,000 acres of the national total of 1,460,000. Thus acceptable protection against curly top damage for the region was obtained for sugar beets at an annual cost of about 14 cents per acre—or for less than 1 cent per ton of roots.

Among the many countries producing sugar from the sugar beet, the Netherlands usually ranks first in yields per acre. The acreage of sugar beets in the Netherlands is approximately equal to our Pacific Northwest region and about two-thirds of that in California. In 1963 the yields per acre of roots in the Netherlands was 18.7 tons; in California 20.2 tons; and in the Pacific Northwest, 23.6 tons. Thus the regions in this country where sugar beet production would not be profitable with curly top susceptible European varieties are now the highest producing regions in the world, with protection from significant losses due to curly top being provided by resistant varieties.

3. The Hessian fly

Approximately 50 million acres of wheat are seeded each year in the United States and 30 million of this is in areas infested by the Hessian fly. Of this amount approximately 20 million acres are within the area where serious losses would occur each year if some method of Hessian fly control was not practiced. An estimated 4,000,000 acres are grown in the Hessian fly infested areas where wheat would furnish valuable fall and winter pasture if it were not damaged by this insect.

Even with the use of present Hessian fly control methods, there is an estimated loss in grain of 1.7% or $32,000,000 in the U.S. each year. This does not include the estimated $6 per acre loss in fall and winter grazing in the southern portion of the Hessian fly infested area.

Control methods for Hessian fly.—There are three principal control measures available for the Hessian fly; (1) delay seeding until the fall brood has disappeared, (2) chemical control, (3) planting Hessian fly resistant varieties.

Value and cost of various control measures.—Loss if no control measures were practiced: It is estimated that the average yield reduction on the 20,000,000 Hessian fly infested areas would be 18% by the fall brood (Jour. Econ. Ent. 53:501–503) and 4% by the spring brood or a total of 22% if no control measures were practiced. This loss would amount to 83,600,000 bushels per year (Avg. yield of 19 bushels per acre) or $167,200,000 (average value $2.00 per bushel). In addition, there would be an estimated $24,000,000 loss per year in grazing value (4,000,000 acres at $6.00 per acre). Therefore the estimated loss each year due to Hessian fly would be $191,200,000 if no control measures were practiced.

Control by delayed seeding: Delayed seeding is an effective method for control of the fall brood of Hessian fly but does not prevent damage by the spring brood. From available information it is estimated that if delayed seeding was not necessary to control the Hessian fly an increase in yield of 3% could be expected from wheat planted at an earlier date. Therefore if we had to rely entirely on delayed seeding for Hessian fly control, and if this practice was applied on all the 20,000,000 acres the loss due to Hessian fly would still be $53,200,000 in grain (20,000,000 acres x 7% loss x 19 bu. yield x $2 per bu.), and $24,000,000 in grazing (4,000,000 acres x $6) or a total of $77,200,000. Since the loss if no control measures were available is estimated at $191,200,000, the value of delayed seeding for Hessian fly control has a potential value of $114,000,000 a year ($191,200,000—$77,200,000).

Cost of developing and maintaining delayed seeding method of control: The delayed seeding method of control has been in use for many years and is based on a knowledge of the biology of the insect. We estimate that 10 man-years per year (5 entomologists and 5 agronomists) for 20 years were involved in developing this control method. The cost per man-year (from 1915 to 1935) is estimated at $10,000 per year. Therefore, the total cost of developing the delayed seeding method would amount to $2,000,000. Although the fly-free date is well established for most areas, a few states maintain a service to inform the farmers of the fly-free date each year. It is estimated that this service amounts to $20,000 per year. We therefore have a potential saving of $114,-200,000 per year for a *total research cost* of $2,000,000 and a maintenance cost of $20,000 per year, about $55 per year for each dollar invested in research.

Control by chemicals: Although some of the systemic chemicals give excellent control of the fall brood of the Hessian fly, chemicals have never been used on a commercial scale for control of this insect. This is because other methods are as effective and are much cheaper. Chemicals for the control of Hessian fly would cost about $3 per acre for the material and $1 per acre for application. If the entire 20,000,000 acres were treated the cost would be $80,000,000. Since this method only controls the fall brood, there would be a 4% loss by the spring brood or $30,400,000. Treated wheat could not be grazed so there would be a loss of $24,000,000 in grazing value, or a total cost and loss of $134,400,000. Since the loss if no control measures were used is estimated at $191,200,000 chemical control measures could still save the growers $56,800,000 per year, less than $2 for each dollar invested. In the absence of other control measures, growers in the more critical areas would no doubt use chemicals but many would accept the losses without treatment of any kind.

Cost of developing chemical control measures: Only a few individuals have been engaged in developing chemical control measures for the Hessian fly, so the total cost in developing this method has probably not been more than $200,000.

Control by resistant varieties: The growing of resistant varieties is the ideal method for controlling the Hessian fly. If satisfactory agronomic varieties possessing resistance are available, this method can be used at no extra cost to the grower, without creating a residue or other toxicological hazards and without upsetting nature's balance between insects and other natural enemies. Seed can be planted at the optimum time, and there is no loss in fall and winter grazing. Varieties can be developed which are practically immune to Hessian fly attack, so it would be possible to prevent the entire potential loss of $191,200,000.

