WASTES IN RELATION TO AGRICULTURE AND FORESTRY

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WASTES IN RELATION TO AGRICULTURE AND FORESTRY

By Cecil H. Wadleigh
Director, Soil and Water Conservation Research Division
Agricultural Research Service

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PREFACE

In the preparation of this report, four considerations were kept in mind: (1) How are agriculture and forestry adversely affected by wastes? (2) What wastes are contributed by agriculture and forestry? (3) How has research in the U.S. Department of Agriculture and the State agricultural experiment stations contributed to the amelioration of waste problems? (4) What problems in waste production and management continue to need attention by agriculture and forestry? Commentary on these four considerations comprises the corresponding four appendices to the report per se.

The advice and helpfulness received from the many, many people in the U.S. Department of Agriculture and the State agricultural experiment stations during the compilation of this report are deeply appreciated. The compiler accepts full responsibility for all errors of omission and commission found herein.

Cecil H. Wadleigh,
Director, Soil and Water Conservation Research Division,
Agricultural Research Service,
Beltsville, Md.

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WASTES IN RELATION TO AGRICULTURE AND FORESTRY

INTRODUCTION

An enduring cliché proclaims that the only certainties in man's existence are death and taxes. Massive evidence is being accrued in our affluent society that a third inevitable should be added—wastes.

Wastes are ubiquitous. They occur on the farm and in the factory, in the high-rise apartment and on the rural estate, on the city streets and the open highway, in murky mines and verdant forests, in sedate offices and carefree parks, in the waters of lakes and streams, and in the air around us.

One can take the optimistic view that these wastes are merely resources for which we have not found a use. This view offers hope that with understanding, adequate technology, and the proper economic and legal constraints, there is a possibility that the problems inherent in the production, management, and disposition of wastes may be resolved. This is a good objective. But the probability of attainment is another matter.

We set great store by the operations of the marketplace. As is proper, net profit is a key guideline to decision. In the process, that which was previously a resource may become a waste. Waste disposal problems proliferate.

Within the agricultural economy, animal manures provide a case in point. Only a few decades ago, manure was esteemed as a prime source of soil fertility. Much technical information was available on proper handling to attain maximum benefits on the land. Even today, the "Plain People" of the Pennsylvania Dutch region carefully husband manure supplies toward maintaining highly productive lands. But these people have virtually a religious dedication to conserving and improving their land and their farms. They are, first of all, devoted stewards of the land, and only secondarily participants in the marketplace. They have no problems on how to dispose of animal wastes.

But these conscientious Amish are exceptions to the conventional thinking in commercial and agricultural enterprises.

With the abundant availability of synthetic nitrogen fertilizers at low cost following World War II, it became more economical for the farmer to supply plant nutrients to his fields from the fertilizer bag rather than meet the expense of hauling manure from barnyard or feedlot. Further, the general trend in mechanizing and streamlining production was given impetus by labor shortages during and after the war. Poultry enterprises, cattle and hog feedlots, and dairies became enormous by previous standards. Manure accumulated in vast quantities. Disposal of the stuff became a problem in terms of both engineering efficiency and esthetics.

Whether wastes are looked upon as resources, or resources as wastes, is, in the words of the Canadian Council of Resource Ministers, "a matter of attitudes."

Drive along a rural road on a balmy Sunday afternoon. Cast an eye along the roadside. All to be seen is not natural beauty. Many a traveler has obviously contributed to the mess of cans, bottles, and other assorted refuse along the way. The reasoning, or lack of reasoning, that compels humans to contribute to this desecration of the landscape would make a most interesting study.

As mentioned previously, disposition of wastes is a "matter of attitudes." There is a venturous, covetous streak not far below the surface of our people; a streak that erupts now and then into wholesale exploitation of resources. We read of the appalling slaughter of buffalo merely for sport or for their hides during the latter part of the 19th century. We see in the cutover areas of the Lake States the dismal sequel to the rapacious slashing of virgin forests in that region around the turn of the century. We see ugly scars upon the landscape in the form of barren and hideous spoil banks from irresponsible strip mining of years ago—spoil banks that even now are contributing silt and acid to streams. There is in all of these examples an utter disregard toward wastefulness.

Fortunately, there arises now and then from the multitude a man of great stature and wisdom who shows us the errors of our ways in exploiting resources and creating great wastes.

Professor E. W. Hilgard, the distinguished soil scientist and former geologist for the State of Mississippi, gave a hard-hitting lecture on poor farming practices, erosion, and sedimentation before the Mississippi Agricultural and Mechanical Fair Association at Jackson on November 14, 1872. He was gravely concerned over the poor husbandry practices of the farmers on the brown loam soils of the State—practices that were ruining the land, eroding and gullying the landscape, and silting the streams. He told his audience frankly: "If we do not use the heritage more rationally, well might the Chickasaws and the Choctaws question the moral right of the act by which their beautiful parklike hunting grounds were turned over to another race, on the plea that *they* did not put them to the uses for which the Creator intended them." It was another 75 years before effective countermeasures to land deterioration and stream siltation began to be taken in Mississippi.

One of the real giants in the history of the U.S. Department of Agriculture was Dr. Harvey W. Wiley. During the latter part of the 19th century, Wiley was Chief Chemist in the Department and undertook his classic studies on food adulteration. He found endless cases in which food processors were not careful to distinguish between that which was pure food and that which included an adulterant or even wastes. Fortunately, Wiley was also an excellent publicist and skilled agitator. Under his skillful touch, Congress passed the first Food and Drug Act in 1906.

One may not mention forest conservation—the elimination of wastefulness in forestry—without reference to the work of Gifford Pinchot in the early 1900's. Pinchot launched a crusade for sound forest management and harvesting practices, watershed conservation, disease control, and fire protection. It is regrettable that so much exploitation and waste in lumbering had to take place before the need for a Pinchot was recognized.

When the drought years of the thirties depleted the soils of cover and made vast expanses susceptible to the ravages of wind and water, another dynamic leader was at hand—Hugh Hammond Bennett, Chief of the newly formed Soil Conservation Service. He ably dramatized the tremendous duststorms of 1935 as not only depleting the soil on the Great Plains, but also creating enormous pollution of the atmosphere. He dramatized the tremendous soil losses from high runoff and the consequent contamination of streams with silt. The people were with him.

We have touched upon a few instances to emphasize the point that coping with problems in the production, management, and control of wastes related to agriculture and forestry is not a simple matter. It goes beyond the development of new and improved technology; beyond the sophisticated analyses of benefits and costs in the economic arena; beyond the police power of legislation.

One must take into account the general attitude of people towards various wastes: their appreciation for and interest in esthetic values, their concern over health hazards implicit in wastes, their willingness to accept restrictive regulations in lieu of private privileges, and their willingness to pay the added costs of maintaining a better quality of their environment.

If public agencies develop active programs to alleviate environmental contamination, the taxpayer usually pays the bill. If industry modifies its processing procedures to eliminate or abate production of wastes, any added cost will eventually be passed on to the consumer. If agriculture and forestry increase costs of production to reduce wastes, or the adverse effects of wastes, then in due course the consumer will find an adjustment in the price tag.

In addition to the question of how much control of wastes we want, one must ask how much control do we want to pay for? Beyond doing that which is economically justifiable, how far do we go in meeting health standards and social desirability? We must differentiate between the things we would like to do, those we should do, those we must do, and those we can do.

Compromises will need to be made among various objectives. For example, people express concern over pesticide residues. They want no part of the possible ill effects from accidental or inadvertent ingestion of these chemicals. They are just as adamant against biting into an apple and finding half a worm. Both extremes are easily avoidable.

Economic and social goals may need to be abetted by legal constraints.

There must be a mutuality of interplay between the course of technology pertaining to wastes and development of the conflux of legal-social-economic objectives and restraints. Urban people sometimes build homes out among dairy farms. There are cases in which the suburbanites who did not like the odors of dairy farming succeeded in imposing legal constraints on the farmers, thereby incurring the farmers' economic and social distress.

Consideration must be given to zoning laws that protect agricultural areas from untoward encroachment. California has shown the way with the passage of A.B. 2117—the California Land Conservation Act of 1965.

There must be enlightened leadership. Those graced with the good fortune to stand on mountains and discern the bright horizons of a pristine environment have the right—even the duty—to help turn unawareness and indifference into understanding, concern, and action.

Nothing gets done without someone being motivated.

APPROACH

This report provides terse consideration to 10 major categories of entities that contaminate the air, water, and soil of our environment in relation to agricultural and forestry endeavor (see app. I). These categories are radioactive substances, chemical air pollutants, airborne dusts, sediments, plant nutrients, inorganic salts and minerals, organic wastes, infectious agents and allergens, agricultural and industrial chemicals, and heat. A brief discussion is also presented on economic evaluation.

A few comments are offered on each category about the importance of the problems, the extent to which agriculture and forestry are involved, contributions that have been made to ameliorate the problems by research in agriculture and forestry, and an indication of the need for new or better information and technology towards meeting pressing problems. More complete discussion is presented in the four appendices.

It is imperative to recognize that different kinds of wastes may not be completely allocated to distinct pigeonholes, such as appears to be the procedure in this report. There are many interrelated effects.

The consequences of animal wastes moving into a stream must be considered with reference to the burden of oxygen-demanding organic wastes that the stream may be carrying from sewage, municipal garbage, processing plants, and dead or dying algae and other aquatic life. Discussion of animal wastes cannot be wholly discrete from that of infectious agents of animal origin. Both may arise from the same barnyards, feedlots, and poultry houses. The effects of animal wastes may not be discussed as something quite apart from plant nutrients. Obviously, animal wastes are a good source of nitrogen, and there is evidence that elevated levels of nitrate found in some ground waters are associated with accumulations of these wastes. Barnyard runoff may carry as much as 1,000 p.p.m. (parts per million) of phosphorus.

In discussing organic wastes as contaminants of water, one must recognize the importance of heat as a water pollutant. The elevated temperature of a stream that has been diverted to provide cooling for industry can have just as adverse an effect on poor assimilation of wastes as an increased load of biochemical oxygen demand.

A sediment burden in the water may lower oxygen content and thereby accentuate the adverse effects of organic wastes bringing in biochemical oxygen demand. Plant nutrients moving into waters may not be fully evaluated without considering the amounts adsorbed on the sediment being carried. Sediment from surface soils carries phosphorus into streams. Nutrient-poor sediment from the subsoils of construction areas may deactivate the soluble phosphate of a stream by tenacious adsorption. Sediment may be the prime carrier of chlorinated hydrocarbon insecticides that are occasionally detected in streams.

The interplay of these various categories of wastes in their impairment of our environment related to agricultural and forestry endeavor must be evaluated. The full perspective of waste problems cannot be gained by wearing blinders.

Radioactive Substances

Radioactive substances, which are possible contaminants of air, water, and soil, may be produced by several sources. Radioactive wastes resulting from mining and refining radioactive minerals such as uranium and thorium may wash into streams. There may be accidental or unauthorized releases of radioactive isotopes from power reactors or from research laboratories. There is atmospheric fallout from testing nuclear weapons. This has diminished with the existence of the test ban treaty involving the United States, the U.S.S.R., and Great Britain. Unfortunately, all nations having nuclear capability are not members of this treaty and therefore do not adhere to the ban. Potential for radioactive contamination under nuclear war staggers the imagination.

Agriculture and forestry contribute but very little to either actual or potential contamination from radioactivity—some phosphate rocks used for fertilizer production contain very low levels of radioactive uranium and thorium. Agriculture has experienced minor adverse effects from this source of contamination. During the spring of 1966, milk was confiscated in Nevada because of an unduly high level of iodine-131 in the area as a result of accidental venting during and following an underground weapons test. Potential damage to agriculture from radioactive fallout could be serious under unrestricted testing of nuclear weapons. Under nuclear warfare, the situation would be catastrophic.

Much information has been attained through research on the behavior of radionuclides in soils, plants, and animals. Attention was especially focused on the behavior of strontium-90. This isotope justifies serious concern because of its relatively long half-life and its chemical behavior so analogous to that of calcium in soils, plants, bones, and milk.

Engineering research has designed equipment to decontaminate soil that has been surface-coated with radioactive fallout. One procedure involves skimming off the contaminated surface, and another involves burying the surface by plowing deeply—2 feet—and adding a chemical root inhibitor to the buried layer.

There is need of much better information on the duration and effects of retained fallout particles on plants to improve validity of prediction of radiation doses to plants and animals. There must be much better techniques in terms of effectiveness, cost, and rapidity of operation for decontaminating forage, food plants, and soils. Research should ascertain the possibilities for specific genetic lines of feed and food plants that have the physiological capability to exclude radioactive elements.

Agriculture should support a relatively modest program of research on measures counteractive to radioactive wastes. If ever the unfortunate time arrives when such information is urgently needed, it will be too late to start.

Chemical Air Pollutants

Airborne chemical contaminants include such substances as sulfur dioxide, fluorine, carbon monoxide, ozone, nitrogen oxides, peroxyacetylnitrate, sundry hydrocarbons, and just plain smoke. Thirty million tons of sulfur dioxide are spewed into the atmosphere over the United States every year from smelters, use of fossil fuels for heat and power, and burning refuse. Seventy-five million tons of the other chemical contaminants are emitted into our atmosphere by exhausts from internal combustion engines, industrial mills, refuse burning, home heating, forest fires, and agricultural burning.

Crop plants, ornamentals, and trees are subjected to chronic injury in and near every metropolitan area. Livestock have been afflicted with fluorosis near certain industries, such as steel, aluminum, and phosphate mills. In southern California acute injury is widespread. About 14,000 square miles in that State are now afflicted with airborne toxicants (*82*).[1] Losses to agriculture and forestry in the United States because of the flood of these noxious chemicals into the atmosphere are estimated as exceeding $500 million annually (*88, p. V–137*).

Agricultural endeavor makes a small local contribution to chemical air pollution in the form of hydrocarbons and smoke emitted from burning crop residues in fields. Major forest fires produce tremendous quantities of smoke. Fires in our forests produce upwards of 500,000 tons of hydro-

[1] Italic numbers in parentheses refer to Literature Cited, p. 108.

carbons annually. In nearby areas, these hydrocarbons can become more serious by being converted to photochemical toxicants.

During the past 20 years, considerable research has been underway on (a) evaluating the relative sensitivity of different kinds of economic plants, trees, and livestock to various levels of specific air pollutants; (b) determining the actual components in polluted air that cause damage; (c) measuring the acute and chronic effects of given levels of specified pollutants in different plants and animals; (d) developing management practices that would minimize or ameliorate the adverse effects of given air pollutants; and (e) developing and selecting varieties of crops and trees with higher tolerance to air pollutants. Very promising research is underway towards prediction and abatement of forest fires due to electrical storms.

In meeting the problems inherent in the damages of airborne toxicants to agriculture and forestry, it would be most advantageous if these chemical effluvia could be eliminated at the source. Some accomplishment has been attained on this objective—for example, virtual discontinuance of sulfur dioxide emanation from the smelters in Trail, British Columbia, Canada—and more certainly will be accomplished. But there is little hope that this approach will adequately cope with the growing problems of air pollutants in agriculture and forestry.

There is an urgent need to improve the validity of the techniques available for assessing damages from air toxicants. Information is particularly weak for assessing chronic damages.

Little is known of the actual physiological mechanisms by which the harmful effects of air toxicants take place. Ignorance on these fundamental problems is a roadblock to valid understanding of damages and possible countermeasures.

One of the most promising avenues for attaining countermeasures to air toxicants is that of developing and selecting species, varieties, and genetic lines of crops, ornamentals, and trees that are tolerant, if not immune, to the major effects of chemical air contaminants.

There is evidence that expansive areas of vegetation, particularly woods, have a cleansing action on toxic wastes in the air. Much more information is needed on this effect.

The possibility of developing chemical protectants against air pollution damage needs much further exploration and study.

Even though total contribution to air contamination from forest fires seems relatively small, the total damages from these fires go far beyond their contribution to air pollution. All possible effort to develop better technology and better information to curb such fires should be pursued.

In view of the magnitude of the growing problems, and the paucity of research effort on air toxicants by agriculture and forestry in the past, it is urgent that research effort on the problems in this general area be expanded and pursued without delay.

Airborne Dusts

During the average year, 30 million tons of natural dusts enter the atmosphere. Most of this arises as soil blowing from inadequately protected fields under cultivation, deteriorated rangelands, and sand dune areas. A small amount arises from highway and industrial construction sites. Susceptibility to wind erosion is the dominant problem on 55 million acres of cropland in the United States.

Industries such as cotton ginning, alfalfa mills, lime kilns, cement plants, smelters, and mining operations release 17 million tons of dust into the atmosphere annually. This dust often coats the foliage of nearby crops, ornamentals, and trees. Growth and quality of product may be impaired.

Windblown soil not only robs the land of good topsoil, it also becomes a serious air pollutant. Respiratory ailments of man and animals are accentuated. Eyes are afflicted. Highway and air vision is impaired. Machinery is scourged by paint removal and dirt in bearings. Offices, homes, schoolrooms, and factories are completely permeated by dust. Pesticides may be carried long distances. Farmsteads, fence rows, ditches, and roads may be partially buried by drifts of dust.

Wind erosion research and its application has contributed importantly to the effectiveness of today's conservation and other advanced farming methods in reducing the threat of future "Dust Bowls" in the Great Plains. Meteorological records show that the drought in Kansas during the mid-1950's was just as bad as that during the 1930's. Yet records show that soil blowing was not nearly as serious during the fifties as it was 20 or 25 years earlier. At Dodge City, Kans., in 1936–37, there were 120 days of blowing dust. At the same location in 1956–57, under comparable meteorological conditions, there were only 40 days of blowing dust.

Research has developed a wind erosion prediction equation used by action agencies to provide technical guidance in farm and ranch planning.

In expanding the research on the problems of soil blowing in the Great Plains consideration must be given to various concepts for describing and delineating the influence of atmospheric wind and turbulence on soil detachment and transport; effect of wind and related atmospheric factors in soil drying and creation of soil surface conditions susceptible to high rates of detachment; modification of tillage practices and machines to provide effective and lasting crop residues and soil cloddiness conditions to resist soil detachment; the tolerance of crop plants to wind abrasion; the development and selection of better strains and varieties of grasses and crops to tie down soils susceptible to blowing; design of better windbreaks; and selection of better shrubs and trees to serve as windbreaks.

Much better information is needed on techniques to curb dust production on large feedlots.

Research has developed greatly improved screens to permit continuous operation of cotton gins while reducing lint fly. But much-improved engineering technology is needed to effectively filter the air from cotton gin operations as well as to handle trash without contaminating the air with dust or smoke or carrying diseases and insects back to the fields.

The current emphasis by the Federal Government to do whatever is feasible to attain clean air over the United States must include research to control or abate dusts from agricultural sources.

Sediment

Sediments are primarily soils and mineral particles washed into streams by storms. Although most of the sediment comes from land, a relatively small amount is contributed from the spoil banks of mining operations and smelters.

Some 4 billion tons of sediment are washed into tributary streams in the United States each year. About one-fourth of this sediment is transported to the sea. Water erosion is the dominant problem on 179 million acres of cropland and a secondary problem on an additional 50 million acres. At least half of the sediment is coming from agricultural lands. Some 30 percent of total sediment delivery arises as geologic erosion such as that found on the tributaries of the Missouri, Colorado, Rio Grande, Red, and Arkansas Rivers. For example, the Badlands of South Dakota are a tremendous source of geologically eroded sediment. Five to ten percent of the silt delivered comes from forests and associated rangelands. Streambanks erode and streambeds degrade, but aggradation may fully compensate for sediment losses. Urban, industrial, and highway construction sites and roadbanks also contribute eroded materials. Although such sources make but a small contribution to the national sediment delivery, they may contribute over half of the silt to the streams in a local watershed undergoing intensive construction activity.

Research conducted on many different soils varying in characteristics, slope, cover, and prevailing climatic conditions provided a mass of empirical data on soil loss as induced by rainstorms. The data were subjected to complex mathematical analysis by a digital computer which enabled the formulation of a universal erosion equation. This equation aids action agencies to predict what soil losses will be on a given soil of specified slope, under varying cropping conditions, with a given rainfall energy input.

Watershed research has shown that land cover is the major deterrent to sediment delivery into tributary streams. Extensive empirical information has been accrued on the entrainment, transportation, and deposition of sediments in the upstream watersheds towards making valid predictions of sediment accumulation behind flood-detention structures.

Improved technology in logging and construction of forest roads has reduced sediment delivery from forestry operations.

Forestry research on the abatement of wild fires (fires not started by man) has made a major contribution in diminishing sediment delivery from forested lands. Soil loss from a burned area is frequently tremendous.

Most all research in this area has been empirical. There is an urgent need for fundamental studies on the energetics involved in the detachment and movement of soil particles by raindrop splash and flowing water. Surface sealing and related phenomena that result in decreased infiltration need to be understood in order to be corrected. Water intake and movement through soil during freezing and thawing is especially important, but the interplay of forces involved is inadequately understood. Control practices need to be developed and integrated into systems that will reduce runoff a maximum amount and provide for the removal of surface drainage without appreciable erosion.

There is an urgent need for new concepts and procedures for identifying critical sediment sources and predicting sediment delivery from areas affected by climatic factors, soils, geology, topography, stream channel characteristics, and watershed protection measures. Special emphasis must be given to developing better technology for stabilizing and revegetating gullies, spoil banks, roadbanks, strip mines, overgrazed rangelands, forest burns, and badly disturbed construction sites.

Research towards diminution of forest fires and overgrazing of rangelands would greatly contribute to reducing sediment delivery.

Criteria for engineering design of sediment traps and debris basins could stand much improvement.

There needs to be a much better understanding of sediment transport in tortuous upstream tributaries, with emphasis on better understanding of the hydraulic forces necessary for design and maintenance of stable stream channel systems.

Limited information is available on the role of sediment as a transporting agent for pesticides and other chemicals.

Since comprehensive river basin planning is moving forward rapidly under the leadership of the Water Resources Council, expansion of effort to gain new or better information and technology on sediment problems in upstream watersheds should keep pace.

Plant Nutrients

Surface Water

Plant nutrients, as here used, are inorganic chemicals essential for the mineral nutrition of plants. When present in surface waters they may become contaminants in that they provide for unwanted growth of aquatic plants. Nitrogen and phosphorus are the two elements principally involved, but potassium is sometimes involved.

The algae "blooms" that frequently develop in nutrient-laden waters cause an off-taste and an unpleasant odor to the water. When streams and lakes reach the "green soup" stage of algae growth, the odor of decaying plants becomes offensive, fish are killed because of reduced oxygen content of the water, and there is interference with boating, swimming, and water skiing.

These nutrients enter surface water by discharges of raw or treated sewage, some industrial wastes, and runoff and seepage from land. Barnyards and feedlots yield nutrients. Use of chemical fertilizers on lands is sometimes suspected as being a significant source of plant nutrients found in streams and lakes. Such growths can ruin farm ponds. They harm the usefulness of the permanent pools of upstream watershed structures. Along with other water weeds, they can seriously impair the flow in irrigation and drainage ditches.

Detergents used in households and industry provide an abundance of soluble phosphate to sewage effluent. Evidence indicates that sewage delivery of phosphate amounts to 2 pounds per person per year. If the sewage effluent from 1 million people enters a stream with an average annual flow of 5,000 cubic feet per second, the average phosphorus content will be 0.2 p.p.m. This level is more than ample to enable excellent growth of algae without the phosphorus from other sources.