Cost of developing and maintaining resistant varieties: The first concerted effort to develop Hessian fly resistant wheats started in the 1920's. Since that time an estimated 300 man-years (Federal and State entomologists, breeders, pathologists) have been devoted to this research effort or a total of $6,000,000 (300×20,000 per year). An estimated $210,000 a year is now devoted to developing Hessian fly resistant varieties.

Present status of Hessian fly control.—The discussion up to this point has been largely a statement of potential losses and gains. Now let us look at the actual situation as it was in 1964.

Recent estimates place the annual loss of wheat in the United States due to Hessian fly at 1.7% or $32,000,000 a year. This does not include loss in grazing value of infested wheat. Seventeen Hessian fly resistant wheats are grown on an estimated 8,500,000 acres in the United States, but approximately 1,000,000 acres of this is on land outside of the Hessian fly infested areas. Perhaps another 1,000,000 acres are grown in areas where the variety does not effectively control the Hessian fly. For example, Pawnee wheat is resistant only to the western strain of Hessian fly, although it is grown to some extent where the eastern strain occurs. We therefore have effective control of the Hessian fly by resistant varieties only on an estimated 6,500,000 acres and of this 1,500,000 is in the area where it can be used for grazing. Of the remaining 13,500,000 acres in the infested areas, 11,500,000 is probably protected by delayed seeding and there is an estimated 2,000,000 acres on which no control measures are practiced. Therefore the loss on the 11,500,000 acres protected by late seeding would be $17,480,000 (acres×4% spring damage×19 bu. per acre×$2 per bu.) and on the 2,000,000 acres where no control measures were applied, the loss would be $16,720,000 or a total loss of $34,300,000 which is fairly close to the estimated $32,000,000 loss previously mentioned. This does not take into consideration the $9,000,000 value of grazing that was provided on the 1,500,000 acres sown to resistant varieties or the loss of $15,000,000 in grazing due to no protection or delayed seeding on the 2,500,000 acres in the grazing area, or the 3% loss on the 11,500,000 acres due to late seeding ($17,110,000).

If we add the $15,000,000 grazing loss and the $17,110,000 late seeding loss to the $34,300,000 grain loss, the present loss due to Hessian fly would be $66,410,000 per year. Therefore Hessian fly control as presently practiced prevents a loss of $124,790,000 per year (191,200,000–66,410,000).

One other factor often overlooked is the over-all reduction in Hessian fly population resulting from growing resistant varieties. The total population reduction has been very apparent even though less than ⅓ of the acreage has been seeded to resistant varieties. Thus there is less damage to susceptible varieties when some resistant varieties are grown in the same areas.

Cost of research to develop present control: This estimated annual saving of $124,790,000 has cost the taxpayer a total of $8,000,000 in research ($2,000,000 delayed seeding research, $6,000,000 resistant variety research), a return of about $15 a year for each dollar of the original research investment. To maintain this degree of control costs an estimated $230,000 per year ($210,000 in research on resistance and $20,000 for services to determine safe seeding dates).

4. The spotted alfalfa aphid

Alfalfa is by far the nation's most important hay crop. It is grown on about 28.5 million acres or about 42.3% of the total acreage devoted to hay production. The spotted alfalfa aphid, first found in the United States in 1954, spread into 33 states within 5 years. However, the area most susceptible to damage consists of 12 lower midwestern and southwestern states from western Missouri and Arkansas west to the Pacific Coast. In these states, alfalfa is grown on 7,194,000 acres of which 4,037,375 acres are subject to severe damage. These 4,037,375 acres represent about 14.5% of the total alfalfa acreage in the United States, and produce about 19% of the nation's alfalfa hay valued at about $286 million. In 1956 this area suffered a loss of $42,000,000 due to the spotted alfalfa aphid. Current annual losses are estimated at 4.9% or about $14,000,000.

Since 1954 cooperating plant breeders and entomologists have developed 4 alfalfa varieties resistant to this aphid. The first of these, Moapa, was released in 1957 only 3 years after the aphid was first found. Another resistant variety, Zia, was released in 1958 followed by Cody in 1959, and Sonora in 1963. In addition, Lahontan alfalfa developed previously for resistance to stem nematode is also resistant to the spotted alfalfa aphid.

It is difficult to estimate the cost of developing a new variety since researchers who work on such a project are concurrently working on other problems. In 1961, Hanson (Crops and Soils, Vol. 13, No. 7) estimated that the cost of developing Moapa was around $30,000. It required more time and personnel to develop some of the other varieties but it is felt that $50,000 per variety or $250,000 for the five resistant varieties are conservative estimates.

Before resistant varieties were available, it was necessary to spray alfalfa from 2 to 6 times per year to control the aphid. The cost of the insecticide ranged from $1.18 to $3.12 per acre per application depending on the material used. The cost of labor and equipment to apply these insecticides would add about $1.25 per acre. Figuring that an average of three sprays per year are needed and using the above figures, it is estimated that $10.00 per acre per year would be an average cost to control the aphid.

In the 12-state area mentioned above, resistant varieties are now grown on about 1,509,600 acres or on about 37% of the acreage subject to serious damage. Insecticides are rarely needed on this acreage so the use of these resistant varieties is saving farmers $15,096,000 per year or about $60 for every dollar spent in the development of the resistant varieties. In addition these varieties possess other agronomic qualities that make them more valuable than varieties formerly grown. Their use also eliminates the hazard of pesticide residues. Certified seed of these resistant varieties costs little more than seed of other varieties, so the expense of switching to resistant varieties is very little. One other factor often overlooked is the overall reduction in spotted alfalfa aphid population resulting from growing resistant varieties. Thus, there is less damage to susceptible varieties when some resistant varieties are grown in the same area. Continued research must be conducted in order to incorporate aphid resistance into the many new varieties constantly being developed.

While the growing of resistant varieties of alfalfa will no doubt provide the most effective long range solution to the control of the spotted alfalfa aphid, certain biological agents have and will continue to contribute to the control of this insect and a consequent decreased use of chemicals. These biological agents and their role are discussed by Stern (J. Econ. Entomol. 55(6): 900–904, 1962) as (1) response of native predators to a new and abundant food supply, (2) establishment of imported parasites, and (3) the widespread utilization of integrated control. In addition, there has been an increased incidence, under favorable conditions, of parasitic fungi that infect the aphid.

Several species of insect predators exert an influence on the population of the spotted alfalfa aphid. The convergent lady beetle is the most important. These predators do not necessarily prevent economic damage by the aphid, but they do help to hold the pest in check, and may often obviate the need for chemical control or lessen the frequency of treatments.

Several species of parasitic fungi attack the aphid and, with favorable moisture conditions, are capable of bringing about a marked reduction in the population (Hall and Dunn., Calif. Agr., Feb 1957). Observations in Arizona by Barnes (unpublished) showed up to 97% mortality by fungus diseases during a rainy period in 1957 and that an average mortality of 37% in 22 fields followed heavy rains in 1959.

In 1955 and 1956 three species of parasites of the spotted alfalfa aphid were imported from Europe and the Middle East in a cooperative effort of the California Experiment Station and the U.S. Department of Agriculture. These parasites were reared in large numbers and related in several States. About 600,000 laboratory-reared individuals were released in California in 1956. In 1957 more than six million were collected by machine in the field in California and liberated in other areas

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(Hagen et al., Calif. Agr., Feb. 1958). By the end of 1957 these parasites were established in about 1,000,000 acres of irrigated alfalfa in California. One species, *Praon palitans* Mues., is most promising in areas where the winters are so cold that the aphid is dormant, and another species, *Trioxys utilis* Mues., is most effective in warmer areas where the aphid can reproduce throughout the year. The third species, *Aphelinus semiflavus* Howard, although established, is of less importance (van den Bosch et al., J. Econ. Entomol. 52(1): 142–153. 1959).

From 1955 to 1957 more than 200,000 individuals of the three species of parasites were liberated in Arizona and all of the species became established. However, only *Trioxys utilis* has become sufficiently abundant to be important in the semi-arid areas of that State. This species has spread widely and rapidly and by 1959 occurred in most alfalfa areas in central and southern Arizona where it is a substantial factor in controlling the aphid, providing as high as 90% parasitism in certain fields (Barnes., J. Econ. Entomol. 53(6): 1094–1096. 1960).

California entomologists pioneered in the use of an integrated approach, utilizing both biological and chemical methods, to control the spotted alfalfa aphid. They found that the use of demeton, a systemic insecticide, in heavily infested fields of alfalfa would drastically reduce the number of aphids and was much less destructive than other insecticides to parasites and predators. Thus, the natural enemies were able to exert more influence in maintaining control of the low aphid population remaining after insecticide treatments (Stern et al., Hilgardia 29(2): 81–129. 1959).

We do not have the data necessary to estimate the monetary value of insect parasites, predators, and diseases, as they affect the spotted alfalfa aphid. These biological control agents undoubtedly exert a marked influence in depressing populations of the insect. It has been clearly shown that integrated control—the judicious use of a specific insecticide as a complement to the effect of beneficial insects and diseases—reduces the number of insecticide applications needed and the number of fields of alfalfa requiring treatment.

5. *The screw-worm fly*

The screw-worm is a major pest of livestock and is also a serious pest of wildlife. Prior to the eradication of the screw-worm, this pest was estimated to cost the livestock industry in the Southeastern States about $20 million annually. It is difficult to determine losses precisely but it is estimated that $15 million of the losses could be attributed to labor and $5 million to deaths of animals, weakened animals, and cost of the screw-worm treatments with insecticides.

Research on the development of the sterile-male method of control was initiated about 1950. The total cost for this specialized research

(1950–57) prior to the eradication program in the Southeastern States was only about $250,000 or an average of about $50,000 per year.