Each 1,000 tons of suspended sediment can be expected to carry about 1,000 pounds of phosphorus, most of which is in the adsorbed or fixed state unavailable for plant growth. Depending on the source, usually not more than 10 percent of the phosphorus on sediment is available for plant nutrition. Sediment derived from subsoils low in phosphate may actually deactivate much of the soluble phosphorus in a stream.

Phosphorus is moving into streams from agricultural lands. Many years of research by soil scientists using lysimeters and other techniques show that only infinitesimal amounts of phosphorus move through the soil in the soluble state. Some of this may be carried as complex organic molecules. Surface runoff may well carry phosphate as part of the suspended particles. Barnyard wastes may carry 1,000 p.p.m. of phosphorus. Water in the drains from fertilized fields in irrigated areas in rare instances have been found to carry as much as 1 p.p.m. of phosphate.

Very little modern information is available on the phosphorus content of runoff from soils varying in geochemical characteristics, treatments with chemical amendments and fertilizers, cultural practices, and hydrologic conditions.

Far more study is needed on methods of determining phosphorus content of water in terms of biological significance. Total phosphorus values are meaningless. We ought to be able to distinguish four different states of phosphorus in water samples: (*a*) That which is in true solution as orthophosphate; (*b*) that which is in solution in a nonpolar form as an organic polyelectrolyte; (*c*) that which is adsorbed on suspensoids; and (*d*) that which is a component part of the mineral of suspensoids.

In view of the widespread concern over eutrophication of surface waters, a major effort should be launched as rapidly as possible to attain evidence as to the cause and effect sequence. Even on large bodies of water such as Lake Erie, there is frequent accusation that use of fertilizer on farmers' fields is the causative source. The dearth of accurately accrued quantitative and qualitative information on phosphorus in runoff water from the land does little to allay argument.

Nitrate in Ground Water

Nitrate in drinking water can cause methemoglobinemia in babies—"blue babies." It is also toxic to livestock. The biochemical status of a baby's stomach readily reduces nitrate to nitrite, as does that of a ruminant. Thus, one hears of nitrate in well waters causing "blue babies" or nitrate poisoning in ruminants. Cases of "blue babies" associated with nitrate in well waters have been reported in the Middle West.

When nitrate is found in ground water, the sources may be several—sewage or septic tank effluent, feedlots or barnyards, field fertilization, or the natural accumulations such as found in the caliche of semiarid regions. The Public Health Service Standards (*125*) specify that the nitrate-nitrogen content of drinking water should not exceed 10 p.p.m.

Research evidence in Missouri indicates that virtually none of the nitrate in ground water comes from field fertilization. Evidence from a secluded valley under concentrated study in California indicates that sewage effluent and nitrification processes in the semiarid soils may be the main sources of the rather high levels—100 p.p.m.—of nitrate found in the ground water. Studies in Hawaii on high nitrate levels in the aquifer indicated that nitrogen fertilization of irrigated sugarcane fields may be the source.

The diversity of observations and conclusions with respect to nitrate from various sources moving into ground water indicates the need for better information that may be gained by expanded field studies. The degree to which nitrite may be associated with nitrate during downward percolation needs careful study. The very modest level of research in this area needs to be increased appreciably to gain reliable answers to pressing questions.

Inorganic Salts and Minerals

This category includes neutral inorganic salts, mineral acids, and fine suspended metal or metal compounds. These substances enter into streams or onto soil from the effluent of various smelting, metallurgical, and chemical industries; from drainage from mines; and from natural sources. Industrial sources of these chemicals are comparatively minor in relation to total dissolved solids carried by the Nation's streams.

The Public Health Service estimated in the early 1930's that 2.7 million tons of sulfuric acid were produced annually by mines and delivered into tributary streams. Although the amount of acid delivery from mines has decreased, awareness of the problem has increased. Acid mine drainage kills fish and spoils water for domestic, livestock, irrigation, and recreation uses. Agriculture and forestry have an interest in the elimination of this problem.

Salts normally present in the soils and geologic materials of arid regions move into streams and onto irrigated farms. Colorado River water at Yuma, Ariz., carries about 1.2 tons of salt per acre-foot. Average annual flow of the Colorado at Hoover Dam is about 15 million acre-feet annually. At this location, the river transports more than

15 million tons of salt. Three thousand freight trains, 100 cars long, would be needed to carry this much salt. Much of it comes from geological deposits or accumulations in arid lands. It means that a farmer in the Imperial Valley of California who applies 5 acre-feet of irrigation water to his crops, also applies 6 tons of salt per acre. Hence, he must remove at least 6 tons of salt per acre in the drainage water from his farm.

Salinity is a hazard on about half the irrigated acreage in the Western States. Crop production on one-quarter of this acreage is already impaired by salt-affected soils. Production is threatened in irrigated projects the world over.

Over the past couple of decades, research has enhanced the capability of coping with salt problems affecting agriculture.

Improved procedures for evaluating water quality for irrigation have been developed, using electrical conductivity as the primary criterion and sodium-absorption-ratio as the secondary criterion.

Far better standards have been developed for leaching procedures in the reclamation of soils and for leaching requirements during continued management.

Much advancement has been attained in understanding the physico-chemical behavior of salt-affected soils.

Since water is the vehicle by which salt moves in soil, an understanding of the physical principles of water movement is absolutely essential. Excellent progress has been made in measuring the energetics of water retention and movement in soils.

Good progress has been made in characterizing the salt tolerance of important crop plants.

There is a real need to develop better means of assaying salty-soil problems as related to characteristics of irrigation waters. The relationships are very complex, and oversimplification can lead to poor technical guidance.

Recent advancements in making key measurements on the physical forces involved in soil water must be exploited towards far better appraisal of field conditions related to water.

There is an increasing need to attain an understanding of the biochemical and physiological mechanism in plants that determine their tolerance to various salt-affected soils. The role of climatic conditions in modifying these mechanisms also needs clarification. There is an urgent need to develop crop varieties higher in salt tolerance. An understanding of basic mechanisms in each important species would obviate the present superficial approach of cut-and-try testing.

The management practices followed in an irrigated field that is subject to salinization need far better quantitative characterization.

Hard experience in the Western States has shown that successful irrigation requires effective drainage. Accumulating salts must be continually leached out. Excessive leaching wastes water and nutrients. There is an urgent need to develop and test better mathematical expressions for the calculation of leaching requirements, drainage requirements, and the proper salt balance that ought to be maintained.

One of the pressing needs for information in irrigation agriculture is the development and evaluation of alternative procedures for the disposal or reclamation of return flow—procedures that seek to maximize beneficial use of total water available, while minimizing contamination for downstream users.

The heavy salting of highways in Northern States to facilitate traffic movement following snowstorms has caused serious damage to right-of-way vegetation and has increased silt damage to streams when erosion followed killing of the vegetation. The consequences of highway salting need far better evaluation.

The Federal Council of Science and Technology has recommended that agricultural research involved in this general area should increase fourfold during the current 5-year period.

Organic Wastes

This category includes material such as sewage, animal wastes, crop residues, forest trash, and food and fiber processing wastes. When these substances are carried in water, they incur a high biochemical oxygen demand. When dry upon the land, some are combustile, some produce odors, and some attract flies and vermin.

Sewage

About 60,000 acre-feet of water flows from municipal sewage facilities on the average day. Some of this could be used for irrigation even though that which received no treatment or only primary treatment could not be used in the production of food crops. Such water may be used for irrigating feed and fiber crops. Further, effecting movement of such contaminated water through soil is the best means of attaining purification.

The State agricultural experiment stations and the U.S. Department of Agriculture have already developed useful information on irrigation with sewage effluent both in terms of crop production per se, and in terms of overirrigation to provide ground water recharge with reclaimed water.

The good prospects of this research in sustaining agricultural water supplies in the future, in addition to providing an effective system of water purification, require that this line of endeavor be supported to the fullest extent feasible.

Animal Wastes

Domestic animals produce over 1 billion tons of fecal wastes a year. Their liquid wastes come to over 400 million tons. Used bedding, paunch manure from abattoirs, and dead carcasses make the total annual production of animal wastes close to 2 billion tons. In fact, waste production by domestic animals in the United States is equivalent to that of a human population of 1.9 billion.

As much as 50 percent of this waste production may be produced in concentrated supply. Big operations have developed rapidly in the last 20 years. An outfit with 10,000 head of cattle on a feedlot produces 260 tons of manure a day. Economic research reveals that it is cheaper for the farmer to supply fertility to his fields from the fertilizer bag than to meet the cost of hauling manure to the field. What is to be done with this manure?

If it accumulates, it effuses offensive odors into the surrounding area; it provides a spawning ground for vermin; on drying, it is a source of unsavory dusts; in rainstorms it produces runoff high in biochemical oxygen demand; and it may be the source of certain infectious agents found in streams.

Stockmen have been subjected to lawsuits on the grounds that such wastes were a public nuisance. Dairy farmers have had to make expensive moves to remote areas. Poultry enterprises have offended and been placed under restrictive curbs.

There is a pressing need to develop basic design criteria that are amenable to some adjustment to meet the widely varying constraints associated with different enterprises in different parts of the country. Elements of the problem include characteristics of manures; removal of manure from livestock quarters; storage; transport; feasibility of use on land; and disposal by burning, using lagoons or similar facilities, or burying. Other disposal problems include handling carcasses, milkroom wastes, and silage effluents.

Much effort should be allocated to identify the odor-producing organisms prevalent in manures, and to develop techniques to destroy such organisms.

Treatments of manure that would lower its attractiveness as a breeding ground for flies and vermin are especially needed.

In applying manure to cropland, more acceptable procedures are needed for storage and distribution without emission of offending odors and possibility of contamination of runoff water.

Use of lagoons for disposal has not been fully satisfactory. They tend to be underdesigned, overloaded, and misused. Anaerobic fermentation with the accompanying odors sometimes takes place. Some study is underway and must be continued to provide artificial stirring and better oxidation of water systems used for manure disposal.

The looming urgency of disposal problems on animal wastes, associated with a serious dearth of needed technology on efficient and economic methods, adds up to an immediate need for major expansion of research effort to attain sound answers to these problems.

Plant Residues

Plant residues from crops and orchards impair the environment in two ways: (1) They act as reservoirs of plant diseases and pests, and (2) they emit smoke and hydrocarbons into the surrounding area when burned. Rice straw as well as that of other grains is burned. Burning of residue from grass seed production is used extensively as a sanitation measure. Alternate methods of handling such residues are needed.

If residues are left on the soil, they can aid in preventing wind and water erosion. However, the soil microflora may be altered in nature and activity, as a result of a mulch of crop residue, and can adversely affect production of a succeeding crop.

Although problems pertaining to the handling of crop residues may not be regarded as top priority, new and better information is needed to economically handle these wastes without detrimental side effects.

Trash in Forests and Forestry Operations

Twenty-five million tons of logging debris are left in woods during the average year. This is a reservoir for tree diseases and insects. It is also an exceedingly serious fire hazard. The average size of forest fires originating in logging waste is more than seven times that of fires originating in uncut areas where trash has not accumulated. Average annual losses from forest fires are $600 million. In the average year, wild forest fires produce 160 cubic miles of smoke, 34 million tons of particulates, and 338,000 tons of hydrocarbons. Forest burns have excessive runoff and very high sediment delivery. They contribute to flood damages.

The trash and deadwood from elms killed by Dutch elm disease and oaks killed by oak wilt must be destroyed or treated to prevent vector transmission of the disease to healthy trees.

At the present time, research has produced no economically feasible technique to dispose of forest trash en masse other than by controlled burning. Chipping is useful in isolated instances.

Research needs to be expedited towards the improvement of techniques for controlled burning that reduce atmospheric contamination. All possible effort must be allocated to research that would aid in reducing the incidence of wild fires originating in forest trash.

Processing Wastes

Oxygen-demanding wastes from processing of agricultural and forestry products include runoff or effluent from sawmilling; pulp, paper, and fiberboard manufacturing; fruit and vegetable canning; cleaning dairies; slaughtering and processing of meat animals; tanning; manufacturing cornstarch and soy protein; sugar refining; malting, fermenting, and distilling; scouring wool; and wet processing in textile mills. These wastes, on entering a stream, greatly increase the demand for oxygen. They may make the water unsightly, unpalatable, and malodorous.

The oxidative requirements of the effluent from the woodpulp, paper, and paperboard industries exceed those of the raw sewage from all of the people in the United States.

In a year's time, the canning industry produces effluent with oxidative demands that are double those of the raw sewage from Metropolitan Detroit; the meatpacking industry, double those of Metropolitan Chicago; and the dairy industry, four times those of Metropolitan Boston.

Research has contributed to the abatement of processing wastes by (*a*) developing a commercially useful product out of that which had been a waste—the manufacture of insulating board out of sugarcane bagasse; (*b*) improving the procedure so that less wastes are produced—a new polysulfide modification of the kraft process of pulping results in greater pulp yields, less waste, and reduced air and water pollution; and (*c*) developing methods of waste treatment before disposal in stream—development of oxidative lagoons for potato-processing wastes.

Because of the tremendous contribution of processing wastes to the oxidative demands on our streams, it is obvious that research on farm and forest products should be enhanced by every means possible to give much greater emphasis to (1) developing useful products out of materials that are now considered wastes; (2) developing and improving processing procedures that lessen waste production; and (3) improving techniques for processing waste treatment.

Dilution of Organic Wastes in Streams

Depletion of dissolved oxygen in a stream is conditional upon the load of oxygen-demanding wastes added to a stream and the amount of streamflow available to waste assimiliation. Low flows in late summer and fall in many rivers and streams may be only one-fifth or one-tenth the average annual. Capacity of the stream to assimilate organic wastes is concomitantly affected. Hence, river basin planners must give major emphasis to operational plans that would minimize low flows. This will involve both structural and land treatment measures. Forest management and land treatment can affect water yield and abate low flows, but structural measures will undoubtedly have the major influence.

In view of the major emphasis being given to comprehensive river basin planning at this time, it is urgent that adequate research on forested and agricultural watersheds be directed towards gaining new technology and better information for determination of optimal combination of land treatment and structural measures on upstream watersheds to minimize the adverse effects of low flows.

Infectious Agents and Allergens

Through history, water contaminated with infectious agents has caused human disasters. It can still happen. In late May and early June of 1965, 18,000 people in Riverside, Calif., were infected with *Salmonella typhimurium* that by some unexplained means had entered the city water supply.

Soil, water, and air may be transmittal mediums for numerous organisms that afflict man as well as other animals and plants.

Those unfortunates suffering from allergies will not be consoled by evidence that 1.7 million tons of pollen move into the atmosphere over the United States every year.

Animal Disease Agents

Agricultural losses caused by infectious agents of livestock and poultry carried by air, water, and soil have been heavy. Some of the diseases so transmitted are leptospirosis, salmonellosis, hog cholera, mastitis, foot-and-mouth disease, tuberculosis, brucellosis, histoplasmosis, ornithosis, infectious bronchitis, Newcastle disease, anthrax, blackleg, footrot, coccidiosis, blackhead of turkeys, erysipelas, and transmissible gastroenteritis. A number of these may afflict humans.

The presence of coliform bacteria in water has been used as an indicator of bacteria for about 75 years. Although the coliform bacteria are not pathological, their presence has been taken as an indication that infectious bacteria might also be present.

Recent evidence suggests that more definitive information on bacterial contamination of water may be gained by making counts of both fecal coliform and fecal streptococcal bacteria. Empirical observations indicate that if the bacterial contamination of water is coming from animals, the f. coliform/f. streptococci ratio is less than 0.5. If the bacterial contamination is from human sources, this ratio usually exceeds 4. On this basis, a water bacteriologist may use the following as a general guide: If this ratio is less than 1.0, the pollution is coming from nonhuman sources; if the ratio exceeds 2.5, the bacterial pollution is most probably coming from human sources. Ratios between 1.0 and 2.5 suggest that the pollution is a mixture of human and nonhuman sources.

On the basis of the foregoing, bacterial assays on water samples from the upper Potomac Basin indicate that most of the bacterial pollution of this river system is coming from nonhuman sources.

Much needs to be learned about the complete reliability of the f. coliform/f. streptococci ratio as an indicator of the source of infectious agents in river water. Comparable studies need to be made on other river systems.

Excellent progress has been made in veterinary research in the United States over the past 85 years. Bovine tuberculosis has been reduced to a remarkably low point. Counteractive measures involving environmental sanitation have been highly successful in curbing brucellosis and hog cholera.

Even though much has been accomplished, much needs to be done.

Research underway on parasitic diseases will contribute to reduction of environmental contamination in two distinct ways: First, by the development of methods to reduce parasitism in our livestock population which will, in turn, reduce environmental contamination by parasite-infested animal wastes; second, by reducing the opportunity for environmental contamination by pesticides through development of methods of reducing or eliminating parasitism based on biological control, immunization, improved management, or more efficient use of better chemicals.

Expansion of research on developing counteractive measures to animal diseases is warranted fully on the basis of the huge annual losses these diseases impose on agriculture.

In view of the key objectives for clean air around us and clean water in our river basins, it is essential to have (*a*) far better information on the extent to which infectious agents in our surface waters come from agricultural sources; (*b*) possible procedures to curb movement of infectious agents from the farm or feedlot to the water; and (*c*) continued progress in eliminating animal diseases that contaminate air, water, and soil. Some animal diseases—for example, encephalitis—are spread by mosquitoes that are often spawned under irrigation agriculture. Needed research should be supported to the fullest extent feasible.

Plant Disease Agents

Diseases of crops, ornamentals, and trees have caused losses in billions of dollars. Many of these diseases are transmitted via air, water, or soil—that is, by contamination of the environment.

Black shank of tobacco has been a very serious disease in several tobacco-growing areas. It is spread by contaminated water, soil, or plants. The disease spores can contaminate ponds or streams into which infested fields drain. The disease persists for many years in some soils but not in others. Research on this problem has developed resistant plant varieties and a system of field sanitation.

Red stele disease of strawberry is an example of a plant disease fungus that persists in contaminated soil for many years even if strawberries are not present.

Stem rust of wheat is an example of a plant disease that is often spread, with disastrous results, by contaminated air. This disease has cost agriculture billions of dollars in losses. Countering the broad transmission of strains of this disease by tainted breezes has gained through development of disease-resistant varieties of grains. Since the disease organism mutates and attacks previously resistant varieties, a continuous breeding program is essential. In fact, one of the most laudable contributions of research in the United States is that of developing control measures for stem rust of wheat—a disease that can ravage millions of acres of a food crop by contaminated winds.

White stringy root rot of conifers is a disease caused by the fungus *Fomes annosus* Fr. It is present throughout our softwood forests. Airborne spores inoculate freshly cut stumps. Once tree roots are infected, the fungus may survive below ground for 50 years or more.

Although the potato blight epidemic that caused such widespread starvation and misery in Ireland occurred over a hundred years ago, we still know very little about the spread of such plant disease epidemics by a contaminated environment.

Research on the control of plant pathogens that contaminate the soil needs particular attention, since few are subject to control by either chemicals or plant breeding. High priority must be given to studies on changes in microbial populations in soils on incorporation of specific crop residues, with especial emphasis on the extent to which populations of plant pathogens on the soil are suppressed.

Plant disease agents carried by air, water, and soil can be just as disastrous to man's welfare as an infectious agent such as *Salmonella typhosa*—the cause of typhoid fever. Research towards minimizing the prevalence of these agents is tantamount to improving environmental quality for man's welfare. This is a high priority objective.

Allergens

The Public Health Service reports that in the average year, there are 12,646,000 sufferers from asthma or hay fever, or both. Of these, about 5 million are asthma sufferers, and about 75 percent of the asthma cases are due to pollen. The remaining 7,646,000 suffer from pollen allergies. Costs in terms of medical treatment and workdays lost are enormous.

There is very little research underway designed specifically for the control of plant species that produce allergenic pollen. In fact, there is no complete catalog of allergenic pollen.

Chemical control by herbicides having high physiological specificity offers a real possibility for the weeds that are troublesome. Pollen is carried long distances by wind, and any control measure must significantly reduce pollen counts.

The evidence suggests that very rewarding research could and should be undertaken in this area of serious aerial contamination.

Agricultural and Industrial Chemicals

The use of synthetic organic chemicals has been beneficial to man and his environment. But the discharge of some of these chemicals into the environment has induced problems. These chemicals include such substances as household detergents and the more recent insecticides, herbicides, fungicides, and nematocides.

Detergents

Agriculture and forestry have interest in problems caused by detergents. The excellence of these chemicals as cleansing agents is related to their high capability to disperse colloidal particles. They also disperse soil colloids. A dispersed soil has relatively low hydraulic conductivity in either the saturated or unsaturated state. An installation such as a septic tank with its distributing field at a farmhouse, in a rural community, or on a forest recreation area depends on reasonably good hydraulic conductivity of the soil around the distributing tiles. Reports of malfunctioning septic systems are common. Design of septic systems could be improved; they could be better adjusted to soil characteristics and to degree and nature of probable detergent load.

No hazard to humans or animals is apparent from the presence of detergents in surface waters.

Detergents carry phosphate as an active component. When sewage effluents enter rivers, lakes, and estuaries, this phosphate becomes a key plant nutrient promoting the development of obnoxious algal blooms. This role of phosphate is discussed in the section on plant nutrients. Much more factual information is needed on the respective contributions of phosphate from detergents and sewage in general compared to that from land runoff.

Insecticides

The potential contamination of the environment by pesticides, particularly the chlorinated hydrocarbons, has been a matter of public and private discussions. Within a few years after DDT began to be used extensively as a field and forest insecticide, DDT and its metabolites were found in the fatty tissues of fish and wildlife, both living and dead. Newspapers carried features on fish and wildlife losses with an implicit indictment of agriculture and forestry for having used insecticides.

The use of these chemical tools has made a tremendous contribution to man's health and welfare over the past 25 years. Unfortunately, in some instances, they have also been abused and misused without due consideration to their impact on the nontarget organisms.

In 1964, 470 million pounds of insecticides were used on 83 million acres of land. In a few instances, adverse effects have occurred in agriculture and forestry. Insecticides that have broad spectrum activity are just as effective on many nontarget insects as on the target ones. For example, use of certain insecticides has resulted in losses of honeybees and other beneficial insects.

The application of certain insecticides to cotton, corn, or other crops may lead to insecticide residues in soybeans or peanuts grown in the soil a year or more later. Certain chlorinated hydrocarbons can persist in soil for many years. In one experimental study 50 percent of the original high-level application of DDT was found in the soil 8 years after the material had been applied.

The pesticide monitoring program maintained by the U.S. Department of Agriculture on widespread soils and waters is, therefore, exceedingly important. Evidence revealed from these monitoring activities does not show cause for concern on pesticide buildup. But this does not warrant complacency over the diverse problems stemming from insecticide use.

Over the long pull, research efforts towards avoiding the adverse effects of insecticide residues in the environment must continue to receive major attention.

Far better information is needed on insect population trends with the objective that emergency use of chemicals may be avoided.

Research on developing insecticides with higher biodegradability and lower persistence in the environment must move forward apace.

There needs to be far better information on the chemical behavior of insecticides in soils varying widely in physico-chemical attributes. The extent and level of pesticides in waters and in soil-water systems must be better evaluated and the significance of the findings better understood.