Eradication of the screw-worm in the Southeastern States was accomplished by the sterile-male release method in about 18 months. The total cost of the combined State and Federal program was $10 million, or less than the estimated pre-eradication annual loss from the screw-worm. Thus in 5 years (1960–64) since eradication was achieved, the livestock economy in the Southeastern States is estimated to have benefited up to $100 million less the eradication costs, or a return in 5 years of $10 for each $1 invested. Many livestock growers feel that the $20 million estimate of annual loss was too low.

There was no other feasible way to have eliminated the screw-worm from the southeast. The use of insecticides on an area basis was impractical. The volume of insecticide used was not great, since the only use was in smears applied to wounds. The problem lay in the difficulty of finding and treating all infested livestock. It was aggravated by the fact that wild animals, especially deer, served as reservoirs. Even if all livestock could have been completely protected, deer could have maintained the screw-worm population.

Following the successful program in the southeast, the livestock interests in the southwest urged a similar program in their area. Scientists were reluctant to recommend such a program because of the fact that the population in that region was continuous into Mexico, and success would be uncertain because of long-range migration of the insect. However, it might be possible to maintain a barrier zone constantly stocked with sterile flies. Unlike the southeast program, the southwest program was not regarded as an eradication program because of the continuous infestation without known natural isolation barriers.

Livestock organizations estimated that screw-worms cost the livestock industry in the Southwestern States $100 million annually. Estimates from other sources range from $25 to $100 million annually, depending on screw-worm incidence. There are probably four times as many livestock in the Southwestern States as in the Southeastern States. Direct losses, especially from deaths, from the screw-worm probably were proportionally higher in the Southwestern States than in the Southeastern States, because the great size of the ranches and nature of the terrain make it difficult to find infested animals in hiding. Labor and feed costs would also be higher proportionally than in the Southeastern States. A $50 million annual loss would be conservative.

The current eradication effort in the Southwestern States has proven more effective than could have been hoped for in spite of longer range migration than had been anticipated. Experience has shown that a 200-mile barrier is necessary with occasional insects breaching even this barrier. Nevertheless virtual elimination of the screw-worm has been achieved in Texas and New Mexico. At least 10 other states that normally had screw-worms in the summer have been kept completely free. The overall seasonal reduction in Texas in comparison with pretreatment incidence was estimated to be 99.9% in 1964, a negligible screw-worm problem remaining that had no economic significance. Thus, the control program is saving the livestock industry about $45 million a year, a return of $9 for each dollar of the annual $5 million cost.

Research in anticipation of a southwestern eradication program was initiated in 1960 at about $50,000 annual level. Because of increased funds, work was expanded to a $200,000 level in 1961 and 1962. Research costs in 1963 and 1964 were reduced to approximately $165,000 and $135,000, respectively. Thus, over a 4-year period about $750,000 has been devoted to research in support o fthe southwestern eradication program.

Long-range plans are under consideration for pushing the screw-worm further south by temporarily increasing the size of the operation. If this could be accomplished a more strategic place to establish a barrier would be at the Isthmus of Tehuantepec or perhaps eventually at the Isthmus of Panama. In either of these places the length of the barrier would be much shorter than along the Mexico-United States border region. Such a barrier would no doubt cost much less than the present barrier. In addition the livestock industry in most of Mexico would then also profit from the program.

IV. IMPROVED UTILIZATION OF PESTICIDES

A. More Efficient Usage of Pesticides

Despite the intrinsic effectiveness of any insecticidal or fungicidal chemical, its usefulness in insect control depends largely upon its proper formulation and efficient application to the treatment area. The methods and equipment presently used for large scale applications of pesticides to fruit and row crops and to field, forest, and forage are relatively inefficient and unsophisticated. Very limited data indicate that only 10 to 20% of insecticides applied as dusts and 25 to 50% applied as sprays is deposited on plant surfaces so as to be effective against the pest. Far less than 1% is actually applied to the pests themselves. This useful percentage depends upon the type of application, e.g., ground or air, the characteristics of the discharge (dust, spray, or aerosol), the type of plant surface to be treated, and the meteorological conditions. Thus under the most optimum conditions 50 to 75% of the insecticide applied as dust or spray to foliage is useless for pest control and falls to the ground or drifts away from the treatment area so that it becomes an undesirable and unnecessary environmental contaminant.

The uneven distribution of the material which impinges on the foliage is also a source of waste and inefficiency. Variations of 3 or even 5 to 1 in the amount of chemical deposited from bottom to top of fruit trees is common. The variations in swath cross section from aerial spraying may range up to 10 to 1. Thus if the maximum deposit is required for efficient pest control, the effect in the areas of low deposit is poor. Conversely if the minimum deposit gives good control, then the areas of higher deposit represent unnecessary waste.

Although the past 25 years have seen marked changes in pesticide applications directed largely toward the utilization of aircraft and air-blast equipment, much of the improved success obtained is due to the introduction of more efficient pesticides. These with their increased activity, better persistence, systemic and residual fumigant action have decreased the overall dosages necessary and have in many cases made it unnecessary to seek complete coverage. Thus although new developments in equipment have increased the uniformity of discharge and the speed of coverage, other improvements in efficiency are both desirable and practicable.