Certain residue problems arise as a result of spray or dust drift beyond the target area. There are good possibilities of developing better methods of application or lower application rates. These must be pursued.

The use of physical attractants to aid in nonchemical control of economic insects needs to be more fully explored.

All possible support should be allocated to research for completely selective methods of controlling major insect pests. These techniques include the use of predators and dissemination of specific insect diseases; development of specific insect attractants; breeding and selection of insect diseases; breeding and selection of insect-resistant crop varieties; the use of self-destruction mechanisms such as release of sterile males; and the development of chemical insecticides that act on selective physiological systems peculiar to the target insect.

Herbicides

Weed control by use of selective herbicides has increased substantially during the past 20 years. In 1964, 184 million pounds of herbicides were sold in the United States and 97 million acres of agricultural land were treated with these unique chemicals.

Although good progress has been made in the technology of herbicide use, much research is needed to refine this technology. Herbicides applied to control weeds in one crop may leave residues in the soil which prevent the growth of certain other crops planted immediately following harvest of the treated crop. Diuron used for weed control in irrigated cotton in the Southwest may leave residues in the soil which could injure vegetable crops such as lettuce, carrots, cabbage, and cucumbers when planted in the winter following cotton harvest.

Spray drift of 2,4,5-T and 2,4-D from applications on nearby forests, cropland, roadsides, and rights-of-way has damaged chemically sensitive trees such as dogwood, paper birch, box elder, chestnut, black locust, and other shade trees, shrubs, and herbaceous ornamentals. In some situations injury has occurred as much as 10 miles downwind from the target area.

The aromatic solvents and other herbicides used to control aquatic weeds in irrigation systems are known to be toxic to fish at levels generally higher than the amounts needed for weed control. However, judicious use of certain solvents or herbicides will provide weed control with little or no fish toxicity.

Limited information is available on the behavior of some herbicides in soils. It is a complex picture. Adsorption of a herbicide by a soil is determined by the specific surface of the soil, organic matter content, nature of the clay mineral, moisture status, temperature, nature and degree of base saturation, and structure and polarity of the herbicide molecule.

Soil micro-organisms are important in detoxifying herbicides in soils. It is largely because of these soil micro-organisms and other dissipation mechanisms that most herbicide residues in soils do not show progressive buildup.

The fact still remains that the toxicology of residual herbicides on succeeding crops is often unpredictable. Consequently, there is a pressing need for far better information on the fate of herbicides in soils, including the cultural practices and climatic conditions that incur a modifying influence.

There is a continuing urgency to develop superior herbicides with greater specificity and fewer adverse residual side effects.

Concentrated research effort is needed on engineering principles to develop better techniques to reduce drift.

There would appear to be tremendous economic advantages in developing weed control chemicals that are more specific; for example, a chemical that would only inhibit pollen production on ragweed.

The extensive use of herbicides and the problems arising from residues in soil and water or drifts in the atmosphere focus on the need to emphasize investigative studies on the pertinent array of problems.

Fungicides

Fungicides do not appear to be of major concern in environmental contamination. The organic mercury compounds are generally the most hazardous to man, but these are used mostly for seed treatment. Accidental feeding of such treated seeds to livestock and poultry sometimes causes poisoning.

Apple orchards and vineyards that have had a long record of spraying with copper fungicides may have very high levels of copper in the surface soils. Zinc and manganese can accumulate to toxic level in soils, but evidence indicates that application of fungicides is not at fault.

In terms of residues contaminating the encironment, there are many other substances that cause more concern than fungicides.

Heat

Heat acts as a water pollutant because the amount of oxygen that water can hold in solution diminishes with increasing temperature. The introduction of heat in any substantial quantities into surface water has the net effect of introducing additional oxygen-demanding wastes.

Heat also has a detrimental environmental effect upon fish and other aquatic life. Some fish can stand only a very few degrees of increase in temperature, and a substantial increase in temperature can result in the elimination of some forms of aquatic life.

There is little in agricultural and forestry endeavor that contributes heat to streams and lakes.

One example comes to mind. Water seeping from or flowing through a recent forest burn may have a higher temperature than if the area had been in deep forest.

Industry may contribute serious heat pollution of streams. The Mahoning River in Ohio provides a good example; it is used extensively for industrial and power cooling in the Youngstown area. The temperature of the river in the summer is raised to such an extent that fish life is completely eliminated, and the river is rendered unfit for further use in either waste assimilation or additional cooling.

Agricultural and forestry interests wishing to use surface waters for recreation or fishing would be seriously affected by water unduly heated by industrial cooling.

Socioeconomic Evaluation

A whole array of decisions must be made among alternative approaches posed by wastes in the environment. How do we define quality of the environment? Where do we draw the line between contamination and noncontamination? How much are we willing to pay for specific levels of quality improvement? What level of waste treatment do we want? Do some segments of society want different levels of environmental quality than others? How do we set up standards that provide flexibility? How do we attach monetary significance to esthetic values? How do we relate these values to quantitative aspects readily evaluated in the marketplace? Do we want to maximize economic benefits, or should we seek to maximize social benefits, or should we attain an optimal combination of the two?

Answers must be sought to these and similar questions if optimal economic and social solutions to waste problems are to be attained.

Economic research on wastes should emphasize the evaluation of costs and benefits associated with waste production and waste disposal. Such evaluations are needed for each of the agents that do or may affect this quality of our environment. Such studies would identify which areas of waste production are most in need of correction in terms of dollar costs and benefits.

To this end, economic studies are underway on data from the Pesticide and General Farm Survey for 1966. Evaluation of these data in relation to those previously obtained will indicate trends.

Studies are underway on the economic significance of water quality, erosion and sedimentation processes, and the salinity of irrigation waters.

Economists maintain a continuing research program with respect to fertilizer use.

Organic wastes present a major area for economic studies toward arriving at sound decisions on alternate ways of handling animal and poultry manures and food and fiber processing wastes.

There is an immediate need for information on the status of rural waste problems. Surveys should be designed to provide for better knowledge on abatement costs, economic effects, existing institutional control arrangements, and other information as specified by survey objectives.

These surveys should highlight critical problems requiring studies in depth. Such studies should trace the economic implications of selected problems, specify feasible alternatives for solution, and provide information for the rational compromises between production efficiency and waste-free environments.

There are presently serious problems of adjustment within agriculture to meet changing concepts of environmental quality. Local ordinances and court actions have caused abrupt cessation of agricultural operations in some areas. Studies need to be made on the role that local leadership in county and district organizations can play in guiding the amelioration of rural waste problems.

There is a critical need for improved techniques for measuring secondary economic effects, and nonmonetary benefits and costs, of waste control programs.

The need for information thus is great in the complex of decision-making processes.

APPENDIX I

Wastes Adversely Affecting Agriculture and Forestry

It is altogether fitting and proper that an affluent society should show mounting concern over the deterioration of environmental quality from an appalling effluent of wastes. The total problem has been so well documented that little of importance can be added. Obviously, the sectors of our National economy concerned with agriculture and forestry are in many instances seriously afflicted with the adverse effects of waste production. These specific problems warrant further delineation and evaluation.

The purpose of the discussion in this appendix will be to comment upon those wastes that have, or may have, an adverse effect on agricultural and forestry endeavor, and to give some degree of appraisal as to seriousness of these effects.

Committee Print No. 9 of the Senate Select Committee on National Water Resources (*119*) specifies these eight general categories of water pollutants.

(1) Sewage and other oxygen-demanding wastes
(2) Infectious agents and allergens
(3) Plant nutrients
(4) Organic chemical exotics
(5) Salts and mineral substances
(6) Sediments
(7) Radioactive substances
(8) Heat

In discussions of air pollution, four broad categories of substances are usually delineated:

(1) Dusts
(2) Chemical contaminants
(3) Radioactive substances
(4) Biological entities (pollen, fungi, bacteria)

For convenience, this discussion on the environmental contaminants that adversely affect the quality of air, water, and soil in relation to agricultural and forestry endeavor will represent the following amalgamation of these two sets of air and water contaminants:

(1) Radioactive substances
(2) Chemical air pollutants
(3) Airborne dusts
(4) Sediment
(5) Plant nutrients
(6) Inorganic salts and minerals
(7) Organic wastes
(8) Infectious agents and allergens
(9) Agricultural and industrial chemicals
(10) Heat

Radioactive Substances

Radioactivity is nothing new. All living things are constantly exposed to radiation. A smattering of cosmic rays from outer space continually passes through our bodies. We breathe and eat minute amounts of radioactive materials. We are exposed to such radiation when we have X-ray examinations. X-rays of the proper intensity have been used to destroy the abnormal cells of cancerous growths without seriously harming healthy tissue. But X-rays can be sufficiently strong, or applied over sufficient duration to cause abnormalities or death of healthy cells and tissues.

Therein lies the concern of agriculture with radioactive substances. They emit penetrating rays that in sufficient strength, or over sufficient time, can bring about abnormalities or death of cells, tissues, and organisms analagous to the effects of X-rays. Medical use of X-rays occurs under carefully controlled conditions by a highly trained specialist. Radioactive materials that enter into air, water, soil, and plants are not under comparable supervision.

It must be emphasized, however, that the Atomic Energy Commission and certain State agencies exercise careful surveillance and strict controls with respect to (1) the release of radioactive substances into our environment and (2) the handling of soil, water, and food that may have been inadvertently contaminated. Radioactivity cannot be destroyed. One can only confiscate, isolate, and restrictively dispose of materials that have become dangerously contaminated.

Radioactive materials that enter, or may enter, our environment derive from testing of nuclear weapons; power reactors, with emphasis on accidental release; mining operations involving minerals containing natural radioactivity; refining of uranium and thorium; and accidental release from medical and research centers.

Radioactivity can affect livestock either by direct external radiation or by ingestion. Effects of direct radiation from a nuclear catastrophe would depend on the intensity and duration of the radiation received. Animals that receive a lethal dose at a slow rate may survive for weeks, whereas deaths may occur within a few days from the same radiation dose applied at a high intensity over a few hours.

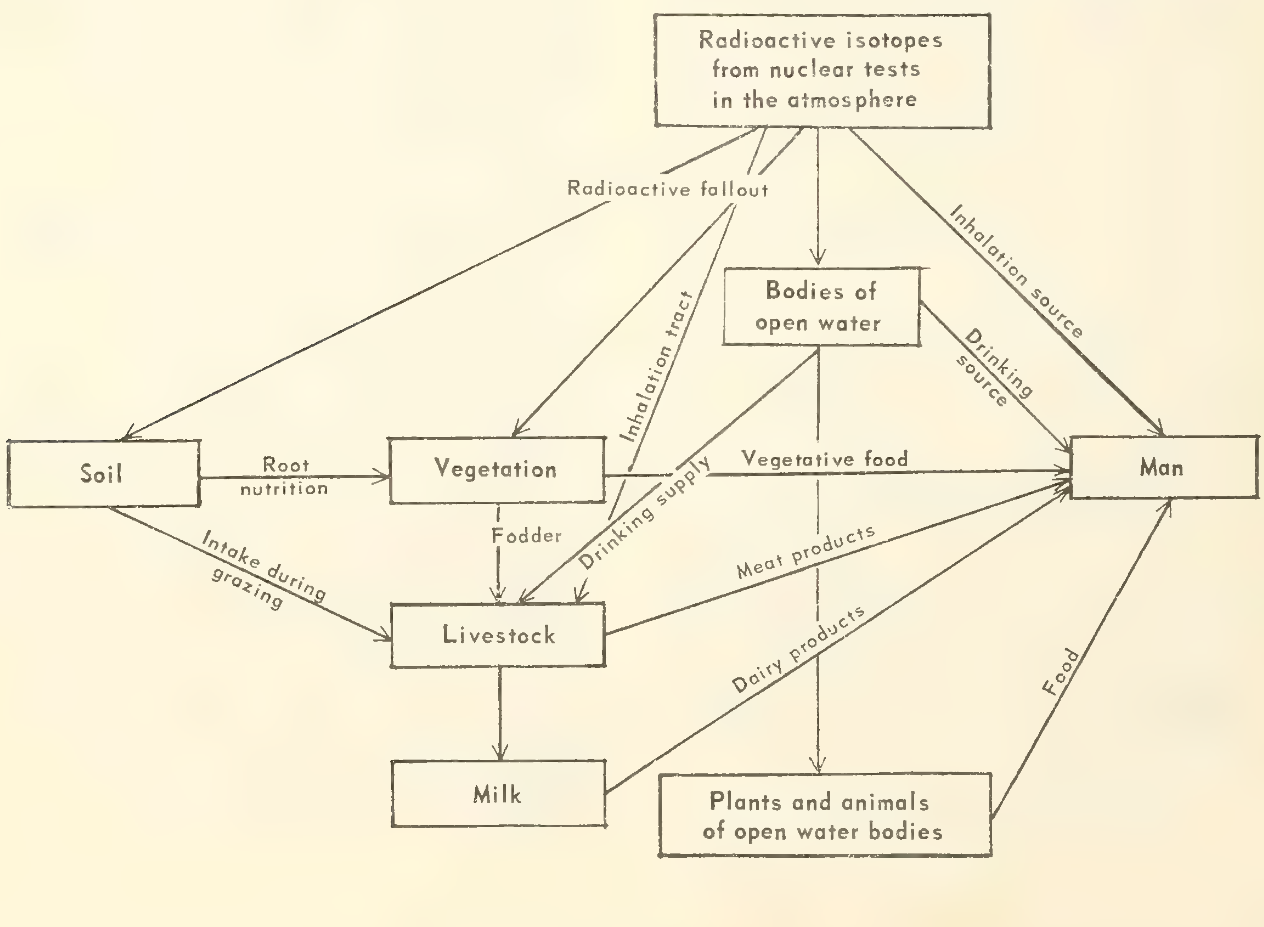
Detonation tests of nuclear weapons give off an array of radioactive substances. We are particularly concerned with the ones known as strontium-90, cesium-137, and iodine-131 that enter into the air as a result of atmospheric or surface tests, and thereby are widely dispersed through the stratosphere. These radioactive particles may fall to the earth as a downward drift known as radioactive fallout. Snow and rain help bring such fallout to earth. A nuclear detonation anywhere in the northern hemisphere could produce fallout on the United States. Fallout can contaminate food, water, fields, and buildings.

A general diagram developed by Aleksakhin (7) illustrates the importance of agricultural activity as routes by which nuclear fission products may be conveyed to man. (See diagram below.)

Chemically, strontium is similar to calcium. It enters into and behaves in water, soil, food and feed, plants, animal tissues, bones, and milk much as calcium does. Strontium-90 has a half-life of 28 years, meaning that it loses half of its radioactivity every 28 years. Because of its long half-life and its readiness to enter into bones wherein accumulations could cause bone cancer, it is a potentially dangerous contaminant.

Radioactive iodine may accumulate in thyroid glands and induce thyroid cancer. Fortunately, iodine-131 has a half-life of only 8 days so the danger period is short.

Cesium-137 behaves much like potassium. It has



a long half-life of 30 years and may collect in muscle tissue. Cesium-137 is bound very tightly by clay particles in soil, which lowers its probability of entering into plants providing food and feed for livestock.

Phosphate rock used for making phosphatic fertilizers sometimes contains traces of uranium-238. Although uranium is not readily absorbed by plants, radioactive decay of uranium-238 gives, among other products, radium-226, radon-222, lead-210, and polonium-210. These elements may be absorbed by plants, or settle as dust onto plant tissue. At present, radioactivity from phosphatic fertilizers is not a significant threat, but it may bear watching.

Tobacco leaves are reported to contain the peculiar capacity to accumulate polonium-210 at an appreciable level. This level varies with location, culture, type of tobacco, and curing methods. Polonium-210 volatilizes at the temperature of tobacco combustion, and may be inhaled into the lungs by smokers. Thus, it has been suspected of being one of the factors causing lung cancer that is associated with smoking. This potential effect of polonium-210 in tobacco is still a debated question. Many scientists consider its level to be too low in tobacco to constitute a hazard to smokers.

Radioactive contaminants in farm products may cause economic losses to farmers. During the spring of 1966, milk was confiscated on a dairy in Nevada because of an unduly high level of iodine-131 in the area as a result of accidental venting during and following an underground weapons test. Dairymen in central Minnesota considered using stored feed instead of pastures during the summer of 1962, when worldwide fallout from nuclear testing reached its highest level. The estimated direct cost of this action in one small area would have been $9,000 a day.

Knowledge of the behavior of fallout in soils is adequate to permit a rough prediction of amounts of fallout radionuclides that will be taken up by plants and to recommend remedial measures. Keeping plant uptake at a safe level will be expensive. Recent studies indicate that the fallout must be physically separated from plant roots. Even for shallow-rooted crops, burying contaminated surface soil 25 inches deep did not prevent significant amounts of uptake by the plants. A physical or chemical barrier was required to be placed between the roots and the radioactive contaminants. However, for plants that are directly contaminated with fallout, factors affecting the residence time of particles on plant surfaces are inadequately known. This seriously hampers prediction of levels of forage and milk contamination during periods with moderate-to-heavy fallout.

The adverse effects of radioactive contaminants on the agricultural economy at the present time are small. But if the world should resort to use of nuclear weapons to settle international disputes, the degree of radioactive contamination of our soils, water, crops, and livestock that could take place staggers the imagination. Adequate preparations for civil defense require that all possible techniques for counteracting the adverse effects of nuclear fallout on agriculture be developed.

Chemical Air Pollutants

People like clean air. But public concern over polluted air is not new. During the reign of Edward II (1307–27), England put a man to the torture ostensibly for filling the air with a "pestilential odor" from the burning of sulphurous "sea" coal. In 1661, John Evelyn, one of the founders of the Royal Society, published the first really scientific paper on sources, effects, and problems in control of air pollution in London. The problem has snowballed. Technical advancement which abets air pollution outruns that which abates it.

As shown by the city of Pittsburgh, good progress can be made in stopping the emission of appalling levels of industrial smoke. Yet, smoke along with carbon monoxide, sulfur oxides, hydrocarbons, nitrogen oxides, and other gases and vapors emanating from municipal and industrial activity continues to increasingly burden our atmosphere. Some of these gases react in sunlight to produce still other toxic constituents such as ozone and peroxyacetylnitrate. Agriculture and forestry are adversely affected.

Internal combustion engines used in transportation in the United States pour out 75 million tons a year of carbon monoxide, hydrocarbons, nitrogen oxides, and lead compounds into the air.

Central-station generation of electricity belches 16 million tons of air pollutants a year, largely made up of sulfur oxides.

Industry contributes about 23 million tons of air pollutants per year that involve a whole array of substances including sulfur oxides, fluorine, and hydrocarbons.

Space heating, refuse burning, and forest fires contribute to the mucky atmosphere by emitting 10 to 12 million tons of stuff largely appearing as smoke.

The concentration, transportation, and dispersion of air pollutants from the various sources are determined by topography and meteorological conditions. Wind is the transporting and dispersing agent. In the typical American city, the air is three times as polluted when the wind speeds are 6 miles per hour or less than on days when the winds are 18 miles per hour or more. Concentration of pollutant decreases with distance from the polluting source except as modified by topography and temperature inversion layers. Hills or mountains surrounding an area can provide a pocket for concentrating air pollutants. Such a situation exists in the Los Angeles Basin. Although the western part of this basin is not blocked topographically, the prevailing winds are from the west.

Under normal atmospheric conditions, air temperature decreases with altitude. Expansion of the air under decreasing pressure with altitude involves adiabatic cooling. In the presence of an inversion layer, temperature increases with altitude. The situation is well illustrated by a diagram presented by Wanta (*131*). Cool air that displaces warm air, such as air that blows from a cool ocean onto warm land, can cause a pronounced inversion. Similarly, warm air may flow over a cold surface layer, especially one trapped in a valley, and cause an inversion.

Inversions effectively suppress vertical air movement and cause an atmospheric stagnation in which smoke and other volatile contaminants cannot rise from the earth's surface. Persistent inversions occur in Los Angeles, New York, and other industrial and metropolitan areas. Under such conditions, potentially lethal layers of toxicants including sulfur dioxide, carbon monoxide, ozone, and nitrogen oxides can become statically entrapped for days. Forest trees, horticultural plants, field crops, and domestic animals living in such an area can be sorely afflicted. In fact, vegetation damage from air contamination has been recorded in over half of the States of the Nation and no doubt occurs to some degree in all States.

Different air contaminants have specific effects on agricultural crops and forest trees.

Sulfur Dioxide

One of the really classic examples of the drastic effects of sulfur dioxide (SO_2) contamination still prevails at Copper Basin in the Ducktown-Copperhill, Tenn., area. Over a century ago, this basin in the southern Appalachian Mountains was covered with hardwoods and some conifers. Mining was started in the basin about 1850. Open-hearth wood-burning furnaces were later installed directly at the mine locations, with their greatest activity being in the years 1890–95. Soon after 1900, the sulfur dioxide fumes combined with timber overcutting to fire the furnaces and wild fires had killed most of the vegetation in the basin. Even today, some 7,000 acres to the leeward of the smelters are nude of vegetation. Erosion has been intense. Most all of the soil and subsoil are gone. Another 17,000 acres surrounding the nude area are devoid of trees and produce only broomsedge and some plantings of kudzu. White pines 30 miles from the smelters were injured. One cannot visit Ducktown without standing in awe at the tremendous damages that airborne sulfur dioxide can inflict. Most smelters have now installed absorptive equipment to prevent pouring SO_2 into the atmosphere. Smelters in the Ducktown-Copperhill area for many years have converted the SO_2 into a profitable byproduct, sulfuric acid, but the scars remain on land still highly acid.

Sulfur dioxide still threatens the vegetation around cities. Philadelphia daily releases about 850 tons of SO_2 into the atmosphere. New York City air most of the time contains SO_2 near the threshold level of injury to sensitive plants. Injury to vegetation depends on concentration in the atmosphere, length of exposure, and tolerance of the species. Alfalfa, cotton, wheat, and conifers are relatively sensitive to SO_2, whereas potatoes, corn, and maples are more tolerant. If the SO_2 content of air is 0.3 to 0.5 part per million for several days, sensitive vegetation will be injured. The threshold value for alfalfa is one hour's exposure to 1.0 p.p.m. of SO_2.

Since industry and metropolitan areas in the United States are pouring 30 million tons of sulfur oxides into the atmosphere each year, appreciable

SO_2 injury to forest trees, horticultural plantings, and field crops can be expected.

Fluoride

Airborne fluorides have become a serious toxicant to vegetation and animals over the last few decades. The industries mainly responsible are aluminum reduction, smelting of iron and nonferrous metals, ceramics, and phosphate fertilizer manufacture. Some manufacturers have been making good progress over the last decade in installing equipment to curb fluoride effluent.

Fluorides appear to act as cumulative poisons to the plant. In 150 hours, corn foliage will concentrate 0.005 p.p.m. of atmospheric hydrogen fluoride to 178 p.p.m. dry weight of plant. Gladiolus, prunes, peaches, and grapes are also sensitive to this low level of hydrogen fluoride. More than 500 p.p.m. of fluoride can be concentrated in foliage during a single season from an atmospheric fluoride level of 0.5 part per billion. Fluoride injury on ponderosa pines has been detected 20 miles from an aluminum smelting plant.

Most agricultural soils contain 100 to 150 p.p.m. of fluoride, but most plants absorb very little of this element from the soil because of the low solubility of calcium fluoride (1.6 mg./100 ml. H_2O); that is, it is nearly as insoluble as calcium oxalate. Consequently, when plant leaves contain more than a few parts per million of fluoride, atmospheric contamination with fluoride can be suspected.

When one considers that air samples from a heavily industrialized city such as Baltimore reveal 0.08 part per million of fluoride, the potential for damage to vegetation by this air contaminant is extant. In fact, legal claims for fluoride damage to crops within three States—Utah, Florida, and Idaho—totaled nearly $3 million in 1957.

Chronic fluorosis may develop in livestock from ingestion of small amounts of fluoride over several months or years. Eating contaminated forage growth near industrial areas emitting fluorides will induce fluorosis. If the animals receive mineral mixture or water containing fluoride the effect of the contaminated forage will be accentuated. All kinds of livestock may be affected by accumulation of fluoride in their systems, but cattle are most sensitive followed by sheep, swine, horses, and poultry. Cattle may ingest 1 to 2 milligrams of fluorine per kilogram of body weight without harmful effects if they are in good health.

Symptoms of fluorosis involve excessive wearing of the teeth, staining, pitting of the enamel, and exposure of the dentine. In severe cases, the leg joints may become enlarged and the shaft of the long bones may thicken.

In past years, numerous dairy herds in central Utah have shown extensive symptoms of fluorosis.

Peroxyacetylnitrate and Ozone

Peroxyacetylnitrate (PAN) and ozone are the two most important plant toxicants that are produced in smog that has been activated by light energy. There are many sources of compounds that will react in the presence of sunlight to produce PAN and ozone, but the automobile exhaust appears to be the worst offender.

PAN is extremely toxic to citrus, forage, salad crops, ornamentals, and coniferous trees. Acute leaf damage by PAN to sensitive species has been observed at 0.005 p.p.m. in the air. PAN tends to produce injury symptoms on the lower surface of leaves, whereas ozone primarily affects the upper surface. PAN may also seriously retard growth and stimulate leaf abscission. Crops of romaine lettuce have been so badly damaged by PAN as to be unsalable. Cigar-wrapper tobacco grown beneath cloth shade, as in the Connecticut Valley and Florida, has been seriously damaged by "weather fleck" caused by ozone injury. Sensitive plant species such as tomato, tobacco, radish, and white pine may be damaged after exposure to 0.06 p.p.m. ozone for 3 to 4 hours.

Annual losses to crops in California from damage caused by photochemical smog have been estimated at millions of dollars; the estimates also show that these losses have been rising rapidly. Damage of this type has been observed in 27 States and the District of Columbia. For example, eastern white pine has been killed, discolored, or stunted by photochemical smog in Tennessee and Pennsylvania.

Oxides of Nitrogen

Nitrogen oxides are produced by high temperature combustion; thus they may be emitted by any fuel combustion source. Nitrogen dioxide is more injurious to living cells than nitric oxide and causes irregular blotches of collapsed tissue near the edges of the leaves. Pinto beans and tomatoes will show reduced growth and leaf distortion when exposed to 0.5 p.p.m. of nitrogen dioxide for 10 to 22 days. Most of the time, concentration of nitrogen dioxide in the atmosphere near sources of effluent are below 0.3 p.p.m.

Ethylene

Cotton plants growing downwind from industrial establishments making polyethylene were found to be seriously damaged by ethylene contaminated air. Air samples revealed 0.04 to 3 p.p.m. ethylene. Ethylene in the atmosphere has caused considerable loss to orchid growers in California. Exposure for 6 hours at 0.05 p.p.m. will cause sepal damage to Cattleya orchids. Carnation flowers often fail to open after a 6-hour exposure to 0.1 p.p.m. ethylene.

Lead Compounds

In the middle twenties, tetra-ethyl lead began to be added to gasoline, enabling use of engines with higher compression and higher efficiency in energy conversion. Since that time, millions of pounds of lead have been poured into the atmosphere from motor vehicle exhausts. Most of this was eventually deposited on soil and plants. In Los Angeles, the average air concentration is 2.5 micrograms of lead per cubic meter of air.

Pasture grasses collected at the intersection of two U.S. highways near Denver contained 3,000 p.p.m. lead, while grasses collected next to a less-traveled roadway contained 700 p.p.m. Grasses collected 50 to 100 feet away from the latter road contained 5 to 50 p.p.m. of lead. When the lead from auto exhausts is fortified by airborne particulate lead from certain smelters, the lead content of forage may become a hazard to the health of livestock. Although there is little evidence of lead poisoning to livestock from combustion products up to the present time, numerous authorities believe the situation is becoming critical.

Summary

Judging from past trends, the adverse effects of air pollutants on agriculture, ornamentals, and forests are going to become worse before they get better. Recent evidence was obtained showing a synergistic (more than additive) action of low concentrations of ozone and sulfur dioxide. The mixed gases caused plant injury, whereas there was no damage from the same concentration of individual gases. As several toxicants are usually present in polluted air, we must be concerned about the additive effect of the various toxicants on vegetation.

Middleton (*82*) stated in 1964:

> The industrialization of California has resulted in an increase in air pollution which has, in turn, caused extensive and serious damage to vegetation. About 14,000 square miles in California are now known to be affected by oxidants, ozone, and ethylene, which are typically emitted from combustion processes and motor vehicles, and by fluoride and sulfur dioxide which are typically emitted from industrial sources.

Crop losses from air contaminants are exhibited by suppression of yield, delay of maturity, and reduction in quality. As the flood of these noxious chemicals continues to pour forth into the atmosphere, and as capability in diagnosing their damages to plants and animals increases, we can expect estimates of annual damages by air pollutants to crops, ornamentals, forests, and livestock to soar.

Airborne Dusts

"May the gusty wind that blows the ladies' skirts knee-high, also blow dust in the naughty man's eye." Although this ditty penned by a woman many years ago involves extreme bias, it probably represents the only case wherein a benefit was attributed to airborne dusts in day-to-day living.

Dusts in the atmosphere derive from natural dune-lands; inadequately protected farm and rangelands; highway and industrial construction sites; certain mining operations, such as strip mines; mineral processing operations, such as cement plants; fly ash from smelters; dust from cotton gins, feed mills, and feed lots; and volcanic action.

Photographs of farmsteads in the Great Plains half buried in windblown soil as a result of the duststorms of the thirties are stark reminders that agriculture and agricultural people may suffer grievously from airborne dusts. In addition to the mess incurred on the afflicted farmsteads, the airborne dust threatened the health of people and livestock, damaged buildings and machinery, filled ditches and waterways, buried fences, damaged or destroyed crops, and removed topsoil from millions of acres of land. Finnell (*36*) reported that 6,541,000 acres of land were put out of cultivation in the thirties by duststorms. In 1947, Finnell (*37*) made a survey of wheat production in the heart of the old Dust Bowl to appraise the effects of the storms of the thirties on soil productivity. Land severely eroded by the earlier duststorms showed about 40 percent lower production as measured by wheat yields. During each of the drought years of 1954–57 on the southern Great Plains, the annual damages from windblown soil were about as great as those during the thirties (*87*).

Airborne soil is indeed a resource out of place. Windblown soil particles such as fine sand can completely destroy a stand of seedling or young plants by an action that is essentially sandblasting. This damage frequently occurs on young crops in the Atlantic Coastal Plain from the Connecticut Valley to Florida. Allen (*8*) reports that in Hoke County, N.C., dust blowing caused replanting of 2,500 acres of cotton, 1,000 acres of corn, and 100 acres of tobacco in 1955. Serious damage to seedlings by sandblasting has also been reported in Wisconsin, Illinois, Indiana, and Arkansas.

Dust blowing hurts livestock. An extension service forester made a survey of the benefits of farm windbreaks in abating soil blowing on 200 Nebraska farms. Livestock feeders indicated annual savings of $800, livestock breeders reported an annual savings of $500, and dairymen estimated their savings at $600 a year.

Dust from soil blowing or volcanic action that settles on plants and coats the leaves has the same stunting effect as the dust and soot from industrial flues, cement plants, and lime kilns. Coating of leaves impairs use of available sunlight in photosynthesis and obstructs the leaf stomata that permits gas exchange between the leaves and the surrounding atmosphere. Hence, growth processes are retarded. Dust accumulating on greenhouses cuts down available light intensity and thereby weakens the crop plants grown therein. This is particularly serious in the wintertime.

When these airborne dusts accumulate on leafy vegetables such as lettuce and celery, the quality of the crop may be seriously damaged. Small fruits and ornamentals may be harmed by dust accumulations.

Dusts may carry pesticides. If a herbicide were so carried, damage could occur on crops miles away from the area of application. Insecticides could be carried into farm ponds and tributary streams used by farmers or used for recreation in forested areas.

Information that would enable a quantitative appraisal of the adverse effects of airborne dusts on agriculture and forestry is seriously lacking. One can rest assured that the farmer who has experienced the duststorms of the Great Plains, or who has seen his young crops along the Atlantic coast sandblasted, or who has tried to grow fruit on the leeward side of a cement plant prolific in its eolian effluent does not need voluble arguments to be persuaded that the adverse effects of airborne dusts on agriculture are serious indeed.

Sediment

Many of us are so accustomed to seeing muddy water in our streams, ponds, and reservoirs that we come to look upon the situation as somewhat like taxes—it is just part of our way of life.

Sediment is the perfect example of the definition of a waste as being a resource out of place. Sediment has a bilateral effect. It depletes the land resources from which it is delivered and impairs the quality of the water resources in which it is entrained and deposited.

Sediment carried by streams has been both a benefit and a curse to agriculture for over 5,000 years. Sediment deposited from the annual overflow of the Nile River during the reigns of the Pharaohs and their followers added a modicum of fertility for the agriculture of that valley in ancient Egypt. The relatively efficient crop production so made possible enabled the release of large forces of labor to build the massive structures of masonry that are now prime tourist attractions.

Sediment brought down the Tigris and Euphrates Rivers, following wars and destruction of water control works, led to the eventual disappearance of the fabulous civilization of ancient Sumeria. The sediment was deposited in, and eventually destroyed, the brilliantly engineered canal system built by the Sumerians in the fifth to third millenia B.C., to provide an irrigation agriculture that supported an astounding construction of magnificent buildings in prosperous cities. Some historians have indicated that the high level of civilization in ancient Mesopotamia was destroyed by the vicious raids of Mongols led by Hulagu Khan in A.D. 1258. But recent evidence indicates that Hulagu and his horsemen found nothing but desolation when they invaded the region. Archeologists Jacobsen and Adams (*60*) found that by the 12th century the natural phenomena delivering sediment into the irrigation waters had caused far greater devastation to the irrigated land, and thus to the food supply of the cities, than any invading hordes could have inflicted.

These bits of history leave no doubt that sediment in water can adversely affect agriculture.

The sediment burden in streams may come from many different sources through the erosion process. It arises from forested lands that have been devastated by fire, construction of forest roads and other forest improvements, certain logging practices, overgrazing and trailing of animals on rangelands, cultivated lands that are inadequately protected, industrial construction sites, highway construction, unprotected roadside cuts, suburban development projects, spoil banks from strip mining and other mining activities, unstabilized stream banks, and geologic erosion of such areas as the Badlands of South Dakota. The land is robbed and the water despoiled.

The material is entrained by water in motion, transported by moving water, and deposited by relatively quiet or still waters.

Aside from filling stream channels, irrigation canals, farm ponds, and reservoirs used for irrigation, recreation, fishing, and farmstead water use, sediment in water increases the expense of clarification of the water used on the farmstead or in sprinkler irrigation systems. Suspended sediment impairs the dissolved oxygen balance in water and thereby slows amelioration of other oxygen-demanding wastes. Reduced oxygen supply hurts fish life. Fish population is also reduced by the sediment blanketing fish nests, spawn, and food supplies. The thousands of farmers using farm ponds to sell fishing rights are much concerned with the deterioration of water quality by sediment burden.

Recreational interest in water in the ponds of farms and ranches varies inversely with muddiness of the water.

The useful life of many farm ponds is surprisingly short because of sediment accumulation. Surveys on 30 farm ponds in the Iowa and Missouri Deep Loess Hills land resource area showed that, on an average, they would be completely filled with sediment in 20 years. However, the ponds will have been rendered essentially useless, and many will have become a nuisance, long before their original water storage capacities have been replaced by sediment.

The adverse effect of waterborne sediment upon agriculture is by no means limited to losses associated with recreational use of farm and ranch ponds. Damage to agricultural land resources from overwash of infertile materials, impairment of natural drainage, and swamping and increased flooding because of sediment accumulations in stream channels are also aspects of the silt problem having a direct bearing on farmers and ranchers. Irrigation canals and waste water disposal ditches are also subject to costly maintenance because of silt deposited from muddy water.

Ford (*43*) estimated that sediment damages in upstream watersheds come to about $87 million annually. The damages from this particular resource waste are over and above those caused by gully erosion, flood plain scour, and streambank erosion and by impairment of water quality from sediment in farm ponds and farm water supplies.

In the nearly 4 billion tons of sediment that are delivered to our waterways each year, the equivalent of 4 million acres of topsoil are transported. We can validly assume that at least 75 percent of this mass is derived from agricultural and forested lands and that it will have an average analysis of 0.10 percent nitrogen, 0.15 percent P_2O_5, and 1.50 percent K_2O. This means that more than 50 million tons of primary nutrients are lost from our agricultural and forested lands each year through sediment delivery.

The adverse effects of sediment in streams on agriculture and forestry is indeed a Texas-size problem.

Plant Nutrients

Plant nutrients in the soil are a must for food on the table. Volumes of benign words have been written on the essentiality of fertile soils to meet one of the basic needs of mankind. But when these nutrients become resources out of place in ground water and surface water, they are serious pollutants. There are about 150 species of algae and other aquatic plants that grow in farm ponds, woodland lakes, canals, and tributary streams. Aquatic plants must have mineral nutrients to flourish; and flourish they will if the plant food is there. Lack of phosphorus appears to be the main limiting factor in the growth of these plants in most waters, but nitrogen is also required.

These nutrients may enter surface waters by way of runoff from fertilized fields; runoff from barnyards and feedlots; municipal and rural sewage; sanitary facilities in recreation areas; and industrial wastes.

Accumulations of water-loving plants on farm ponds and similar surface waters impair use of the water for recreation. Such plants may reduce fish production and harvesting, impede boating and swimming, and provide a good habitat for mosquitoes and snakes. When these plants die, they become a pollutant with high oxygen demand while deteriorating. In turn, this deterioration evolves offensive odors, bad tastes, and seriously impairs fish life.

As of June 30, 1965, the Department of Agriculture had given technical or cost-sharing assistance, or both, in constructing 1,420,733 farm ponds. Unwanted growth of water plants now limits the usefulness of an appreciable number of these ponds.

Canals and ditches used for irrigation and drainage may have their usefulness seriously impaired by becoming clogged with growths of aquatic weeds. Measurements have shown that ditch capacity may be reduced to one-third or one-fourth and the reduced capacity may contribute to flooding. The control of aquatic weeds in irrigation ditches is a major item in the maintenance costs to irrigation and drainage districts.

As of June 30, 1965, the Department of Agriculture had provided technical or cost-sharing assistance, or both, in establishing 37,179 miles of irrigation canals and laterals, as well as 279,256 miles of drainage mains and laterals. These figures do not reflect the total installation of these waterways, since the Bureau of Reclamation, State agencies, and private concerns were also involved in ditch construction and maintenance.

Agriculture and forestry are indeed adversely affected when plant nutrients become wastes in surface waters and thereby permit aquatic weeds to luxuriate.

Concern is mounting over the presence of nitrate and small amounts of nitrite in ground water in many parts of the country because of the toxic effects on livestock and rural people using wells for drinking water.

The sources of nitrate and nitrite in ground water are usually considered to be (*a*) naturally occurring accumulations, (*b*) nitrogen fertilization, (*c*) sewage, (*d*) corrals, and (*e*) industry.

Farmers must be concerned with the nitrate content of the water in their wells. Nitrate poisoning can affect both cattle and infants. In ruminants, such as cattle, micro-organisms in the rumen reduce the nitrate to nitrite. Nitrite converts the hemoglobin in red blood cells to methemoglobin, which cannot transport needed oxygen from the lungs to body tissues. Thus, nitrate poison shows the general symptoms of oxygen deficiency. Since swine are not ruminants, they are much less susceptible to nitrate poisoning than cattle are. An example of damage to agriculture by an industry was recently reported in the West where a fertilizer plant was put in operation slightly upstream from a large cattle and sheep enterprise. Shortly thereafter, this livestock enterprise experienced abortions of 3,100 ewes and 300 cows. Losses in lamb and calf drops from nitrate in water or feed have long been recognized as serious.

In infants, particularly those under 6 months of age, the pH of the stomach tends to be above 4, permitting growth of organisms that reduce nitrate to nitrite. Here again, in such infants the hemoglobin is also converted to methemoglobin, causing an affliction known as "blue baby." The incidence of blue babies is largely on farms depending on well water for drinking.

From 1947 to 1950, 139 cases of infant methemoglobinemia (blue baby), including 14 deaths, from nitrate in farm wellwater supplies were reported in Minnesota alone. Adults drinking the same water are not affected, but breast-fed infants of mothers drinking such water may be poisoned. It has been reported that cows drinking water containing nitrate may produce milk sufficiently high in nitrate to result in infant poisoning.

There are no reports of methemoglobinemia in infants fed water from public water supplies in the United States, although levels in nitrate in some may be in excess of 45 mg./liter. Thus, the evidence shows that farm people are the ones who are adversely affected by nitrate in water supplies.

Inorganic Salts and Minerals

Farmers in the Imperial Valley of California know about salt. This very productive valley is entirely dependent on Colorado River water for survival as an economic entity. About 3 million acre-feet of Colorado River water is brought into this valley each year through the All-American Canal. Colorado River water at Imperial Dam contains about 750 p.p.m. dissolved salts—a rather moderate level. But this concentration means approximately 1.2 tons of salt per acre-foot of water. An irrigator applying 5 feet of water over the season, also applies 6 tons of salt per acre.

Since evapotranspiration consumes water and leaves the salt behind in the soil, extra water over and above consumptive use must be added to leach the salt residue below the root zone, to avoid excessive salt accumulation. The saltier the available water supply, the more water will be required for leaching. Since the valley receives over 3 million tons of salt in the irrigation water each year, 3 million tons of salt must be removed annually from the irrigated soils into the elaborate drainage system in order to maintain a favorable salt balance. Fields that are improperly managed with respect to leaching and drainage produce only one crop—"Imperial Valley snow"—a white crust of sodium sulfate. When this happens, agriculture is not only hurt, it is virtually eliminated. Adverse effects on production take place at even modest levels of salinization because of stunted crop growth.

Inorganic salts and minerals that impair the quality of soils and waters derive from natural deposits, acid mine drainage, industrial processes, and return flow from irrigated areas. The main losses to agriculture occur through salt accumulation on irrigated soils with its consequent effect on crop production.

There are about 30 million acres of irrigated land in the 17 Western States. Salinity is a potential hazard on about half of this acreage, and crop production has been affected adversely by salt in the soil on about 8 million acres.

Rainfall generally contains negligible quantities of salt, but as the water flows over and through the land, its salt content increases. Salts are formed in the soil by solubilization of soil minerals, or they may be present in geologic deposits such as saline shales. In arid climates, soils may contain appreciable quantities of salts because rainfall and drainage are often inadequate to leach out the salt. Thus, surface and ground waters in arid regions may contain moderate, and even high, concentrations of salt as a result of normal or natural processes. When such natural waters are used by man, the salt content may be increased by the addition of salts not originally present in the water. Thus, metropolitan and industrial wastes can increase the salt burden of the water system. Such salt additions are usually minor in importance, although in certain cases, such as in the contamination of surface and ground waters by brines from oil well fields, the additions can be critical to the further use of the water for agriculture.

The salt concentration of the water system may also be increased by evaporation of the water. Industrial and municipal use of water contributes relatively little to this effect, since only about 7 percent of water diverted for these uses is evaporated. Agricultural use, on the other hand, results in evaporation of 60 percent of the diverted water. Thus, agricultural use tends to concentrate the salt in the water, whereas industrial and municipal use largely adds exogenous salts.

In addition to total salt content, the salt components may be altered by the use of the water. For municipal and some industrial uses (boiler water), it is necessary to soften the incoming water supply by replacing calcium and magnesium with sodium. The effluent water will, therefore, be enriched in sodium at the expense of calcium and magnesium, and its quality for agricultural use thereby impaired. Reclamation of sodic soils effects similar changes in the quality of the water used in leaching, although total salt content as well as the proportion of sodium may be greatly increased in the effluent.

Initial use of water for irrigation also results in changes in composition, as well as concentration, of dissolved salts. Some precipitation of lime and calcium sulfate may occur as the volume of the water is reduced by evaporation, whereas the more soluble sodium salts do not precipitate. The effluent water, therefore, is often relatively more enriched in sodium chloride than in the sulfates or bicarbonates of calcium. Both increasing salt concentration and altered ionic compositions of once-used waters have great significance in their reuse potential for agriculture.

Although all crops tend to exhibit decreased growth and yield with increasing salinity of the water supply, the differential salt tolerance of crops and the specific sensitivity of some crops to some ions make a single-scale set of values for irrigation water quality quite unrealistic. Soil, climatic, and management factors also influence how damaging an increase in salinity of the irrigation water supply will be. When all conditions are favorable, an increase in total salt content of the water supply from a few hundred parts per million to even a few thousand parts per million may not affect agriculture adversely. Under less favorable conditions, such an increase of salinity may render the water totally unfit for further use.

A high proportion of sodium in the irrigation water supply will affect soils and plants adversely because sodium causes soil aggregates to disperse and renders soil highly impermeable. Thus, water softened for metropolitan use is usually unsatisfactory for irrigation. The sodium may also be directly toxic to woody plants (fruit crops) at levels well below those that cause deterioration of soil properties.

Other specific salts or ions may be highly injurious to plants. Boron, although essential for plant growth in concentrations of a fraction of a part per million, rapidly becomes toxic as concentrations in the water increase above 1 part per million. Municipal use and some industrial processes involving borax or other boron compounds may add enough boron to the water to preclude its further use for agriculture or for supporting growth of native or ornamental plants.

It has been estimated that about 25 percent of the irrigated lands of the United States are now affected to some degree by salinity. As available water resources are used more intensively, the incidence of salinity problems will increase because saline return flows usually mix with the river or ground water supplies, thereby salinizing the water available for further use.

The use of salt on highways to melt snow and ice from winter storms is creating very serious problems to rural areas in many States. Salt running off the highways has killed trees and shrubberies along the frontage of farmsteads. Worse yet, the salt has penetrated into the ground water, and rural wells have been condemned because the water was polluted with excessive levels of chloride.

Salinity from return flow in the lower Colorado River has caused an international problem with Mexico. This was solved by building a bypass concrete-lined conveyance which returns the drainage water to the Colorado River below the point at which Mexico diverts its water for irrigation.

Agricultural and forestry endeavors using tributary streams for recreational benefits are concerned with acid mine drainage. In Pennsylvania alone, about 2,000 miles of streams are ruined by acid mine drainage. The acidity of mine drainage is usually due to the oxidation of iron pyrites to ferrous sulfate and sulfuric acid. Estimates of the amount of sulfuric acid reaching streams in the United States run into about 3 million tons annually. At present there is no satisfactory way of reducing this acid load. The problem is serious in the coal mining areas of the Ohio River Basin, but the adverse effects on agriculture and forestry are minor in relation to the effects of other wastes.