Examples of desirable trends include the development of a rotary atomizer for aircraft that has permitted the relatively even and rapid distribution of 95% malathion at rates of 2 to 16 oz. per acre. More than 1,000,000 acres of western rangelands have been treated in this way at 8 oz. per acre for grasshopper control and an equally large area for cotton boll weevil suppression. This development therefore permits the effective large scale use of one of the safest and most rapidly degradable insecticides. The development of uniformly sized coated granular formulations with uniform rates of dispersal and release of the pesticide has immensely improved the efficiency of aircraft applications for mosquito larviciding and for other applications and has greatly reduced the drift potential. Granular preparations of systemic insecticides applied by special equipment either with the seed at planting or as side dressing during cultivation have markedly decreased the necessary dosage and materially improved the efficiency of plant protection.

There is an urgent need for team research on the principles involved in pesticide application and on the design of better application equipment. Most entomological or pathological research is carried out by biologists who are admirably equipped to study the effects of chemicals upon insect pests but who must adapt commercial equipment to the peculiar problems of their own research. Few entomologists or plant pathologists have the training, skills, and facilities to study the physical and mechanical principles of pesticide application and to design equipment for specialized purposes or based upon new developments in physics and engineering. The establishment at major agricultural experiment stations of research teams of physicists, engineers, chemists, and biologists directed to explore the field of pesticide application would yield valuable dividends in improving the efficiency of pest control and in decreasing the problems of environmental contamination by pesticides.

B. Narrow Spectrum, Degradable Pesticides

For a variety of reasons, the attention of the chemical industry has for the past twenty years been concentrated on the development and production of pesticides with broad spectrum action and a high degree of environmental persistence. The insecticides presently in the largest scale usage today ($>$10,000,000 lb. per annum)—DDT, lindane, the cyclodienes (aldrin, dieldrin, heptachlor, toxaphene), parathion, methyl parathion, malathion, and carbaryl—are generally effective against a wide range of insect life both destructive and beneficial. DDT, lindane, and the cyclodienes are of low biodegradability and subject to the grave flaw of ecological magnification in food organisms. Parathion and methyl parathion, although rapidly degradable, are of general toxicity to all forms of animal life. Only malathion and carbaryl combine adequate safety to higher animals with suitable degradability. For many applications in integrated control, however, these materials are not of sufficiently narrow spectrum of action against invertebrates. A similar situation exists with the herbicides in the largest scale usage; 2,4–D, the chlorinated ureas, carbamates, and the triazines are all relatively stable compounds and particularly when applied to the soil as pre-emergent treatments or soil sterilants may sometimes persist for embarrassing long periods with deleterious effects to crop plants.

In contrast to the situation with insecticides, most of the commonly used organic and certain inorganic fungicides and certain volatile nematocides do not present serious problems with respect to resistance to degradation and long-term residual effects in the soil.

The microbial community of soil and water is capable of degrading a wide variety of organic compounds. Indeed, it is likely that every natural or synthetic organic molecule will under certain conditions at least be destroyed by one or several species of microorganisms in soil or water. Because these microorganisms are so readily adaptable and acquire the ability to destroy such a vast array of simple and complex organic compounds, it has not been considered essential heretofore to be concerned with the resistance of specific classes of substances to degradation.

The accumulation of the persistent pesticides in soils and their frequent presence in ground water has demonstrated that microorganisms are not biochemically omnipotent in destroying, at significant rates, the persistent materials previously referred to. These microbial failings may be attributed either to structural characteristics of the chemical which may not have "weak links" susceptible to the biochemical degradation processes of hydrolysis, oxidation, and reduction, either generally or under specific environmental conditions. Much more research is needed to elucidate the process of such microbial degradations and the rates of disappearance of various pesticidal molecules from soil and water under a great variety of natural conditions.

It is well within the capacity of the chemical industry which annually screens some 100,000 new organic compounds as potential pesticides, to develop biodegradable pesticides of suitably narrow spectra of action. It is estimated, for example, that there are at least 25,000,000 potentially effective organophosphorus insecticides. A rapidly developing fundamental knowledge of biochemistry and toxicology has suggested a number of avenues of research and development leading to the discovery of compounds having the desired properties. Thus it is known that the safety of malathion to vertebrates results from its rapid conversion in the mammalian liver, through the action of carboxy-esterase enzymes, to the carboxylic acid derivatives which are non-reactive with the biochemical target, cholinesterase. This principle has already been used for the rational development of other "safe" insecticides. Minor molecular manipulations of such general toxicants as parathion have produced compounds such as Sumithion which has a general safety factor of 50 to 100 times that of its parent. Isopropyl parathion has been shown to be virtually non-toxic to bees and to certain beneficial hymenopterous parasites yet retains high activity to numerous insect pests. The fundamental reasons for these processes of selectivity are beginning to be understood and can be applied to the synthesis of other selective "narrow spectrum" insecticides. Similarly modifications of the 2,4–D esters, such as those employing readily hydrolyzable or beta-oxidizable groups, and of the substituents in the triazine ring have greatly improved both selectivity and biodegradability. Controlled reactivity of this sort can be built into countless pesticidal molecules.