Organic Wastes

Sir Albert Howard (*56*) had an answer for the problem of coping with vast accumulations of vegetable, animal, and human wastes: Make humus out of the stuff by his Indore Process. The humus so produced would benefit many soils. For the product to have economic feasibility, someone would have to provide large masses of very cheap labor for all the collection, piling, stirring, repiling, and distribution activities.

We lack economical procedures for effectively handling all the mountainous quantities of putrescible organic substances coming from domestic sewage, garbage, food processing industries, lumbering operations, pulp mills, crop residues, and animal and poultry enterprises. This group of wastes is rather readily attacked by aerobic bacteria to reduce them to more stable compounds. Thus, when these wastes are dispersed in water, the oxygen content of the water may be seriously or completely depleted by the action of decomposition processes. When the oxygen in the water is reduced to zero by the demands of aerobic decomposition, a different type of bacterial action occurs—nonoxygen-demanding, or anaerobic, bacteria take over the processes of reducing these organic wastes to inert materials. This latter situation produces what is called a septic condition, and the water takes on the dark-colored, evil-appearing, vile-smelling character of grossly polluted water.

Agricultural and forestry activities involving use of water for fishing or recreation cannot tolerate waters having organic wastes that have not been fully assimilated by action of aerobic bacteria. Since recreational use of water in association with agriculture and forestry has become an activity involving expenditures of hundreds of millions of dollars, water polluted from anaerobic decompositions of organic wastes may have serious economic consequences on such activities.

Water that is polluted in any way or shows the effects of additions of organic wastes that have not been fully assimilated by aerobic decomposition cannot be used on the farmstead. Agriculture faces serious limitations on use of water for irrigation on crops used for food, if that water is polluted with unassimilated wastes.

Accumulations of putrescible wastes may hurt agriculture in other ways than by entering into water supplies. Manure heaps, piles of crop residues, and accumulations of food-processing wastes usually emit pungent aromas that are offensive. Along with the stench, piles of animal wastes can be tremendous spawning grounds for flies and other vermin that pester livestock as well as people. Large sums are spent each year on insecticides to control pest production around manure piles.

As suburban people move into agricultural areas, they protest against accumulations that give off foul odors. When the protests are legally sustained, agricultural people may have to pay a high price to meet imposed restrictions.

Within the last 6 years, 43 California dairy farms having a total of about 12,000 cows have had to relocate from the Los Angeles area to the Bakersfield area, a distance of about 80 to 100 miles, because of their "noncompatibility" with activities of the expanding Los Angeles metropolitan area. Provision of new facilities for these dairies averaged about $112,000 each, of which $35,000 to $42,000 was for constructing milking facilities. The total relocation cost within this one county for the milking facility portion of these enterprises alone is over $1.6 million. Such relocations have occurred in several other areas and States and the problem will probably increase. These relocations apply to all classes of livestock. The costs to agriculture are high.

Lawsuits are pending in Milford, Tex., pertaining to a 27,000-head beef cattle feedlot located well out in the country. The owners had purchased land to provide what they thought to be an adequate buffer zone between themselves and the other rural residents. The feedlot operators recently had 11 damage suits, averaging about $15,000 each, filed against them. Four have been settled, with the court allowing claims ranging from $2,500 to $7,500. One claim, for death of cattle, was denied primarily because the claimant had failed to have a veterinarian determine the cause of death of cattle downstream from the feedlot. The other claims are still in litigation. Odor nuisance, dust, insects, water pollution, and noise are among the grievances alleged.

Coping with manure accumulations can cost money. Farmers are suffering from damage suits and are having to make costly changes.

In Sullivan County, N.Y., poultry and tourist industries have conflicting interests. In one instance, the State supreme court issued a temporary injunction against a large poultry producer restraining him from allowing noxious odors to permeate the air of two adjoining resorts pending the outcome of a $125,000 lawsuit against the producer. The injunction was issued in spite of the fact that the poultry industry represents a large part of the county's income. These poultrymen have received a rough blow. Other damage actions have been filed, but it may take years for courts to decide and the decision will not solve the problem.

Removal from animal quarters, transport, and, where feasible, spreading of animal waste on land represent a significant item in the cost of production. A 1961 Michigan study indicated that beef feedlot operators spend $3.43 per head marketed and dairymen $9.29 per head for waste removal and spreading. An Illinois study indicated that annual operating costs were $0.62 to $1.28 per hog. A million-bird laying operation in Mississippi estimates the annual waste handling costs at $100,000, or $0.10 per bird. A Maryland egg farm with automated cage operations spends about $0.12 per dozen of eggs. Other operators of egg farms have reported costs more than double this amount. Eastern Shore (Delmarva) broiler producers are paying about $9 per 1,000 birds ($0.09 per bird) to contract removal companies for each cleaning, which may be as frequent as four times a year.

These studies emphasize that in earlier times manure was highly prized as a source of soil fertility, whereas now it has become a costly burden to many livestock operators. Furthermore, costs in the future probably will rise as better pollution abatement procedures become mandatory. These procedures will not increase either the quality of the product produced or the efficiency of production. The economic value of manure as a fertilizer or a gas does not compensate for the processing required to modify the manure. Hence, manure disposal systems can only add to the cost of production.

The adverse effects of accumulations of putrescible wastes on agriculture and forestry are growing to major proportions. Surface waters associated with the farm, the ranch, or the forest are a great source of potential revenue for fishing and recreation if they can be kept free of oxygen-demanding wastes. On the other hand, the financial burden to farmers for coping with wastes that are offensive is becoming tremendous.

Infectious Agents and Allergens

Man's hard march down through the ages is largely a record of calamities induced by three grave adversities: Famine, pestilence, and war. One can argue that the ravages of pestilence kept famine from being more extensive than that recorded. However, an infectious agent attacking a food crop caused one of the most serious famines in history. Late blight of potatoes almost totally destroyed this main food crop in Ireland in the middle 1840's. Records indicate that the physical misery and spiritual anguish because of the famine caused by this one crop disease go far beyond anything that ordinary experience equips one to understand. The farmers suffered along with everyone else.

Phytopathogens

The infectious agents of bacterial and fungus diseases of field crops, fruits, and forest trees are almost entirely carried by wind, water, or soil. Many of the most serious virus diseases of plants are carried by insects, and such insects cannot be ignored in evaluating the effects of infectious agents on environmental quality. The destructiveness of these plant diseases merits a few illustrations.

In the 50 years or so since chestnut blight was first discovered in this country, this disease has killed virtually all of the American chestnuts, one of our finest hardwoods, in its native range.

Fifty years ago, white pine blister rust was making extensive ravages in one of our finest conifers. Our white pines would have been doomed within a few years except that the fungus had to be transmitted back and forth under proper aerial environment with the alternate hosts, currants and gooseberries. An extensive campaign of eliminating these alternate hosts saved our white pines.

A wheat stem rust epidemic destroyed almost 300 million bushels of wheat in the United States and Canada in 1916.

In the epidemic year of 1935, stem rust caused a 60-percent loss to the wheat crop in Minnesota and some of the neighboring States, and the loss for the whole country was almost a quarter of the crop.

As recently as the 1950's, losses to the Nation's wheat crops from the highly destructive stem rust race, 15B, were estimated at over 8.5 million bushels annually in 1953 and 1954. A large part of the spring wheat crop was virtually eliminated in those years.

In 1946, airborne spores of the late blight disease of tomatoes caused an estimated reduction of 50 percent of the national tomato crop.

Thirty to forty years ago, Granville wilt of tobacco was taking 20 to 50 percent of that crop in Granville County, N.C. The physical and mental sufferings of the farmers because of economic losses incurred by this bacterial disease were enormous.

Crop diseases may be spread by agricultural machines that move contaminated soil on wheels or carry disease organisms on the blades of mowers. Thus, diseases are spread most rapidly in the direction of cultivation. Contact of plants often is necessary in the spread of disease fungi which produce no spores but spread by slow mycelial growth from one plant to the next. Texas root rot and Rhizoctonia root rot exemplify such cases.

In picking beans when the vines are wet, the hands distribute the bacteria of bean blight so effectively that the greater part of the crop may be lost.

Handling of tobacco or tomato plants in transplanting, pruning, and staking may be followed by 100-percent infestation of tobacco mosaic.

Weed Seeds

Farmers' fields can be infested by weed seeds that are transmitted by wind, soil, birds, and animals. In a sense, these seeds become infectious agents, since weed pests can be just as harmful to a crop as insects or diseases. Wind is the natural disseminator of many weed seeds to millions of acres of cropland. Use of irrigation water contaminated with weed seed reinfests thousands of acres of irrigated land each year. Spreading manure, especially that with an abundance of bedding, spreads weed seeds.

Witchweed, a parasitic plant, produces thousands of microscopic seeds that are easily disseminated by wind, water, or soil. The spread of these seeds increases the cost of quarantine and eradication programs.

Seeds of many weed species are poisonous to livestock, birds, and wildlife. A number of *Crotalaria* species have poisonous seeds (*114*).

These natural mechanisms of weed seed dissemination provide for continual replenishments of these weeds in soils. Some degree of weed control is needed on 365 million acres of cropland each year. Weed and brush control are urgently needed on several hundred million acres of rangeland.

Farmers spend about $2½ billion annually to control weeds. Yet during the period 1951–60, the estimated annual loss due to reduced crop yields and quality caused by weeds varied from 3 to 25 percent, depending on the crop.

The winds that transport infectious agents to soil, water, crops, and trees can be just as devastating in terms of financial loss and human suffering as the waters that transmit scarlet fever.

Nematodes

Nematodes move from one infested area to the next on plants and soil and in water. Irrigation water is suspected to be a principal means of distributing nematodes affecting alfalfa in the Northwest. Direct examination and bioassay of irrigation water from a farm pond in south Georgia indicated several species of plant-parasitic nematodes can be spread by irrigation water.

Animal Disease Agents

Agricultural losses caused by infectious agents of livestock and poultry carried by air, water, and soil have also been great. Some of the animal diseases that may be so transmitted are leptospirosis, salmonellosis, hog cholera, mastitis, foot and mouth disease, tuberculosis, brucellosis, histoplasmosis, ornithosis, infectious bronchitis, Newcastle disease, anthrax, blackleg, foot rot, coccidiosis, blackhead of turkeys, erysipelas, and transmissible gastroenteritis.

Hog cholera was first noted in this country in the 1880's, but it spread rapidly. The virus causing the disease may be picked up from polluted water, polluted soil, or polluted feed. Over the years, the ravages of this disease have caused losses of hundreds of millions of dollars to hog farmers.

Brucellosis of cattle, swine, and goats can be spread by water, feed, or soil polluted with the causal bacteria.

In the summer of 1966, approximately 130 clinical cases of encephalitis in horses were reported in southern Louisiana. Mosquitoes developing in the waste waters of marshlands carried the infectious agent. This example well illustrates how stagnant water may provide the vectors for a serious infection afflicting agricultural endeavor.

Costs

Infectious agents transported by the environment are causing heavy annual losses to agriculture and forestry. In fact, each crop and domestic animal grown on a large scale in the United States is susceptible to one or more highly infectious diseases that may be transported by air, water, or soil.

During the 1950's, estimates of losses in potential production of domestic food animals because of diseases ranged from an average of 3 to 28 percent annually. During 1966, there were over 100 million cattle on U.S. farms valued at more than $14 billion. The value of all meat animals exceeded $17 billion. Thus, losses on the order of 10 percent are staggering. The infectious agents of most all of these diseases were carried in wind, water, or soil.

Estimates of losses in production potential owing to diseases of pasture and range plants varied from 3 to 9 percent for the same period. Comparable figures for fruit and nut crops and for vegetables are 2 to 38 percent and 2 to 23 percent, respectively.

In 1965, losses from forest diseases amounted to 1.2 billion board feet; equal losses were suffered from forest insects (*124, p. 101*). This would have been enough lumber to build 100,000 five-room frame houses.

Agricultural and Industrial Chemicals

In 1828, Friedrich Wohler achieved the first synthesis of an organic compound; that is, he produced urea from ammonium cyanate. Hundreds of thousands of organic chemicals have since been synthesized: many with powerful physiologic action; many that sometimes seem to be a curse.

The organic chemicals under discussion are largely detergents, insecticides, herbicides, fungicides, nematocides, rodenticides, growth regulators, defoliants, and miscellaneous industrial byproducts that may impair quality of air, water, and soils. Proper use of many of these chemicals has made tremendous contributions to human convenience (use of detergents), human health (controlling disease-carrying pests), and human welfare (greatly augmenting needed food production).

Just as ordinary aspirin may be misused and cause human deaths each year, the kinds of chemicals aforementioned may be misused. Agricultural endeavor may suffer from unwise, inadvertent, or careless use of these organic chemicals.

Detergents

Detergents entering into sewage effluent from rural homes, rural communities, or camping areas in National Forests adversely affect the operation of septic tanks. These chemicals effectively disperse the soil particles as part of their cleansing action. They retain this capacity in moving through a sewage disposal system such as a septic tank into a tile system dispensing the effluent. Clay particles adjacent to the tiles become dispersed and seriously lower soil permeability to water near the tile line. Thousands of septic sewage disposal systems have become inoperative or malfunctioning, depending on the nature of the soil. Adverse effects of detergents on the tile dispensing system may be especially serious in soils containing appreciable amounts of clay.

If treated sewage effluent is used for irrigation, and if detergents in the sewage are not biodegraded, use of such water would impair rate of infiltration of water into the soil and possibly lower irrigation efficiency. This possible adverse effect of detergents on agriculture has not been fully explored.

Concern has been expressed from time to time that detergents in water used for livestock may be adverse to their health, but this has not been demonstrated.

Insecticides

Along with their many benefits to agriculture, insecticides can adversely affect agriculture in many ways.

The application of insecticides to protect cotton led to drift that destroyed the beneficial insect complex in citrus groves, necessitating the use of insecticides to control certain pests of citrus that were ordinarily controlled by beneficial insects.

The use of malathion to control and eradicate a cereal, forage, or forest insect pest has destroyed honey bees and other insects necessary for crop pollination.

The application of persistent insecticides to potato lands has led to residues in sugarbeets grown in the same soil the following year, for which there are no tolerances.

Residues may occur on agricultural commodities as a result of accidental contamination, inadvertent use, or even recommended use of pesticides. Losses from condemnation may be serious. Congress authorized an appropriation of $10 million to reimburse cranberry growers following confiscation of certain lots of cranberries found to contain illegal residues of a herbicide. This herbicide had been applied by some growers at the wrong time of the growing season in spite of warnings from recognized authorities. Dairymen whose milk was confiscated because of pesticide residues were compensated in the amount of $350,000.

Fish in farm ponds have been killed because of the drainage of insecticide wastes from nearby lands into these ponds following heavy rains.

Pesticides such as heptachlor and aldrin formerly were applied on rangelands to control grasshoppers, but their use was discontinued. Residues of these pesticides in meat of beef animals are not permitted. Such uses are no longer registered.

The use of heptachlor in the past for the control of alfalfa weevil has led to soil contamination, and through translocation or external contamination of the hay during harvest has caused nonpermitted residues in milk of dairy cows consuming such hay. This use is no longer registered or recommended.

The application of persistent insecticides, such as dieldrin for the eradication of the Japanese beetle, led to low-level but significant residues in livestock grazing in the eradication area.

The careless disposition of insecticide and insecticide containers has caused injury to livestock through contamination of drinking water and feed.

Improper use of insecticides and so-called empty containers have caused injuries, and in a few cases even death, to farmers and farm labor applying the materials, and has created hazards to workers in the treated fields.

Herbicides

Use of selective herbicides has made a tremendous contribution to agricultural and forestry production. But these chemicals can be misused or used without proper precautions. The adverse effects arising from the use of these chemicals fall predominantly on agriculture and forestry.

Spray drift and vapors from aerial and ground applications of herbicides for the control of weeds and brush on nonagricultural lands, such as utility rights-of-way, roadsides, railroads, ditchbanks, and industrial and aquatic sites, often cause damage to nontarget crops—flowers, ornamentals, and trees. The volatile ester formulations of the phenoxy herbicides cause the greatest number of damage claims, but other herbicides also may cause damage.

Drift from aerial application of a herbicide on a crop such as rice may seriously damage a sensitive crop such as cotton, even miles away. In years past, there were serious incidents of this sort, but adherence to careful field application procedures has largely eliminated this source of damage. In addition, many States now control the application of herbicides by aircraft.

A herbicide may be carefully tested under certain enviromental conditions for a specific crop and deemed to be completely safe: but under a changed environment, identical use on the same crop may cause serious damage. For example, prometryne was found to be completely safe for use as a selective herbicide on potato fields at many locations in the Northern States. However, in the San Joaquin Valley of California, residual effects caused serious damage to potatoes in the spring of 1966.

Herbicide wastes from sprayer-loading areas and storage areas, improper disposal of empty containers, and excess herbicides may damage nearby crops. Herbicide wastes may enter drainage and irrigation ditches and cause damage far removed from the source of contamination.

Fungicides, Rodenticides, Industrial Chemicals

Occasional incidents occur wherein careless handling or misuse of these substances cause damage to agriculture or forestry, but adverse effects from these entities are much less than those experienced from insecticides and herbicides.

Seriousness of the Problem

The presence of residues in agricultural commodities, resulting from accidental contamination or inadvertent use of pesticides could constitute a significant economic problem. Small quantities of potatoes, sugarbeet pulp, and soybean oil have been seized because of pesticide residues. Such events can adversely affect consumer acceptance and consumption of agricultural products once these incidents are brought to public attention.

The economic impact from the loss of honey bees and other beneficial insects, due to pesticides, has not been determined. In areas highly dependent on pollinating insects the losses could be substantial.

The economic losses incurred by damages from herbicide vapors and spray drift are unknown. However, the litigation and damage claims were sufficiently serious during the past 20 years to cause passage of laws and establishment of regulations in 45 States which authorize certain restrictions on the use of herbicides.

Damages to agriculture have occurred from use of pesticides, but the benefits far outweigh the damages. Whitten (*133*) has provided a penetrating review of the evidence concerning adverse effects from using pesticides. Mistakes have been made. Decisions and recommendations have in the past proceeded from inadequate information. We must exercise every caution. But when one considers all the evidence relating to the use of these chemicals, their great assistance in man's eternal fight against insects, diseases, and weeds dwarfs the damages incurred by inadvertent use.

Heat

Tremendous quantities of water are withdrawn daily from streams and lakes for cooling in industrial and processing plants. After use, these waters are usually returned to the stream or lake from which they were withdrawn. Large quantities of heat are thus transferred to these water bodies. Since the amount of oxygen that water can hold decreases with increasing temperature, the introduction of heat into water has the net effect of introducing additional oxygen-demanding pollutants.

Added heat to streams and other water bodies is adverse to fish life in terms of oxygen supply. Heat also has a direct detrimental effect upon fish and other aquatic life because it changes their physical environment. Some fish can stand only a few degrees increase in temperature.

Forests providing recreational and fishing rights on associated lakes and streams, rural area development programs providing fishing opportunities, and farmers and ranchers providing fishing opportunities in their ponds, lakes, and streams can be and frequently are hurt by loss of fish life as a result of heat added to these waters.

Although heat as a water pollutant is not a waste having a major adverse effect on agriculture and forestry, the growing interest in providing recreational opportunities in rural and forested areas indicates that the effect of added heat on fish life will arouse mounting concern.

APPENDIX II

Wastes From Agriculture and Forestry

Of the total wastes produced in the United States, agriculture and forestry contribute a share, but not an inordinate share. In fact, agriculture provides a prime means for amelioration or disposal of many wastes that might otherwise pollute the environment.

A grouping of substances that impair the quality of the environment was set forth in appendix I. Where applicable, this list will be followed in appendix II. The discussion will cover—

1. Chemical air pollutants
2. Dusts
3. Sediment
4. Plant nutrients
5. Inorganic salts and minerals
6. Organic wastes
7. Infectious agents and allergens
8. Agricultural chemicals

Chemical Air Pollutants

The burning of plant residues in fields produces a small amount of photochemical air pollutant. Trash and residues in forests that burn produce a significant amount of hydrocarbons that may become photochemical air pollutants to the leeward of a forest fire.

These possible sources of photochemical air pollutants from agricultural and forestry activities are mentioned in the discussion of organic wastes.

Dusts

Thirty million tons of natural dusts are emitted into the atmosphere of the United States during the average year. This is equivalent to the topsoil from 30,000 acres of land. Agriculture makes no claim to being the source of all of this dust, but windblown soil is by no means a minor contributor.

Agricultural dusts arise from processing operations such as cotton gins and alfalfa mills, as well as from the soil of unprotected fields.

Cotton Ginning

Dust and lint particles emitted from cotton gins create a distinct nuisance to everyone in the vicinity of a cotton gin during operation. The smaller particles are reported to be the most injurious to health and the most widely dispersed by wind currents. The bulk of the dusts settles within 300 feet of the gin, but smaller particles are carried a half mile or more.

Medical authorities report a noticeable increase in human respiratory ailments in the vicinity of cotton gins when they are operating.

Throughout the 14 major cotton-producing States there are about 5,000 gins, which process an average of 3,000 bales each season. The foreign matter to be discarded ranges from 50 pounds per bale for handpicked cotton (of which there is now very little) to more than 2,000 pounds per bale for machine-stripped or machine-scrapped cotton. Gins must dispose of up to 3,000 pounds of waste per hour. The dust includes soil particles, pollen, fungi, fibers, pesticide residues, and various types and sizes of vegetative matter.

Over 50 percent of this trash is burned at the gin. With cotton production at 15 million bales and a thousand pounds of trash per bale, some 3,750,000 tons of residues are burned, giving rise to 375,000 tons of particulates in smoke.

Years ago the gins were established in open country. In many instances, residences and businesses have now moved into the immediate vicinity of the gin. Often, the city limits have extended to include gin property. Lawsuits have been instituted as a result of the various nuisances and some gins have had to be moved.

As mechanical cotton harvesting brings more trash from the field to the gin, the production of dust at the gin will increase.

Alfalfa Dehydrators

Alfalfa processing plants discharge dust and small vegetative particles into the atmosphere. Since the plants are located near the source of raw materials and remote from centers of population, they are more serious contributors to pollution in rural areas than in suburban areas.

Airborne Soil

Airborne soil can depress visibility; act as an irritant and health depressant to people; impair machinery; cover up highways and railroad tracks; fill ditches, fences, and waterways; cause dirtiness in homes, offices, schools, stores, and factories; and exasperate people.

Measurements in western Kansas and eastern Colorado in 1954–55 during a period of relatively severe blowing indicated visibilities as low as $\frac{1}{20}$ of a mile associated with dust loads of 1,290 tons per cubic mile (8 mg. per cu. ft.). The reduced visibility is often a cause of serious automobile accidents on the highways of the Great Plains.

The local newspaper in Dodge City, Kans., carried this item on April 6, 1893:

> The dust was blinding and was deposited so thickly on the office furniture that everything looked as though it were covered with a layer of dirt prepared for a hotbed.

The same situation prevailed in many, many homes, offices, schools, and factories during the 1930's and mid-1950's in the Great Plains. This situation occurs nearly every year at some locations in the Plains. Such duststorms have a pronounced effect on the health and morbidity of the population. In addition, the general atmospheric conditions are very irritating to those who live or travel in the area.

Airborne dusts can be carriers for other entities. Dusts arising from cattle corrals may be astringently aromatic, but this does not improve their acceptability. Significant amounts of pesticides may be carried on the dust, and awareness of this does little to placate the recipients.

One does not need to be a mechanical engineer to appreciate what such heavy burdens of airborne soil do to machinery bearings or the innards of internal combustion engines.

The main cause of soil blowing is devegetation of the land. Drought is an ancillary cause by its effect on vegetation. Any trend in agricultural production that would increase land under the plow in the Great Plains would increase the potential for wind erosion and duststorms. This possibility bears watching. Sound conservation practices on the land will be the main countervailing force.

The nasty effects of airborne soil are not confined to the Great Plains. During the severe duststorms of April 1934, the sun was beclouded by the dust as far east as Washington, D.C. The irritations of windblown soil on people, their habitations, and their work are found in many parts of the country, including the Columbia Basin, the Coachella Valley of California, the Connecticut Valley of New England, and around many of the cultivated areas along the Atlantic Coastal Plain.

At noon on January 26, 1965, a weird red cloud appeared over Cincinnati, Ohio. Soon thereafter, people, houses, cars, and sidewalks were covered with a cloak of red dust. Officials in Cincinnati measured this fallout dust and found that it amounted to 9 tons per square mile. They calculated that 140 tons were deposited in the city proper, and 1,800 tons in the four-county metropolitan area. The deposit took place within an hour. The dust had traveled by wind more than a thousand miles from the plains of Texas and Oklahoma. Tests by scientists at the Robert E. Taft Engineering Center in Cincinnati indicated that the dust contained pesticides.

Seriousness of the Problem

The adverse effects of airborne dusts arising from agricultural endeavor include illness, irritation, morbidity, and exasperation of afflicted people; all-pervading silt within their homes; and filth and depredation upon their work-a-day locations and equipment. The problem is not of minor concern.

Sediment

Sediment derived from land erosion constitutes by far the greatest mass of all the waste materials arising from agricultural and forestry operations. Committee Print No. 9 of the Senate Select Committee on National Water Resources (*119*) states:

> Rough estimates of the suspended solids loadings reaching the Nation's streams from surface runoff show these to be at least 700 times the loadings caused by sewage discharge.

Wolman and others (*137*) emphasized that pollution of the Potomac River by sediment is so great it dwarfs the effects of all other pollutants.

The Mississippi River dumps more than 500 million tons of sediment into the Gulf of Mexico during the average year. This amount constitutes about half of the average annual sediment delivery to the oceans by the rivers of the conterminous United States. Brown (*20*) estimated that only one-fourth of the silt produced by erosion from our watersheds ever reaches the ocean. Thus, total sediment production in the United States runs about 4 billion tons a year.

Sediment production from representative basins in the United States varies from 51 to 10,000 tons per square mile (*19*). Sediment delivery varies widely according to soils, geology, topography, precipitation, vegetative cover, and applied soil conservation practices.

Measurements of soil erosion from field plots leave no doubt that cultivated fields can be major contributors to the sediment burden. Forested cover provides excellent protection against sediment delivery, but burned out forest land can be a tremendous contributor of sediment. Logging roads also become sites of erosion and sediment delivery.

Highway construction sites, barren roadbanks, mining operations, construction sites for industrial and suburban development, and eroding streambanks are also conspicuous sources of sediment.

Sediment suspended in flowing or impounded water may have a harmful effect on (*a*) water supply, (*b*) recreation, and (*c*) power generation.

Potable water must be free of sediment. Many industrial uses, for example, food processing, require sediment-free water. Sediment deposited in condenser tubes used in industrial cooling may cause costly incrustations. Cost of clarifying water increases with degree of turbidity. High turbidity of water adds costs through the need for greater use of chemicals as flocculants, and more frequent cleaning and disposition of silt from settling basins.

People like clean water for swimming and other recreational activities.

Fine suspended sediment has caused heavy losses of commercial fish and shellfish yield from both inland and tidal waters (*118*).

Coarse sediment passing through power plants has caused serious abrasion of turbine blades.

Deposition of sediment in stream channels or aggradation of flood-plain lands may impair drainage and cause channels to overflow more frequently. Floodflows carrying high sediment loads inundate a much larger area than comparable flows free of sediment (*19*). Floodborne sediment may damage growing crops; and sands, gravel, and such coarse debris when deposited on fertile alluvial soils may reduce their productivity.

Reduction of reservoir storage capacity is another devastating consequence of sediment. About 1 million acre-feet of sediment is deposited in artificial reservoirs of the United States each year. Loss of reservoir capacity to sediment has particular implications for programs of water resources development. Indeed, prevention of such losses is a primary justification for land treatment measures and watershed protection programs in many upstream tributary areas of the country.

Estuaries, bays, and coastal harbors tend to become vast sediment traps where continuous dredging and other operations are required for handling sediment. Commingling of fresh sediment-laden water and saline water, plus the influence of tides, waves, currents, and shipping traffic, complicate the depositional processes in such coastal areas, and we should recognize that sediment is a major contaminant of these areas.

We have become accustomed to thinking of the consequences of sediment in engineering terms; that is, as rates of reservoir silting, dredging of harbors, or channel systems. But we are now beginning to recognize other possible influences of sediment on our environment. We are concerned, for instance, about sediment as a carrier of pesticide residues and the significance of phosphorus adsorbed on sediment in the eutrophication of lakes and estuaries. There are few complete and definite answers to these questions.

Studies in various parts of the country have shown that erosion control practices in the forest, on the range, and on the farm can and do reduce the sediment delivery. The amount of sediment coming from watersheds having good conservation treatment at the Blacklands Experimental Watershed, near Riesel, Tex., is only 12 percent of that from watersheds farmed without soil conserving practices. Sediment yield from a 400-acre watershed receiving good conservation practices at the Central Great Plains Experimental Watershed, near Hastings, Nebr., was only 5 percent of that from a comparable 400-acre watershed that did not receive soil conservation treatment. Application of streambank erosion control measures on the 145-square-mile Buffalo Creek Watershed, near Buffalo, N.Y., reduced sediment delivery from that watershed to Buffalo Harbor by 40 percent. The average turbidity of the Chattahoochee River in Georgia was decreased to 82 percent by applying improved forestry and conservation practices to lands of the river basin (*6*).

Plant Nutrients

High crop production to meet ever-increasing food demands requires an adequate supply of plant nutrients in the soil. Americans applied 32 million tons of chemical fertilizers on their lawns, gardens, fields, and pastures in 1966. Those who are concerned with the adverse effects of plant nutrients in surface water sometimes find this seemingly large tonnage a convenient culprit.

The following table reveals the rather low level of chemical fertilizers being applied to arable soils in the United States compared with the Netherlands—a nation that has responded to the economic need of making highly efficient use of its available cropland.

Plant Nutrients Applied in 1965

[In pounds per acre]

Nutrient	United States	Netherlands
Nitrogen	22	244
P_2O_5	17	93
K_2O	13	116

Plant nutrients in water give rise to two problems of mounting concern: (1) eutrophication of lakes and streams and (2) nitrate in well water used for drinking.

Eutrophication

Complaints abound that many rivers, estuaries, ponds, lakes, and reservoirs are being ruined by a tremendous growth of algae and other water plants, forming what is known as "algal blooms." These blooms are not pretty, and on death and deterioration of the plants unpleasant odors are emitted. The decaying plantlife robs the water of the little dissolved oxygen that may have been present. The water becomes uninhabitable for fish and unsavory for recreation. These excessive growths of water plants constitute the eutrophication of surface waters. The process is an important stage in the death of a lake.

These algae, like all plants, must have mineral nutrients in order to grow. In most waters the main limiting factor for algal growth is phosphorus, since other elements, such as nitrogen, potassium, calcium, and magnesium, are present in much more abundant supply. Accordingly, the phosphorus level in river and lake waters becomes a matter of prime concern.

Available evidence indicates that these algae will grow vigorously if the water contains only 0.1 p.p.m. of phosphorus. It is also evident that the level of phosphorus in the water must be below 0.02 p.p.m., if the growth of algae is to be completely inhibited. The phosphorus content of the water in some streams and lakes may reach 1 p.p.m. Obviously, this water provides a good medium for the growth of algae.

About 1 million tons of elemental phosphorus is applied to the land as fertilizer each year in the United States. Average annual runoff of precipitation into the streams of the conterminous United States is 1,380 million acre-feet, or 1,875 billion tons. If only 10 percent of the applied phosphorus reached the streams as soluble phosphate, the average phosphorus content of our streams would be 0.05 p.p.m. On the basis of these figures, one could erroneously conclude that the phosphorus in surface waters is all coming from land runoff.

Considerable phosphorus is present in domestic sewage, largely arising from use of household detergents. On the average, about 2 pounds of phosphorus per person per year is delivered in metropolitan sewage effluent, but the Public Health Service reports that Lake Washington near Seattle, Wash., receives 3.4 pounds of phosphorus per capita per year from the treated sewage of 76,300 people (*10*). Thus, effluent from a city comprising 1 million people will contain 1,000 tons of phosphorus a year. If this amount of phosphorus enters a stream with an average annual flow of 10,000 cubic feet per second, the average phosphorus content of the water will be 0.1 p.p.m.—an adequate level for growth of algae. The Potomac River has an average annual flow of nearly 10,000 c.f.s.

In a situation like the one just cited, even if the total contribution of phosphorus to the stream by agriculture were eliminated, there would be little effect on growth of algae since the 0.1 p.p.m. of phosphorus in the sewage effluent would be sufficient.

Although some reports have implied that phosphorus in surface waters was a result of fertilizer applied to farms, Verduin[2] has carefully examined the evidence and finds that most of the phosphorus enrichment in surface waters is coming from sewage treatment plants and only secondarily from agricultural fertilizers.

The sediment delivered into farm ponds by soil erosion is usually insufficient to provide enough nutrients to support aquatic plant growth for fish food. Most recommendations (*16*, *89*) on the management of ponds specify the addition of 100 pounds of 8–8–2 fertilizer per acre of pond surface to permit the growth of an adequate supply of miscroscopic plants for fish food. If the pond averaged 13 feet deep, the fertilizer would supply 0.1 p.p.m. of elemental phosphorus in the water, assuming the phosphorus was entirely soluble.

The extensive use of fertilizers in farm ponds for fish production is an indication that land runoff is a poor source of the needed phosphorus.

Phosphorus is getting into streams from farmland; however, it mainly gets into surface water through runoff and erosion of topsoil. Water seeping down through the subsoil or moving laterally through the soil carries virtually no phosphorus because of the high capacity of soil particles to adsorb phosphate. Topsoil contains on the average about 200 p.p.m. of phosphorus adsorbed on soil particles. The clay fraction of a soil usually contains about 1,000 p.p.m. of adsorbed phosphorus. Thus, the richer a particular soil happens to be in clay, the more adsorbed phosphorus that can be carried into the stream by soil erosion.

Soil particles have a tremendous affinity for holding onto phosphate molecules. Even when the fine suspended particles in a river water contain 1,000 p.p.m. of phosphorus adsorbed on their surfaces, the phosphorus in true solution may be only 0.005 to 0.0005 p.p.m. Water samples, therefore, should be analyzed in a way that distinguishes between phosphorus in true solution and phosphorus adsorbed on suspended sediment.

Barnyard waste carries around 1,000 p.p.m. of phosphorus. Runoff that flows directly from feedlots and barnyards into stream channels may be an untoward source of phosphorus.

The conclusion is obvious that the best way to control the phosphorus content of surface water that might arise from agricultural practices is to use soil conservation practices and structures that minimize runoff and sediment delivery from farms and farmsteads.

Certain aquatic plants such as cattails and sedges that have their roots in bottom sediments offer a more difficult problem. These plants may be a serious nuisance in canals and waterways, and on the edges of ponds and lakes. They can obtain their phosphorus supply by their roots permeating the bottom sediment. They appear to flourish best when this furnishes some adsorbed phosphorus and the water of submersion also contains a trace of phosphorus.[3]

Nitrate in Well Water

The Public Health Service (*125*) states:

> Serious and occasionally fatal poisonings in infants have occurred following ingestion of well waters shown to contain nitrate (NO_3). This has occurred with sufficient frequency and widespread geographic distribution to compel recognition of the hazard by assigning a limit to the concentration of nitrate in drinking water.
>
> From 1947 to 1950, 139 cases of methemoglobinemia (blue babies), including 14 deaths due to nitrate in farm wellwater supplies, have been reported in Minnesota alone. Wastes from chemical fertilizer plants and field fertilization may be sources of pollution.

The observation that nitrate moves into ground water is not new. As early as 1910, W. P. Headden published extensively on nitrate (*53*). He found high quantities of nitrate in ground water 80 feet below the surface at a time when chemical fertilizers had not been used in Colorado. He reasoned that the nitrate was formed in the surface soil by natural processes and leached to deep horizons.

Vernon Michael (*80*) District Health Officer, Franklin County, Wash., implied that heavy use of nitrogen fertilizer in that county resulted in relatively high concentrations of nitrate in drinking water.

De Laguna (*31*) found high nitrate (about 10 p.p.m.) in wells in the vicinity of Suffolk County, N.Y. He concluded that the nitrate in the wells was obviously caused by high applications of fertilizer to the potato fields in the area.

[2] Verduin, J. Eutrophication and Agriculture. Presented at Amer. Assoc. Adv. Sci. Symposium, Dec. 27, 1966, Washington, D.C.

[3] Martin, J. B., and Clements, L. B. National Fert. Devel. Cent., Tennessee Valley Authority, Muscle Shoals, Ala.

Stout and Burau[4] studied nitrate accumulation in ground water within the 10-square-mile basin occupied by Grover City and Arroyo Grande, Calif. Concentrations of nitrate at 90 to 130 p.p.m. in water percolating to the underground reservoir were not uncommon. The sources appeared to be nitrification of sewage effluent and natural nitrification processes in the surface soils that are fostered by the climate and the nature of the soil.

The Soils Department (*59*) at Washington State University studied nitrate content of well water in areas where various amounts of fertilizer had been used, and found that high nitrate in the well water was not a direct consequence of heavy fertilizer use.

At a recent American Association for the Advancement of Science symposium, Smith[5] reported on his extensive studies of the nitrate content of 6,000 rural water supplies. He found that animal wastes, improperly constructed shallow wells, and septic tank drainage were the main sources of water contamination. His evidence showed that leaching of fertilizer nitrogen was an insignificant source of nitrate in the well waters of Missouri.

The foregoing presents conflicting evidence. Conclusive evidence is lacking that chemical fertilization of fields results in high nitrate levels in well water. Natural nitrification processes in soils and nitrification of sewage effluent and animal wastes do seem to be major contributors when nitrate is found in ground water. The general problem is one of growing importance and much more definitive information is needed.

Inorganic Salts and Minerals

Of the water diverted from massed supply and consumptively used, 90 percent is used in irrigation. Thus it is that agriculture is sometimes referred to as "the greatest water hog of all" (*26*).

Because of this high consumptive use through the processes of evapotranspiration, salts present in the irrigation water supply become more concentrated in the drainage effluent. Consequently, frequent claims are made that irrigation agriculture seriously impairs the quality of water.

Irrigation agriculture provided the very spawning ground for the beginnings of civilization in the valleys of the Nile, the Indus, and the Tigris-Euphrates. The benefits that have arisen from irrigated farming have not been fully appreciated.

The irrigation water brought onto a field always carries some dissolved salt—usually within the range of 25 to 8,000 p.p.m. Plants extract water from the irrigated field for transpiration, but most of the salt is excluded by the roots. Water evaporating from the soil surface is pure water. The residual salt accumulates in the soil. In arid climates where Nature has left an accumulation of salt in the soil, the application of irrigation water will fortify this salt concentration.

For irrigation agriculture to survive, this process of salt accumulation in the soil must continually be countered by leaching with excess applications of water. The salt moves to deep horizons, the ground water, or the drainage system. Thus, the salt appearing in drains is that brought in by the irrigation water plus that which may have been naturally present in the soil. The irrigation farmer adds but little to this salt burden by his application of chemical fertilizers. These fertilizer salts barely meet crop needs. Under the natural conditions of crop production, evapotranspiration depletes the vehicle-water that transports salt to the drainage system. This natural system imposes an increase in salt burden in the drainage water from an irrigated field compared with that in the water supply.

In arid regions, it is a first criterion for the survival of an irrigated area that there be favorable salt balance; salt leaving the project by drainage or deep percolation must equal or exceed that received in the water supply. In the initial years of a project, when there is residual salt in the soil, more salt will have to be removed than is brought in.

Thus, the irrigation farmer does not actually produce a waste in the form of dissolved salts, he merely transfers the waste in a more concentrated form. Nevertheless, drainage water frequently warrants the label of "impaired quality" because of its burden of dissolved solids.

The quality of the return flow from irrigation projects may also be impaired by partial precipi-

[4] Stout, P. R., and Burau, R. Extent and Significance of Fertilizer Buildup in Soils. Presented at Amer. Assoc. Adv. Sci. Symposium, Washington, D.C., Dec. 28, 1966.

[5] Smith, G. E. Fertilizer Nutrients as Contaminants in Water Supplies. Presented at Amer. Assoc. Adv. Sci. Symposium, Washington, D.C., Dec. 27, 1966.

tation of the salts, even though precipitation decreases the total salt concentration. The slightly soluble carbonate and sulfate of calcium precipitate as the water volume is reduced by evapotranspiration, thus increasing the proportion of sodum in the effluent. High proportions of sodium in the irrigation waters are generally damaging because they cause deterioration of soil properties and specific toxic effects of sodium in some fruit crops and other woody plants. For municipal and many industrial uses, an increased proportion of sodium is, however, not harmful.

The increase in total salinity of return flows from irrigation projects will generally render the water unpalatable even before its utility for agriculture is completely lost. Thus, public health standards for potable water have been set at 250 mg./liter of chloride, a level which may damage only some sensitive fruit crops. In fact, waters containing several thousand mg./liter of total salts may still be of value for agriculture, especially when favorable soil conditions prevail and tolerant crops are grown, but such waters cannot be used for municipalities or for many industrial processes. The upper recommended limit of total salts for potable water is 500 mg./liter, although waters with twice this salt content are actually being used. Highly saline waters also have considerable reuse potential for recreational purposes. The drainage waters of the Imperial and Coachella Valleys, containing about 2,000 mg./liter of total salts, flow into the Salton Sea, which affords fishing, boating, and other water sports for many hundreds of people. However, since the Salton Sea has no outlet, continued evaporation will ultimately render the sea so saline that the recreational use pattern will undoubtedly have to be adjusted.

The trend toward intensified use of limited irrigation water resources foreshadows more severe problems in the future. Irrigation projects must generally maintain salt balance. Salt cannot accumulate in the soil without damaging crops, so as much salt must be carried out in drainage water as is applied in irrigation water. The decrease in volume of water with each use results in a proportional increase in salt concentration. Thus, if 20 percent of the total water flow in a river is consumptively used by each of four successive projects along the river, the relative salt concentration of the river will increase from 1.0 to 1.25, 1.67, 2.50, and 5.00 following each stage of use and return flow. It is obvious that as the river flow is depleted, the salt concentration of the remaining flow must increase inversely with the volume of water if salt balance in all projects is to be maintained. It is further obvious that, under salt balance conditions and with return flow of drainage water, complete allocation of the river flow may give the last project a water with prohibitively high salt content.

Alternative procedures for handling return drainage flow along some rivers may have to be devised, especially if downstream users are to have potable water as well as irrigation water. One solution may be to purify the drainage flow by suitable desalination process, returning the purified fraction to the river and disposing of the concentrated salines in other ways, such as outfall drains to the sea, collection in evaporation ponds, or percolation into the ground where usable ground water would not be affected. Such solutions would be practical only when return flows are readily recoverable, as from tile drains or pumped wells, or can be readily intercepted before the underground flow returns to the river.

Organic Wastes

It is in the nature of things that man's domesticated animals produce wastes; that his fields and forests produce residues and trash; and that his food- and fiber-processing plants produce useless byproducts.

There are instances wherein wastes of this category have emitted odors into the atmosphere; have contaminated the water of streams, ponds, lakes, and reservoirs; have provided dangerous fire hazards; have disseminated infectious agents; and have been the very spawning ground of a whole array of vermin.

Animal Wastes

Time was when animal wastes were considered a tremendous asset in providing fertility to the Nation's soils. The 1938 Yearbook of Agriculture (*121, p. 445*) carries this statement:

> One billion tons of manure, the annual product of livestock on American farms, is capable of producing $3,000,000,000 worth of increase in crops. The potential value of this agricultural resource is three times that of the Nation's wheat crop and equivalent to $440 for each of the country's 6,800,000 farm operators. The crop nutrients

it contains would cost more than six times as much as was expended for commercial fertilizers in 1936. Its organic matter content is double the amount of soil humus annually destroyed in growing the Nation's grain and cotton crops.

How times do change!

In 1966, animal excrement was considered by some to be the bête noire of agricultural wastes. Waste production by our domestic animals is equivalent to that of a human population of 1.9 billion. Sewage treatment facilities for this livestock are infinitesimal.

The change in view towards manure has occurred because livestock and poultry production in the United States is becoming concentrated in large scale, confinement-type enterprises. These include multihundred-cow dairy operations, multithousand-head beef or hog feedlots, and enterprises with many hundreds of thousands of birds. Such large concentrations of animals or birds have greatly magnified the problems of handling wastes, including health hazards and esthetic nuisances. Economic studies indicate that the costs of handling manures make them no longer competitive in price with chemical fertilizers. Table 1 provides an indication of the amount of solid wastes produced by livestock in the United States. Domestic animals produce over a billion tons of fecal wastes a year. Liquid effluent amounts to over 400 million tons. Used bedding, paunch manure from abbatoirs, and dead carcasses make the total annual production of animal wastes close to 2 billion tons.

Possibly half of this waste is produced under concentrated conditions. Cattle in a feedlot for fattening, or dairy cows maintained for high milk

TABLE 1.—*Production of wastes by livestock in the United States*

Livestock	U.S. population 1965	Solid wastes [1]	Total production of solid waste	Liquid wastes	Total production of liquid wastes
	Millions	*G./cap./day*	*Million tons/yr.*	*G./cap./day*	*Million tons/yr.*
Cattle	107	23, 600	1, 004. 0	9, 000	390. 0
Horses [2]	3	16, 100	17. 5	3, 600	4. 4
Hogs	53	2, 700	57. 3	1, 600	33. 9
Sheep	26	1, 130	11. 8	680	7. 1
Chickens	375	182	27. 4		
Turkeys	104	448	19. 0		
Ducks	11	336	1. 6		
Total			1, 138. 6		435. 4

[1] Geldreich and others (*47*).
[2] Horses and mules on farms as work stock.

production, may produce double the daily amount of wastes shown in the table.

Table 2 shows the population equivalent of the fecal production by various kinds of livestock in terms of biochemical oxygen demand (BOD). For example, a feedlot carrying 10,000 head of cattle has about the same sewage disposal problem as a city of 164,000 people. The city will be using 8,200,000 gallons of water a day to carry off the sewage. Such amounts of water are never used and are seldom even available at the feedlot.

BOD is an important measurement in determining the quality of water. BOD indicates the amount of oxygen required for the oxidation of the organic matter present in a sample of water. It is expressed by the amount of oxygen the water will absorb when it is incubated for a 5-day period at 68° F.