Nearly all pesticidal research and development is empirical. It is estimated that only about 30 man years of University and Government research are presently devoted to the understanding of "selective toxicity" and the rational development of new pesticides. Industry has depended largely upon mass screening of compounds for new leads and has been guided by the generally held belief that the demand for narrow spectrum selective materials is too small to justify the present day developmental costs which may be 3 to 4 million dollars per commercial product. These intended industrial goals can be radically altered, however, by increased research into the principles of selectivity, undiscovered potential biochemical targets, and simple, effective ways to demonstrate safety to man, domestic animals, and wildlife. Direct governmental support in the demonstration of chemical safety may well be an important avenue for the stimulation and acceleration of research and development in pesticides.

V. INTEGRATED PEST CONTROL

Integrated control is an ecological approach to pest management in which all available necessary techniques are consolidated into a unified program so that populations can be managed in such a manner that economic damage is avoided and adverse side effects are minimized. It is based on the following principles:

1. The ecosystem as a whole, including the total complex of biological entities and the abiotic environment, is considered as one unit. The major interactions of the various components of the ecosystem must be understood in order to manage pest populations successfully.
2. The population level at which a species causes damage or becomes a nuisance varies from one entity to another. Crops, both plant and animal, vary widely in their abilities to tolerate certain levels of infestation without economic damage. The infestation level at which a pest becomes economically important is determined for each individual species. Control measures are applied only when necessary to keep pest populations below economic levels, rather than aiming at 100% control.
3. No single pest management technique can be relied upon to provide satisfactory solutions to all problems.
4. The application of pest control techniques, especially broad spectrum pesticides, may have undesirable side effects.

Integrated control is a relatively new term for an approach to pest management based on applied ecology which many applied biologists have used successfully for decades. Such an approach can entail use of chemical, biological, cultural, physical, or regulatory techniques. It can take every conceivable form capable of serving the purpose and is limited only by convenience of application and economic feasibility. It recognizes that problems of pest control are inherent in the existence of interdependent species and that such problems reflect a state of competition for limited resources between species, of which man is one. Solutions to these problems may be expected to become more difficult as the needs of an expanding population for increasing quantities of food make it necessary for competition with other organisms to be reduced by establishing short and simple food chains ending with man's consumption of the end product. The greatest hope for satisfactory solutions to these problems lies in the deliberate manipulation of the environment in such a manner that injury by pests will be decreased permanently. At the same time, the manipulative procedures employed must be compatible with man's other requirements. Integrated control is the only concept of pest control based on such an approach.

Most entomologists now agree that the only rational philosophy of pest management is integrated control. However, the adoption of this philosophy has been hampered by two extremes of thought. One holds that it is a prostitution of the profession to use pesticides for control of pests. This philosophy is exemplified by some who hold that pests can be controlled solely by the use of parasites and predators. At the other extreme is the philosophy of those who advocate attempts to obtain 100% local mortality of all potential pests by the use of broad spectrum pesticides on fixed schedules of application without any effort to assess pest populations. A third extreme philosophy which advocates regional eradication of pests has developed rapidly during the last decade. Plant pathologists, in general, would not be strongly committed to any of the three extreme viewpoints.

All three philosophies are the antithesis of the concept of integrated control. However, advocates of each can point to outstandingly successful examples of pest control to illustrate his particular approach. Control of the cottony-cushion scale by the Vedalia beetle, control of the cotton pest complex by application of mixtures of broad spectrum pesticides on fixed schedules of application, eradication of the screwworm from the Southeastern U.S. plus its virtual eradication from the Southwestern U.S. by use of the sterile-male technique, and eradication of citrus canker from the U.S. by host destruction furnish notable examples of successful application of the three philosophies of pest control. Quick eradication of an incipient infestation of an introduced pest eliminates the need for annual insecticide applications over a constantly expanding area.

Application of the principles of integrated control in pest population management can reduce the amount of pesticides being used without decreasing levels of effectiveness or increasing costs.

Although it has come to be generally agreed among applied biologists that integrated control techniques offer the greatest hope for satisfactory solutions to pest problems, such an approach cannot be developed to its full potential until sufficient information is available on two main points: a thorough understanding of the major interactions in the ecosytem, especially population dynamics, and determination of the population levels that cause damage. Sufficient information on these points is lacking for virtually all of our major pests.

Chemical pesticides will be the most dependable weapon of the applied biologist until more acceptable alternative techniques can be developed. The situation in agriculture currently, as well as for the foreseeable future, demands that major reliance for pest control must be based upon repressive applications of chemicals. There are many pest problems today for which no satisfactory substitute exists for the use of chemicals alone.

The trend toward establishment of monocultures will probably be accelerated with attendant acceleration of eruptions of objectionable species, thus making it necessary to have techniques of control available which can be relied upon to control outbreaks of an emergency nature. Thus, it is generally accepted that use of chemical pesticides is indispensable to our society.