In such tests, water absorbing not more than 1 p.p.m. of oxygen in 5 days can generally be considered very pure; 3 p.p.m. suggests fairly clean water; but water absorbing 5 p.p.m. or more of oxygen is of doubtful purity.

BOD demand of a waste acts to deplete dissolved oxygen in water. Fish depend upon this dissolved oxygen in order to breathe. Most fish should have 5 p.p.m. of dissolved oxygen—brook trout should have 6 p.p.m. or more. However, a sluggish stream during the summer may have its dissolved oxygen lowered to 1 to 3 p.p.m.

A primary problem in handling animal waste involves coping with its high BOD. A sample of concentrated liquid waste from a pigpen has been reported as having a BOD as high as 50,000. This undoubtedly is an unusually high value.

Untreated municipal sewage has a BOD of about 100 to 400 p.p.m. This means that such sewage entering a stream already low in dissolved oxygen

TABLE 2.—*Population equivalent of the fecal production by animals, in terms of biochemical oxygen demand (BOD)*

Biotype	Fecal	Relative BOD per unit of waste	Population equivalent
	G./cap./day	*Lb.*	
Man	150	1. 0	1. 0
Horse	16, 100	0. 105	11. 3
Cow	23, 600	. 105	16. 4
Sheep	1, 130	. 325	2. 45
Hog	2, 700	. 105	1. 90
Hen	182	. 115	. 14

must be highly diluted if it is not to completely exhaust the dissolved oxygen of the stream.

Wastes carried in runoff from barnyards and feedlots may vary in BOD from 100 to 10,000 p.p.m. depending on dilution and degree of deterioration of wastes. Public health authorities object to runoff entering a stream if it exceeds 20 p.p.m. in BOD. Hence, the problem is obvious.

Many installations using lagoons for oxidation of animal wastes have been tried (*3*). Success has not been complete. The South Dakota agricultural experiment station reports that they are essentially a failure in that State. These lagoons are plagued by problems, such as overloading, floating litter, intermittent loading, aquatic weeds, and sludge buildup.

When a lagoon becomes overloaded, bacteriological decomposition changes from aerobic to anaerobic. During anaerobic decomposition, noxious gases and vile odors emanate. Under such conditions, the lagoon becomes more unacceptable than the ordinary manure pile.

The Pasveer Ditch was developed in Holland to handle municipal sewage. It accentuates natural oxidation by a motor-driven paddle wheel that both aerates and stirs. Modifications of the Pasveer Ditch for handling animal wastes are being tried in the United States. Animal wastes pose a much greater problem since they are not nearly as diluted as metropolitan sewage.

Even though the concern over animal wastes is great in terms of their high BOD, their use as spawning grounds for vermin, and their role as vehicles for infectious agents, public objections mostly arise through olfactory awareness.

Odors and water-polluting wastes from the concentrated egg production industry in Sullivan County, N.Y., is posing a serious threat to the resort industry that has flourished in the favorable climate and scenic attractions of this county. Reports have been made of serious losses in recreational enterprises because of offensive odors and other nuisances arising from the poultry.

The communities of Gardena and Torrance in Los Angeles County, Calif., have enacted ordinances requiring all dairy farmers to move out because of odors and other nuisances. Within the last 6 years, 43 dairy operations have had to move out of Los Angeles County because odors and other nuisances made these dairy cows "noncompatible" with Metropolitan Los Angeles.

People in Milford, Tex., have brought numerous damage suits against a large feedlot separated from the community by a mile-wide buffer zone because of odors, flies, dust, and water pollution.

In 1963, the State of Kansas enacted a feedlot licensing law to provide State inspection and control over the handling of wastes from feedlots 1,000 head and greater in capacity. The law was enacted because of complaints regarding odors, vermin, and water pollutants.

In early 1966, the Interstate Commission on the Potomac River Basin (45) reported:

> Every time its rains . . . . enormous amounts of animal wastes are washed from farmyards into the River, rendering it unsafe for swimming . . . . Although only a quarter-of-a-million people live in the river basin above Great Falls, it has been estimated that the number of farmyard animals—cows, sheep, pigs, chickens, turkeys—is the equivalent of a human population of 3.5 million. While most of the human population is served by some sort of sewage treatment plant, there is no comparable treatment for the animal wastes.

It can be stated without fear of successful contradiction that domestic livestock are producing wastes that are in some degree offensive to the general public.

Plant Residues on Farms and Ranches

Plant residues from crops and orchards contribute to pollution in two ways; namely, as a source of smoke and other air pollutants when burned, and as reservoirs of plant diseases and other pests.

Agricultural wastes from orchards, grainfields, and rangelands, especially in the Western United States, are burned as the practical means of ridding the land of the wastes. In one California county in 1960, an estimated 41,000 tons of orchard wastes were burned. From 30 to 80 percent of approximately 240,000 acres of rice in 8 California counties are burned annually. The smoke may be seen for miles.

Around 900,000 acres of grass are grown for grass seed each year, with the production of about 2 tons of residue per acre. Estimates indicate that about one-third of this acreage is burned each year as a sanitation measure. Such burning emits around 50,000 tons of particulate matter as carbon and ash into the atmosphere.

Evaluations of the relative contribution of burning agricultural wastes to photochemical air pollution have been attempted. The studies indicated concentrations of photochemically active hydrocarbons were negligible at a mile and a half from the fire when more than 1,000 acres of wastes were burned. The emissions of hydrocarbons and oxides of nitrogen from burning of agricultural wastes were considerably less per ton of fuel consumed than those in auto exhaust. The burning of fruit tree prunings, rice straw, barley straw, and dry native range brush produced approximately 14, 9, 18, and 7 pounds, respectively, of hydrocarbons compared with 130 pounds of the same hydrocarbons in auto exhaust per ton of fuel consumed. It appears from limited study that the burning of agricultural wastes does not add significantly to the burden of pollutants in community air. The effects of smoke on visibility from burning the agricultural wastes, however, may be a significant esthetic factor.

As agricultural land in the United States becomes more limited and agriculture becomes more intensive, the danger of plant debris carrying diseases and other pests to the succeeding crops becomes greater. Control of the plant diseases, preferably by disease resistance or nonchemical means, could solve the problem. But until such control becomes a reality, destruction of the plant debris by burning will be a common practice.

A case in point here is the destruction of plant residues of grass seed crops in western Oregon by burning, which is the only practical control for the blind seed disease, but which has led to an air pollution problem. Alternative methods of control must be found if the pollution problem is to be abated while enabling the multimillion-dollar grass seed industry to remain prosperous.

Many plant diseases are transmitted through plant residue, including late blight of potato, cotton verticillium wilt and bacterial blight, apple scab, brown rot of stone fruits, and leaf spot of tung, to name but a few. The extent of the plant disease problem associated with plant residues is not known for many crops. Some estimates have been made, however. For example, observations in Maine and other States indicate that culled piles of potatoes outside potato storage houses, along railway tracks, and on farms are primary sources of infection for late blight, a disease that causes an estimated average 4-percent loss of the potato crop each year.

In the southeastern United States piles of litter left in peanut fields are often an important source of stable fly breeding. Similarly, in other areas of the United States, rotting hay and straw provide suitable breeding places for the stable fly and house fly. Volunteer wheat, resulting from grain waste in inefficient harvesting practices, provides a breeding ground for the wheat curl mite, the vector of wheat streak mosaic. Volunteer beets are a source of beet yellow virus for reinfection of subsequent beet crops in the western and northwestern United States. Pink bollworms overwinter in waste cotton bolls and cottonseed left in fields. The European corn borer and sugarcane borer overwinter in the stalks remaining in the fields.

The European corn borer is one of the most destructive pests to sweetcorn in the United States. It causes coarse, broken stalks, poor ear development, and dropped ears, resulting in reduced yield and increased cost of harvesting. The average annual crop loss is estimated at 3.5 percent of the total production. The sugarcane borer is the most injurious insect attacking sugarcane in the United States and is responsible for an annual estimated loss of 12.1 percent. This insect also attacks corn, rice, and sorghums. The pink bollworm constitutes a threat to cotton comparable to the boll weevil. The stable fly is a serious pest of domestic animals and man throughout the United States, especially in North Central, Eastern, and Southeastern States. Reliable estimates from Illinois indicate that heavy stable fly outbreaks can reduce milk production by as much as 25 percent and reduce beef gains materially. In the Hard Red Winter wheat areas of Kansas and Nebraska, wheat streak mosaic caused an estimated loss of 15 million bushels in 1949 alone. The average annual loss from this disease is estimated at 1 percent of the total wheat production in the United States. The annual loss of beets from yellows disease is estimated at 6 percent; potato losses from aphid-transmitted virus diseases are estimated to be in excess of 3 percent annually.

Residues and Trash in Forests and Forestry Operations

Twenty-five million tons of logging debris are left in woods during the average year. This material is a fire hazard. Some of the most disastrous forest fires in North American history started in slash left from logging and land clearing. The average size of fires originating in logging waste is more than seven times that of fires originating in uncut areas or areas where slash has been disposed of.

Forest fires are a major concern in the United States. During a typical year, there are about 150,000 forest fires in this country, which ravage 5 to 7 million acres. Of these fires, between 7,000 and 8,000 occur in the National forests, between 3,000 and 4,000 on other Federal lands, and the rest on State and privately owned lands.

Prescribed burning in forests each year produces about 32 cubic miles of smoke in the convection column, while generating 6,500,000 tons of particulate matter and 68,000 tons of hydrocarbons.

Wild forest fires in the average year produce an estimated 160 cubic miles of smoke in the convection column. Such fires generate about 34 million tons of particulate matter each year, largely as carbon and ash; and about 338,000 tons of hydrocarbons are vaporized and condensed.

Wild fire yields more smoke and hydrocarbon per ton of fuel than prescribed burning because the oxygen deficiency is usually greater during wild fire burns.

The conclusion is obvious that a way should be found to dispose of logging debris so that it does not become a fire hazard. The cost per ton of eliminating this material by burning is about $1 per ton, whereas disposal by chipping costs about $12 per ton.

Even prescribed burning causes problems. Oregon-Washington applegrowers have filed suit against the U.S. Forest Service because they claim smoke from prescribed fires prevents proper apple coloration. Police in several Southern States have complained that smoke from prescribed fires has been a significant cause of automobile accidents. Smoke from forest fires closes a number of airports each year. Recreation activities are discouraged.

If trash from trees is not burned, it may become a serious source of disease organisms. Elm logs killed by Dutch elm disease and oak logs killed by oak wilt must be destroyed or treated to prevent vector transmission of the disease to healthy trees. The log disposal problem from trees killed by Dutch elm disease is monumental. In Nassau County, N.Y., 3,000 trees die per year and must be burned, buried, or treated with insecticides. Similar conditions exist in all Eastern and Midwestern States.

Roots of conifers killed by *Fomes annosus* and *Poria weirii* root rots are sources of new infections for many years.

Felled oaks with Strumella cankers must be destroyed to prevent fruiting and spread of the pathogen.

The need to dispose of logging debris and dead trees is urgent. It would be desirable to have methods for disposal alternative to burning, but the probability of discovering such alternatives that have economic feasibility appears to be low.

Processing Wastes

Wastes from food- and fiber-processing plants can vary tremendously in potential for pollution. Research at Louisiana State University (*22*) showed that liquid wastes from asparagus canning have a BOD of not more than 100 p.p.m. whereas the BOD for waste from squash canning would run as high as 4,000 to 11,000 p.p.m. A sample from concentrated pea vine ensilage juice was reported to have a BOD of 75,000. These figures must be evaluated in terms of water quality standards to the effect that stream water with a BOD of 5 p.p.m. is looked upon as being of doubtful purity.

Oxygen-demanding wastes from processing of agricultural and forestry products include runoff or effluent from sawmilling; pulp, paper, and fiberboard manufacturing; fruit and vegetable canning; cleaning of dairies; slaughtering and processing of meat animals; tanning; manufacturing of cornstarch and soy protein; sugar refining; malting, fermenting, and distilling; scouring of wool; and wet processing in textile mills. These wastes on entering a stream may be of such concentration in terms of BOD as to make the water unattractive, unpleasant, unesthetic, anaerobic, and reeking with the redolence of fetid putrescence.

There are difficulties in appraising the significance of processing wastes in terms of p.p.m. BOD in the effluent since degree of dilution by water used during processing will be a primary determinant. It is preferable to evaluate water pollution potential of these wastes in terms of pounds of BOD required for wastes produced from a given amount of product processed.

An excellent summary of available information on processing wastes has recently been prepared.[6] The key data are shown in table 3.

The second column in this table presents data on the amount of product from farm and forest that is processed annually.

The fourth column lists the pounds of BOD required per 1,000 pounds of product processed.

The fifth column lists the potential daily load of BOD from the processing of a given product based on a 365-day year. For example, the waste from corn canneries requires 9.8 pounds of BOD for each 1,000 pounds of the 2,364 million pounds of corn processed. Thus, 23 million pounds of BOD are produced a year or 63,000 pounds per day. But the corn canning season does not last 60 days, so that potential daily load of BOD from corn canning during the season may approach 10 times the 63,000 pounds shown in the table.

The sixth column presents the population equivalent (PE) of the BOD load shown in column 5. One PE of a processing waste is an amount of liquid waste equivalent in BOD to the normal sewage contributed by 1 person. The base value of 0.167 pound of BOD per capita per day is used.

Certain comparisons may offer additional clarification. A population of 1 million people will use about 50 million gallons of water a day to carry their sewage effluent. Thus, 417 million pounds of water carry 167,000 pounds of BOD, and the average BOD of raw sewage would be 385 p.p.m. Records of BOD of raw sewage indicate that it ranges from 200 to 400 p.p.m. If the corn canning industry used 1 gallon of water for each pound of corn processed, the average BOD of the effluent would be 1,200 p.p.m. This is well within the range of values given for effluent of many processing industries (*4*).

Table 3 shows that the pollution potential in terms of BOD from the woodpulp industry overshadows all other industries listed. The potential oxidative requirements of the effluent from the woodpulp, paper, and paperboard industries are greater than those of the raw sewage from all of the people in the United States.

Progress in pulp and paper manufacturing processes to reduce water pollution has been good. In kraft pulping, chemicals are now recovered and oxygen-depleting substances are removed by sedimentation to minimize stream pollution. Better utilization of byproducts reduces the amount of material discharged into streams.

[6] Hoover, S. R., and Jasewitz, L. B. Agricultural Processing Wastes. Presented at Amer. Assoc. Adv. Sci. Symposium, Washington, D.C., Dec. 27, 1966.

In a year's time, the canning industry produces potential effluent with oxidative demands that are double those of the raw sewage from Metropolitan Detroit; the meatpacking industry, double those of Metropolitan Chicago; and the dairy industry, four times those of Metropolitan Boston.

Industry has made progress in efficiently utilizing many of its wastes as byproducts and new techniques and processes are constantly being developed. For instance, the sugar industry has found uses for filter press mud and bagasse; effluents from food-processing plants are being used as a source of much-needed irrigation water; a technique for recovering sugar from pear processing wastes has been developed; and a process for recovery of feed and fertilizer values from chicken feathers was developed and is in general use.

Infectious Agents and Allergens

Infectious agents from agriculture and forestry that may be of concern to the general public could comprise a long list. Such a list would include brucellosis, which is transferable from diseased cattle to man; diseases transmitted by mosquitoes and flies from farm ponds and barnyards, respectively; walnut or ragweed pollen to harass people with these specific allergies; and a wide array of insects and plant diseases that may arise on the farm or from the forest and infest the herbage in city parks or suburban backyards.

Animal Disease Agents

A study on the Potomac River Basin indicated the possibility of transmission and dissemination of such organisms. A number of reports have indicated that the lower Potomac could never be made safe for swimming because of the prevalence of pathogenic bacteria. Evidence has been presented alleging to show that most all of the bacterial pollution in the Potomac is coming from farm runoff.

The presence of coliform bacteria in water has been used as an indicator of bacterial pollution for about 75 years. Although coliform bacteria are rarely capable of inducing disease, their presence

TABLE 3.—*Estimated pollution loadings of selected agricultural processing industries* [1]

Processing industry (1)	Annual production (2)	5-day BOD: Data in literature [2] (3)	5-day BOD: Lb. BOD per 1,000 lb. processed (4)	5-day BOD: Potential daily load (5)	Potential daily population equivalent (6)
	Million pounds			*1,000 pounds*	*Millions*
CANNERIES:					
Apples	1,218	32 gal. 3,600 p.p.m. BOD per case (24 No. 2½ cans).	13.3	44	0.26
Peaches	2,970	50 gal. 2,000 p.p.m. BOD per case (as above).	20.8	169	1.02
Corn	2,364	19.5 lb. BOD per ton corn processed	9.8	63	.38
Tomatoes	9,790	8.4 lb. BOD per ton tomatoes processed	4.2	113	.68
Canning (total)				1,370	8
CORN WET MILLING	10,800	1 bu.=1–2 PE	4.5	133	.80
COTTON (processed through basic dyeing step).	4,600	*PE*: Sizing 2; Desizing 96; Kiering 108; Bleaching 17; Scouring 12; Mercerizing 83; Basic dyeing 90 (per 1,000 lb. goods).	68	857	5.14
DAIRY:					
Fluid mild	59,000	10 [3]	[4] 1.0	162	1.0
Evaporated milk	1,888	10.5 [3]	[4] 2.25	11.6	.07
NFDM	2,176	25.0 [3]	[4] 26.4	157	.945
Cheddar cheese	1,157	24.5 [3]	[4] 24.5	77.6	.465
Cheddar whey (dried)	20 percent of total.	17.0 [3]		9.7	.06
Cheddar whey	50 percent of total.	350 [3]		500	3.0
Cottage cheese	1,424	350 [3]	[4] 26.5	64.5	.38
Cottage cheese whey	7,500	350 [3]	[4] 165	1,000	6.0
HIDES AND LEATHER	1,300	650 gal. 1,500 p.p.m. per 100 lb. hides	81	300	.18
MEAT:					
Slaughtering and packing.	59,400	14 lb. BOD per 1,000 lb. live weight	14.0	2,300	13.7
PAPER AND PULP:					
Wood pulp	66,000	300 lb. BOD per ton of pulp	150.0	27,000	162.0
Paper and paperboard	96,600	68 lb. BOD per ton of paper	34.0	9,000	54
POTATOES:					
Chips	7.1	29.3 lb. BOD per ton raw potatoes	14.6	106	.64
Dehydrated	2.7	71.1 lb. BOD per ton raw potatoes	35.6	93	.58
Flour and starch	3.2	57 lb. BOD per ton raw potatoes	28.5	91	.55
Frozen french fries	5.4	22 lb. BOD per ton raw potatoes	11.0	57	.34
POULTRY	8,200	33 lb. BOD per 1,000 birds	10.0	225	1.3
SOAP AND FATTY ACIDS	770	1.75 lb. BOD per lb. soap made	1,750.0	3,700	
SOYBEAN	27,200	1.7 lb. BOD per 100 bu	.19	14	.085
SUGAR REFINING:					
Cane	48,000	5.31 lb. BOD per ton	Av. 3.0 (Cane and Beet)	800	4.8
Beet	47,000	6.64 lb. BOD per ton			
WOOL SCOURING	130	8 gal. 4,000 p.p.m	267	100	.6

[1] Hoover, S. R., and Jasewitz, Leonore B. Agricultural Processing Wastes. Presented at Amer. Assoc. Adv. Sci. Symposium, Washington, D.C., Dec. 27, 1966.

[2] PE=Population equivalent.

[3] Pounds BOD/10,000 lb. milk equivalent.

[4] Milk equivalent.

has been taken as an indication that infectious bacteria might also be present. Coliform counts are considered to be prime criteria of bacterial pollution of water.

Coliform bacteria can enter streams by means of sewage, animal wastes, or runoff from soils since some coliforms persist in soil. A trained technician using appropriate laboratory methods can distinguish between the form of bacteria coming from animal effluent and those from soil. The former are designated as fecal coliform bacteria.

Streptococcal bacteria are also normally present in fecal effluent of both animals and humans.

Kenner, Clark, and Kabler (*67*) established ratios between fecal coliform and fecal streptococci for different pollution sources, as shown in table 4.

Based on such information, water bacteriologists used as a general guide that if this ratio is less than one, the pollution is coming from nonhuman sources; if the ratio exceeds 2.5, the bacterial pollution is most probably coming from human sources. Ratios between 1.0 and 2.5 suggest that pollution is a mixture of human and nonhuman sources.

Fry (*45*) has conducted a number of bacteriological examinations at various points on the Potomac River system. He found that the Potomac River at Shepherdstown, W. Va., has an average f. coliform/f. streptococci ratio of 0.072; the Shenandoah River at Charles Town, W. Va., had an average ratio of 0.24; and the Potomac River at Point of Rocks, Md., averaged 0.25. The Monocacy River (Potomac tributary in Maryland) at a point just below the city of Frederick, Md., had an average ratio of 4.36, showing that the pollution was definitely from human sources. However, at Great Falls on the Potomac (below Monocacy confluence but just above Washington, D.C.) the average for the ratio was 0.042. Fry concluded from these observations that most of the bacterial pollution of the Potomac was coming from barnyards and land runoff.

Although fecal coliform and fecal streptococci bacteria are rarely pathogenic, they do serve as indicators that contamination has occurred and that infectious organisms may be present. It is also important to keep in mind that a variety of wild animal species may contaminate streams with leptospira and other organisms.

TABLE 4.—*Average contents of f. coliform and f. streptococci in fecal wastes of various animals, and ratio of f. coliform to f. streptococci*

Vertebrate	F. coliform	F. streptococci	F. coliform-f. streptococci ratio
	Millions	*Millions*	
Cow	0.23	1.3	0.18
Pig	3.3	84.0	.04
Sheep	16.0	38.0	.43
Poultry	1.3	3.4	.38
Turkey	.29	2.8	.10
Duck	33.0	54.0	.61
Man	13.0	3.0	4.33

Other infectious agents of animals that may pollute streams are as follows: Anthrax, brucellosis, coccidiosis, encephalitis, erysipelas, foot rot, histoplasmosis, hog cholera, infectious bronchitis, mastitis, Newcastle disease, ornithosis, transmissible gastroenteritis, and salmonellosis. Such agents may subsequently infect other animals, or in the case of some disease producing agents, even humans.

In late May and early June 1965, 18,000 people in Riverside, Calif., were infected with *Salmonella typhimurium* that had entered into the city's water supply. Drinking water for Riverside comes from deep wells, a source presumed to be beyond bacterial contamination. No one has satisfactorily explained how salmonella got into this water supply.

In view of our large livestock population and the number of livestock diseases that could afflict man, the actual number of infections from drinking water is exceedingly low. During the 15-year period, 1946–60, there were only 16 human deaths attributable to waterborne agents—eight from typhoid fever, four from chemical poisoning, and four from infections other than typhoid. This excellent record is due to the high level of activity in protecting animal health and curbing dissemination of animal diseases; and intense vigilance in monitoring drinking water supplies.

Encephalitis is the most serious mosquito-borne disease in the United States. It is endemic in virtually all irrigated regions, but certainly not restricted to these. Epidemics occur in scattered irrigated areas every year. Such outbreaks can result in hundreds of cases and scores of human deaths. Serious epidemics frequently kill hundreds of horses.