However, enough information is available to allow for substantial reductions in the amounts of pesticides used without any sacrifice in efficiency of pest control. Use of integrated control techniques in their simplest form will allow this. For example, recognition that 100% mortality of all pests is not required to prevent economic loss in most crops allows for naturally occurring pest regulating factors such as predators, parasites, pathogens, and weather to exert their efforts. Full use should be made of available resistant varieties, natural enemies, planting dates, rotations, judicious application of fertilizers, sanitation, water management and similar cultural control techniques until the necessary information can be obtained for development of more sophisticated and satisfactory systems of integrated control.

VI. FINDINGS

The subpanel concludes that environmental pollution by pesticides could be materially reduced, in certain cases by a half, with no loss in efficiency in pest control by making use of methods already available. To do so will require recognition that neither 100% control of pests on a crop nor eradication of a pest generally is required to prevent economic loss. The public at large, farmers, and extension and research workers will need to be convinced that virtually complete reliance upon chemical pesticides is a mistake, and that bioenvironmental controls offer great promise. To date this promise has not been realized. Our recommendations are directed to the wider use of those bioenvironmental methods already available, to the discovery of additional methods, and to assuring an adequate supply of trained manpower to accomplish these needs.

A. Extension and Demonstration

No matter how effective techniques of pest control may be, if they are to be adopted and used successfully by growers it will be necessary to educate extension specialists and county agents in their use. Effective use of integrated control will require the re-orientation of almost all extension personnel to enable them to change from a relatively simple concept of a single factor approach to the more sophisticated approach based on principles of applied ecology. This change is necessary if the producer is to be furnished with detailed recommendations and consultation on pest population management. Periodic refresher courses on new developments in pest control should be made available to extension personnel and professional consultants.

The greatest immediate needs are: (1) Recognition of the importance of an economic threshold of pest infestation below which significant damage does not occur, and (2) demonstration of the well-established fact that substantial reductions can be made in the amounts of pesticides now being used without sacrifice in efficiency.

Use of integrated control techniques in their simplest form will allow this. For example, recognition that 100% mortality of all pests is not required to prevent economic loss in most crops allows for naturally occurring pest regulating factors such as predators, parasites, pathogens, and climate to exert their effects. Full use should be made of available resistant varieties, natural enemies, planting dates, rotations, judicious applications of fertilizers, sanitation, water management and similar cultural control techniques until the necessary information can be obtained for development of more sophisticated and satisfactory systems of integrated controls.

B. Research

1. Bioenvironmental programs

Greater emphasis should be placed on research aimed at developing bioenvironmental control programs for pests. The following are specific research areas which are suggested as especially important:

a. *Plant and animal resistance.*—Breeding of pest-resistant economic plants and animals should be intensified. Extensive search should be made for additional sources of host resistance factors. Research on genetic factors and biochemical systems involved in resistance mechanisms should be emphasized in connection with attempts to incorporate resistance into acceptable commercial varieties. An appraisal of genetic potential for variation in virulence in given pathogens should accompany evaluation of genetic factors for resistance in host species.

b. *Parasites, predators, and pathogens.*—Research on the uses of parasites, predators, and pathogens in pest control should be intensified. Studies on the principles of parasitism and predation, on the augmentation and conservation of beneficial species currently present in this country, and on the importation of additional species are especially important. Ecological studies on soil microorganisms should be expanded to determine how better to manage antagonistic microorganisms for the reduction of soil-borne plant pathogens.

c. *Genetic manipulation and sexual sterility.*—The possibility of controlling pests through genetic manipulations deserves much more attention. Deleterious genes should be identified and techniques for their use studied. Lethal genes, male producing genes, and genes which control the number of generations per season are examples of promising fields for study.

Sexual sterility induced by exposure to ionizing radiation or radiomimetic chemicals has provided a new principle of insect control. The subpanel recognizes the great potential of this development and urges that all necessary support be provided for determining its proper place among the tools available for pest control. However, it is convinced that the present effort being directed toward the specific goal of pest eradication by this method is disproportionately great.

d. *Attraction and behavior.*—Hormones, pheromones and other chemicals which influence behavioral and physiological changes in pests or hosts should be investigated more intensively. A limiting factor is the number of chemists and biochemists who are engaged in identifying, synthesizing, and producing chemicals which cause these effects. Cooperative arrangements should be made to utilize this chemical competence wherever it can be found.

e. *Environmental manipulation.*—Management practices, such as plant spacing, water management, sanitation, soil preparation, crop rotation and fertilization and mixed-plant-culture in crops and forests profoundly affect pest populations. These practices should be studied with a view to elucidating biological principles that can be applied to minimize pest populations.

2. More effective use of pesticides

a. *Specificity and degradability in pesticides.*—Research should be encouraged toward the development of pesticides with greater specificity, additional modes of action, and more rapid degradability than many of those in current use.

b. *Improved application techniques.*—Pesticidal effectiveness should be increased and total environmental contamination decreased by further research leading to the more efficient application of pesticides to the target organisms.

3. Integrated control

The Subpanel is convinced that the increasingly serious problems of pest control cannot be solved by excessive reliance upon pesticides, biological control, or any single available technique. For success in developing reasonably long-term rather than extremely short-term solutions to the problems, all available techniques must be integrated into a unified approach. Our approach to pest management must be based on much more complete knowledge and understanding of the complex interactions of major components of the ecosystem and population dynamics of the pests than is currently available. We are also convinced, however, that enough knowledge is now available to begin to apply the techniques of integrated control in their simplest forms to pest management; and that use of these techniques will result in substantial decreases in pollution of the environment without a decrease in effectiveness of control obtained.

Since the success of the integrated control concept depends upon the understanding of population processes, studies of population dynamics need to be greatly expanded. Development and testing of population models should be undertaken for representative types of organisms. Information developed from such studies should lead eventually to the ability to predict population trends accurately. The vast amount of diverse types of information required for an understanding of population processes will make it necessary to have the services of ecologists, physiologists, biomathematicians, microclimatologists, geneticists, microbiologists, biochemists, chemists, morphologists, and taxonomists.

C. Teaching and Training

1. Training new scientists

In recent years many applied biologists have been unduly influenced by philosophies of pest control based on a single approach, e.g. the sole reliance on pesticides or on parasites and predators or on eradication. Since any one of these approaches has critical shortcomings, it follows that conventional training in the specific narrow areas of economic botany, entomology, nematology, plant pathology or fish and wildlife management can no longer be relied upon to produce the teachers and researchers of tomorrow's applied biology. Scientists to work intelligently in the bioenvironmental field will not only need broad training in the biological and physical sciences, but also will require special skills in physiology, ecology, and biochemistry. Institutions engaged in training such scientists will need staff with the most diverse scientific backgrounds, more varied equipment and facilities, and ample support for programs for graduate and post-graduate training. In spite of the intellectual challenge, the manifold employment opportunities, and the tremendous scope of the biological problems to be solved, the numbers of students entering these fields are relatively small. Thus, it is imperative to provide better financial support for facilities and training programs and a more attractive approach to recruiting in order to insure that each area of applied biology will attract the capable and promising students it needs.

2. Retraining and reorientation

Retraining and reorientation of present teaching and research workers is one facet in implementing the bioenvironmental program. The system of sabbatical leaves provided at many universities should be extended to state and Federal employees to enable applied biologists to study in institutions where special competence is available. In addition, a limited number of training grants should be made available for retraining some of the teaching and research workers.

D. Needed Support

The subpanel is convinced that—

The level of support for bioenvironmental research in view of its potential value is inadequate. Limited progress can be made by redirecting some of the personnel now working on pesticide investigations toward developing more diverse programs of pest control. The inadequate level of support for bioenvironmental studies, however, can only be overcome by significantly increasing our national investment in this area of work.

An increase in trained personnel is basic to strengthening this program. We recommend an annual increase of 14% in the total effort presently engaged in bioenvironmental pest control. Over a 10-year period this would increase research manpower from 1400 to 3500.

The proposed increase of about 200 new scientists at the doctoral level for the first year is limited by supply rather than needs. It takes account of the present availability of high caliber staff and assures recruitment of scientists trained in all disciplines appropriate to bioenvironmental pest control research, including: ecologists, physiologists, biomathematicians, geneticists, microclimatologists, microbiologists, biochemists, chemists, toxicologists, morphologists, and taxonomists. Many would have been trained as entomologists, economic botanists, and in the other areas specially concerned with pest control, but those with broad training would contribute valuable diversity of approach.

This subpanel recommends that about one half of the support for personnel be focused on a Department of Agriculture supported traineeship program at colleges and universities. Scientists trained for bioenvironmental work will need both depth and breadth in training in the biological and physical sciences. This can only be accomplished with a well planned and an adequately supported traineeship program. Legislative authority for the Department to support such a program is thus essential.

The remaining support for 100 new scientists is for research and should be divided equally between the State experiment stations at land grant institutions and appropriate Federal agencies (principally in the Departments of Agriculture and Interior).

The funds invested in the traineeship program and research program at educational institutions pay double dividends because both training and research programs are strengthened. The investment channeled in this manner is especially important in the initial years of the program when manpower pressures will be particularly severe.

The funds for personnel must be reinforced with funds for facilities which are at present lacking in our land grant institutions and other educational institutions.

E. Operating Practices

Unnecessary use of pesticides should be avoided whenever possible. Substantial reduction in insecticide use, in specific cases as much as 50%, can be made by applying our present knowledge of pests and their control. The same is true of many fungicide and herbicide programs. The two essential steps in this reduction of pesticide use are:

(1) Replacement of wasteful "routine-treatment" schedules by "treat-when-necessary" schedules.

(2) Recognition that 100% control of pests is *not* required to prevent economic losses.

Treat-when-necessary spraying often requires more judgment, but lowered costs for pesticides can often make the provision of specialized advice economically worthwhile.

All possible steps should be taken, especially by all agencies of the Department of Agriculture, to encourage such modification of pesticide practices.

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