In recent years, encephalitis outbreaks have occurred in irrigated areas in the Texas High Plains, the Intermountain States, the Lower Rio Grande Valley, and the Central Valley of California. In addition to their avid and pestiferous hunger for human and animal blood, a few species of mosquitoes transmit human and avian malaria, fowl pox, infectious anemia, as well as encephalitis.

In an irrigated region, the storage reservoirs, water conveyance systems, farm distribution systems, and drainage systems provide favorable conditions for the production of mosquitoes, horse flies, and deer flies. Similarly favorable conditions are often found in coastal areas and near lakes. These insect pests give the word "pests" a really distressful meaning even without transmittal of a primary infectious agent. Some individuals, especially children, often require medical attention for treatment of secondary infection and serious allergic reactions to mosquito bites. These problems, present in all irrigated areas and in many areas without irrigation, have resulted in the formation of organized mosquito control districts and the expenditure of large sums of money. For example, in California mosquito control districts operate in over 40 counties. About 75 such districts now operate in the Western States alone, involving the estimated expenditure of about $9 million annually.

Histoplasmosis is a lung disease of humans. It is caused by a fungus that thrives on collected poultry and other bird droppings. Dusts emanating from such droppings carry the fungus through the atmosphere. Incidence of human infections are relatively high in the Middle West and the Middle Atlantic States (*100*).

The potential for disastrous outbreaks of communicable diseases from livestock is recognized and a high level of vigilance in disease control is maintained and consistently improved.

Plant Disease Organisms

The serious impact on agriculture and forestry of such infectious agents as plant disease organisms and their vectors is briefly discussed in appendix I. These organisms have no restrictions in moving from field and forest to the flora of parks, streets, highways, and suburban lawns and gardens, and vice versa. About one-fourth of the dollar sales of pesticides in the United States comes from small packages sold for use by community and suburban dwellers. Certainly one cannot say that plant and tree diseases in nonrural America arise from agricultural crops and forest trees, but coping with these infectious agents must involve all facets of the environment.

Allergens and Poisonous Weeds

Ragweed, goldenrod, bermudagrass, walnut trees, and a host of other weeds, economic plants, and trees produce pollens and toxins that cause serious human allergies even in most of our heavily populated areas. Allergies reduce working efficiency, impair health, and increase medical costs of our people.

Allergies from pollen are indeed costly. The Public Health Service reports that in the average year, there are 12,646,000 sufferers from asthma or hay fever, or both. Of these, about 5 million are asthma sufferers, with about 75 percent of the asthma cases caused by pollen. The remaining 7,646,000 suffer from pollen allergies. About 10,433,000 workdays are lost each year with a loss in wages—assuming an average daily wage of $12—of at least $125 million. Loss of production capacity by industry would add to this figure.

Little pollen grains can run up big figures in human misery.

Poison ivy, poison oak, and other poisonous weeds cause nearly 2 million cases of skin poisoning each year. The resulting 330,000 lost workdays represent a more than $4 million cost in wages alone. The loss due to restricted activity would increase this amount.

Fungus spores produced on stored pulpwood cause sarcoidosis in man. Such spores from stored maple logs cause human allergies. These fungus spores are also spread to healthy trees.

Allergies caused by pollen and toxins affect the use of parks and recreation areas. Health problems caused by allergens are becoming more widespread as more people use naturalized parks, campsites, and other rural recreation areas.

Insect Vectors

During man's long struggles with a hostile Nature, the host of human diseases carried by insects and other arthropods has been a veritable scourge to man's survival. Livestock, birds, wild animals, and vermin may also be sources.

Simmons (*105*) lists a number of diseases, including some of the most important diseases in the world, that can be completely or partially controlled by exterminating the appropriate arthropod vector by a powerful insecticide:

Malaria	Dysentery and diarrhea
Filariasis	Amebiasis
Urban yellow fever	Leishmaniasis
Dengue	Bartonellosis
Virus encephalitis	Onchocerciasis
Louse-borne typhus	Sandfly fever
Louse-borne relapsing fever	Trypanosomiasis
	Yaws
Trench fever	Infectious conjunctivitis
Plague	Chagas' disease
Murine typhus	Scabies
Cholera	Tick-borne diseases:
Scrub typhus (tsutsugamushi)	Relapsing fever
Rickettsialpox	Rocky Mountain spotted fever

Knipling (*71*) estimated that on a worldwide basis over the first 10 years of use of the insecticide DDT, 5 million lives were saved and 100 million illnesses prevented. Flies, mosquitoes, lice, fleas, and ticks constitute most of the vermin involved. If only a fraction of the pests involved had their spawning ground in rural areas, one cannot dismiss this class of infectious agents as being of secondary importance.

Insects are also vectors of diseases afflicting trees and shrubbery, lawns and gardens, and even pets of urban and suburban residents. The source of the vector or the infectious agents is often from agricultural, forested, or rural areas.

Agricultural Chemicals

Pesticides, when used properly, have resulted in great benefits to man and his surroundings. Conversely, when misused or used carelessly, they have caused harm. On balance, the adverse effects have been relatively minor in relation to the great benefits from pest control.

Use of pesticides continues to increase. In 1964, 693 million pounds of these chemicals were sold in the United States; 65 percent was used in forestry and agriculture. A study was made based on a survey of farmers whose sales represented 90 percent of total agricultural sales in the United States in 1964 (*11*). Of the farmers surveyed, 94 percent used pesticides to some degree. These farmers spent $456 million on pesticides in 1964. Supplementary information indicates that farmers who operated small farms but were not included in the survey spent about $58 million on pesticides. Thus expenditures for pesticides by all farmers in 1964 amounted to $514 million.

Insecticides

Insecticides were applied to about 83 million acres of land in 1964. When these chemicals are applied directly to the environment, it is obviously impossible to avoid exposing most, if not all, of the organisms in that environment to the insecticide applied. Therefore, it is not always possible to avoid hazards to many nontarget organisms living in the same part of the environment treated for insect control. These chemicals may then move to other parts of the environment not actually treated.

Organizations and individuals associated with conservation and the preservation of wildlife have alleged that nontarget organisms are unduly jeopardized by the insecticide treatment. Obviously, most insect problems are now being met by insecticides; and many insecticides currently in use have a broad spectrum of biological activity. It is not surprising that a chemical agent that will kill a harmful insect may also pose hazards to other animal life.

It is not possible with some current materials to avoid the destruction of many kinds of beneficial insects—and there are far more kinds of beneficial than of destructive insects. Insect parasites and predators are helpful in maintaining reasonable population levels of some destructive insects.

It is likewise not always possible to avoid exposing many other organisms such as fish, birds, mammals, and other animals that may exist in cultivated fields, forests, orchards, rangelands, marshes, lakes, or streams. While these animals generally are less likely to be adversely affected by insecticides than beneficial or destructive insects are, significant adverse effects have been noted under certain situations.

The most complex and serious consequences of environmental contamination with insecticides involve the phenomenon of biological magnification of residues in tissues of animals. This phenomenon appears to be limited to the fat soluble pesticides. Certain organisms may be exposed for long periods to low-level, persistent insecticides that accumulate in body tissues. These accumulations may not cause measurable acute effects in these organisms. However, through food chains the residues may accumulate to higher and higher levels in tissues of the succession of animals involved in the food chain.

In some instances, animals near the top of such food chains, such as fish-eating birds, appear to have been killed through such insecticide residue magnification. Robins feeding on earthworms living in DDT-contaminated soil have been killed. Wildlife conservationists and others are concerned over this problem.

An adequate explanation is lacking of how and why certain insecticides such as DDT become so widely distributed in organisms throughout the environment. Conservationists are concerned over the direct kill of animals that occasionally occurs because of accumulation of residues, but they are even more concerned over the possible adverse effects on reproduction in animals because of a low level of residues in tissues. The chief culprits in this problem are the persistent chlorinated hydrocarbon insecticides that accumulate in animal tissues.

These persistent insecticides are being replaced by insecticides that degrade more rapidly in the environment and that do not accumulate in animal tissues. However, use of the more persistent types is still substantial in agricultural and public health programs.

Pesticide monitoring programs conducted by Federal and State agencies show that residues of certain insecticides, particularly DDT, are widespread, not only in soils, but also in the tissues of fish, wild animals, birds, and man himself. The significance of these residue levels has not been established.

DDT residues were detected in the soils of Indiana orchards at levels exceeding 100 pounds per acre when 50 to 75 pounds per acre per year were applied to the trees for 8 to 10 years. Residues of endrin or dieldrin have been found in grass, soybeans, peanuts, carrots, and other crops. These residues are generally associated with corresponding residues found in the soil.

The average human in the United States carries approximately 270 milligrams of DDT or 900 milligrams of DDT-derived materials, expressed as DDT, in body fat (*52*). The human body burden of these pesticides appears to have remained fairly constant for several years. Most toxicologists consider these levels to be of no health significance.

The significance of residue levels of DDT and other insecticides found in fish and wildlife is not known. In some instances the levels are substantially higher in game animals than the maximum tolerance set for meat of livestock.

Because of its potential effect on fish and wildlife, the U.S. Forest Service is restricting the use of DDT for the control of spruce budworm, pine tip moth, tussock moth, and other destructive forest pests, and substitute materials are used wherever possible.

Some conservationists believe that certain marine fisheries' resources, such as shrimp, salmon, and oysters, may be adversely affected in river estuaries.

Entomologists are deeply concerned over the adverse effects of insecticides on insect parasites and predators. Beekeepers sometimes take heavy losses in destroyed or weakened colonies because of insecticide exposure.

The upset in balance of insect parasites and destructive insects gives rise to new problems. For example, it is generally conceded that mites in apple orchards now constitute an important pest problem because the mite predators have been destroyed. Bollworms have become major pests of cotton. Their growing importance is due, at least in part, to the destruction of their natural enemies when insecticides are applied to control boll weevils and fleahoppers.

Fungicides

Air, soil, water, and plant contamination by all types of fungicides does not appear to be significant even though they are used in large quantities on certain crops.

The organic mercury fungicides are generally the most hazardous to man. These compounds are widely used as seed treatments, but the amounts per acre are relatively small compared with those of most other fungicides.

Trace amounts of tetrachloro nitrobenzene (TCNB) and several of the dithiocarbamate fungicides have been detected in the total diet studies conducted by the Food and Drug Administration. The levels detected did not appear to present a problem.

Tolerances set for most currently used fungicides allow applications at rates needed to control or prevent diseases. However, for the antibiotic, streptomycin sulfate, which is used to control fire blight of apples and pears, the Food and Drug Administration permits no fruit residue. Thus, application of this antibiotic is restricted to the bloom season, but this does not allow effective control of this disease and copper-bearing summer sprays are necessary.

Treated seed in excess of current seeding needs may be inadvertently fed to stock by farmers. Poultry and livestock sometimes are poisoned from eating seed treated with mercury or other fungicides. When fungicide-treated seed is detected in shipments of food or feed grain, the entire shipment is subject to seizure and destruction. Label directions on fungicides caution against feeding fungicide-treated grain or intermingling it with untreated grain.

Nickel-maneb fungicides are being used to control rusts in grass seed fields. A significant amount of nickel may accumulate in the soil following repeated applications. This in turn can be taken up by subsequently grown crop plants. Presently available information shows no toxic effects on sensitive plants from 200 pounds of nickel per acre.

Herbicides

In 1964, 97 million acres of agricultural land were treated with herbicidal chemicals. They have been tremendously effective in combating weeds.

Herbicides applied to control weeds in one crop may leave residues in the soil that prevent the growing of certain crops immediately following harvest of the treated crop. Losses are minimized only by restricting subsequent crops to those that are tolerant to the herbicides used.

Diuron applied for weed control in irrigated cotton in the western region leaves residues in the soil which injure vegetable crops such as lettuce, carrots, cabbage, and cucumbers when planted in the winter following cotton harvest. Research in Wyoming showed that residues from an application of 2 pounds per acre of diuron persisted in the soil for 2 years in amounts toxic to oats.

Research in the Mississippi Delta shows that annual applications of diuron for late season control of weeds can build up residues that would damage soybeans and oats, but not subsequent cotton crops.

Atrazine, applied to control weeds in corn, remains as a residue in the heavy soils of the north-central region and often causes severe injury or prevents the growth of fall-seeded grain crops, causes damage to spring-seeded cereal crops, and may prevent the establishment of small-seeded forage grasses and legumes.

Phenoxy herbicides used to control weeds in tolerant crops such as corn, wheat, and rice and on grazing lands are volatile and they drift. Damage may occur to nearby susceptible crops, such as cotton, grapes, tobacco, and vegetables. The yield of cotton can be reduced more than 50 percent by as little as 0.01 pound of 2,4-D per acre.

Spray drift of 2,4-D, and 2, 4, 5-T from applications on nearby forests, cropland, roadsides and rights-of-way has damaged chemically sensitive trees such as dogwood, paper birch, box elder, chestnut, black locust, and other shade trees, shrubs, and herbaceous ornamentals. Damaged trees and shrubbery create long-lasting, unsightly conditions on travel routes and in recreation areas.

There are documentable instances in which spray drift from aerial applications of the phenoxy herbicides without adequate precautions have caused crop injury 10 miles or more downwind from target areas. In addition to major problems, smaller incidents occur. For example, when a sprayer that had previously been used to apply phenoxy herbicides was used for insect control in cotton, more than 200 acres of cotton in Washington County, Miss., were damaged before the contamination of the sprayer was detected. In another instance, a formulation of the herbicide DNBP, applied as a preemergence treatment for weed control in cotton, volatilized and killed an extensive acreage of cotton in the Mississippi Delta. DNBP is no longer registered for this use on cotton.

The use of herbicides for aquatic weed control is subject to regulation and restrictions. No organic herbicides are registered for use in potable water. Certain herbicides are registered for use in water that is to be used for irrigation purposes.

The control of aquatic weeds in irrigation systems improves water conveyance. Many herbicides, such as diquat, potassium and sodium salts of endothall, simazine, sodium arsenite, silvex, 2,4-D, an dichlobenil, do not injure fish at the concentrations required to control most submersed aquatic weeds. At higher rates they may become toxic to fish, humans, livestock, wildlife, and crops.

Dalapon and fenac do not harm fish even at concentration levels far above those required for aquatic weed control.

Acrolein, chlorinated benzenes, xylene, and amine salts of endothall are deadly or injurious to fish at concentrations necessary to control aquatic weeds and are not registered or recommended for use in areas where protection of fish is required.

Sodium arsenite at rates required to control many aquatic weeds is not toxic to fish. But sodium arsenite is highly poisonous to humans and all warm-blooded animals, and extreme caution and attention to details of application are absolutely essential when it is used. It has been used extensively since 1930 under rigid State and local regulations with few human fatalities or injuries, or serious losses of livestock or wildlife. However, its use is now being generally discouraged in many localities and States.

Concentrations of ortho dichlorobenzene-xylene mixtures required to control aquatic weeds in irrigation ditches will damage corn irrigated with treated water. However, under proper management, water so treated can be safely used for irrigation purposes. Copper sulfate usually does not injure bass, bluegill, and certain other fish, but kills trout at concentrations necessary to control algae. Copper sulfate is considered safe in drinking water at concentrations up to 3 p.p.m.

Nematocides

The principal nematocides in use are halogenated hydrocarbons, carbamates, and organophosphates. Chlorine and bromine residues persist in soil, are taken up by crops, and are a potential hazard to man via foodstuffs and animal products. To date no evidence of injury to man or animals from such residues is known to exist. Although no immediate health hazards are apparent, chlorine accumulation is a factor in tobacco production, and bromine levels above normal are reported in milk from cows fed fodder grown on nematocide-treated land. Runoff from fields treated with nematocides and irrigation water to which nematocides have been added are potential hazards as pollutants.

APPENDIX III

Research Underway in Agriculture and Forestry Towards Ameliorating Waste Production and Waste Management Problems

The current terse review will not permit a listing of all the research projects active in the U.S. Department of Agriculture and the land-grant universities pertaining to wastes in relation to agriculture and forestry. Rather, only a few research activities will be mentioned to illustrate the kinds of studies that are underway, or have been recently completed, that are providing needed and useful information on the subject.

As in the foregoing appendices, the discussion will be delineated among nine major groups of entities with one important addition—a section on socioeconomic studies that pertain to wastes related to agriculture and forestry.

The subjects touched upon are—

1. Radioactive substances
2. Chemical air pollutants
3. Airborne dusts
4. Sediment
5. Plant nutrients
6. Inorganic salts and minerals
7. Organic wastes
8. Infectious agents and allergens
9. Agricultural chemicals
10. Socioeconomic evaluation

Radioactive Substances

Concern over radioactive wastes received its major impetus when the aftermath of Hiroshima became known. Subsequent emphasis on nuclear arms as possible instruments in international policy aroused shock at the possibilities of nuclear attack. The public became anxious to know what effect radioactivity would have on people, food, crops, livestock, soils, and water supplies.

Research on the problems of radioactive wastes in agriculture was initiated in the U.S. Department of Agriculture and at many State agricultural experiment stations under the auspices of the Atomic Energy Commission in the late forties. The Atomic Energy Commission is still the main supporter of this research, but some financial assistance is derived from the U.S. Public Health Service and the Office of Civil Defense. The current areas of research may be divided into reducing the levels of radioactive contamination in soils or in plant or animal products and defining more closely the effects of radiation on plants or animals.

The direct removal of surface contamination from agricultural land is under study in the U.S. Department of Agriculture. If radioactive fallout occurs on crops, part of it may be removed by removing the crop from the land. The larger part, however, falls to the soil surface and can be removed only by scraping or otherwise cleaning the soil surface. Cost-effectiveness studies of various methods are continuing. Any method requires disposal of large volumes of surface soil and, therefore, much attention is given to reducing the thickness of soil removal required for effective decontamination.

Methods for reducing plant uptake of hazardous radioactive elements, particularly radioactive strontium, from soils are being studied by many groups. Presently, the most active areas of research are on deep plowing and fixation of strontium in less soluble forms. Deep plowing, with additions of various chemicals to inhibit root growth in the contaminated soil, is under study in the U.S. Department of Agriculture. Various conditions leading to the fixation of strontium are under study at different locations: (1) In calcareous soils at the University of Arizona; (2) with silicone treatments at the University of California at Berkeley; and (3) with aluminum phosphates and silicon-phosphates in the Department of Agriculture at Beltsville, Md. Soil scientists from Ohio State University are studying the long-term behavior and movement of strontium-90 in field plots at Wooster.

Methods for removing radioactive contamination from plant or animal products have recently been studied by several groups. The removal of such contamination from fruits and vegetables during processing is being studied at Berkeley, Calif. Studies have recently been completed toward improving the separation of strontium-90 from wheat flour during milling. The commercial removal of radioactive fission products from milk by an ion-exchange process has been evaluated.

Further studies of radiation effects on plants and animals are being conducted by many groups. The U.S. Department of Agriculture is cooperating with the Office of Civil Defense, Public Health Service, and the University of Tennessee-Atomic Energy Commission Agricultural Research Laboratory at Oak Ridge, Tenn., in a study of the problem of beta radiation dose to plants. This may be the most important source of radiation to plants early after fallout, while many of the radioactive particles remain on the plant surfaces. However, the problem has been largely neglected to date. The University of Tennessee-Atomic Energy Commission Agricultural Research Laboratory and the New York State Veterinary College at Ithaca, N.Y., have the most comprehensive studies of radiation effects on farm animals.

In research that has taken place and is underway on techniques for coping with radioactive contamination, we are seeking information we earnestly hope we will never need. But we cannot feel complacent. We probably will never be able to feel secure in the adequacy of our knowledge in this area. If we should ever be lulled into a sense of security, we could harshly learn the meaning of the words by old Hecate, the Witch, in Shakespeare's Macbeth: "And ye all know security is mortals' chiefest enemy."

Chemical Air Pollutants

As to the vast production of air-polluting chemicals by automobiles, industry, and metropolitan activity, agriculture and forestry can do little. Nevertheless, much work has been underway on the sensitivity of plants and livestock to air pollutants, the injurious components in polluted air, the effects of pollutants in different plants and animals, management practices to reduce the adverse effects of air pollutants, and varieties of plants with higher tolerance of air pollutants. Most of the research with animals has been concerned with fluoride injury to cattle and sheep from eating forage with high levels of fluoride.

The complexity of chemical air pollution problems is indicated by recent studies in the U.S. Department of Agriculture. For example, the discovery has been made that sulfur dioxide and ozone act synergistically in mixed air to produce injury to tobacco leaves when levels of the individual gases used alone are too low to cause injury. The effects of the combined gases are more than additive. There is an increasing amount of evidence, as well, to show that the greatest loss from chemical air pollutants is from chronic rather than acute injury; that is, the continued exposure of plants, such as citrus, for long intervals to toxicants in photochemical smog significantly reduces growth of the trees and yields of fruit.

Tremendous quantities of hydrocarbons and particulates enter the air each year from wild forest fires so that research information that enables better forest fire control is exceedingly important.

Chemical Air Pollutants From Industrial and Metropolitan Activity

The California Agricultural Experiment Station began studies on smog damage to crops in the Los Angeles area back in the forties. Also at this time, the New Jersey and Washington stations began research on fluorine injury to plants. About this same time, several State agricultural experiment stations (Michigan, Tennessee, Utah, Washington, and Wisconsin) started work on fluorine injury to cattle. The U.S. Department of Agriculture began investigations on sulfur dioxide injury to forest trees and other vegetation at about the turn of the century. U.S. Department of Agriculture studies on SO_2 injury to plant life were reported as early as 1905, and to animal life in 1910. The U.S. Department of Agriculture began its investigations on fluorine damage to crops in the early forties.

Plant breeding offers the most promising route towards minimizing air pollution injury to economic crops. Because plant breeders select the most vigorous plants to maintain a line or variety, they have inadvertently selected plants within sensitive species which are most tolerant to prevailing air pollution. Thus, breeders of cigar-wrapper tobacco selected plants that were weather fleck resistant for at least 5 years before the cause of the injury was attributed to ozone in the ambient atmosphere.

Spinach is exceedingly susceptible to photochemical air pollutants. Current observations indicate that several spinach lines are tolerant to certain air pollutants. Crosses have been made to develop lines and hybrids having a high level of tolerance to airborne contaminants as well as having a resistance to major spinach diseases.

Forestry researchers have made selections of ponderosa and eastern white pines that are nearly immune or highly tolerant to specific air pollutants such as SO_2, F_2, ozone, and PAN. Genetic variation in susceptibility has been established. Clonal lines with high tolerance have been selected for reforestation in high-hazard areas, and lines with low tolerance for use as monitors of air pollution. The demand for such clonal materials impelled the research on expediting reproduction of elite clonal materials. To illustrate the urgency of this research, trees along highways and in metropolitan areas may all need to be from resistant clones.

Some corn varieties are susceptible to fluorine injury; however, ever-increasing air pollution show good potential for breeding research in this species.

Even though relatively tolerant strains are developed, plant breeders must continue their research. In 1963, cigar-wrapper tobacco growers around South Hartford, Conn., found that a variety considered resistant was significantly damaged by fleck. The point illustrated is that varieties with higher resistance have high threshold values for injury; however, ever-increasing air pollution around metropolitan areas can overtake the threshold values of injury of even the more resistant varieties.

Air pollution injury has been reduced by application of chemicals to foliage. Field and fumigation tests in California disclosed that a number of fungicides and antioxidants reduced damage to beans, lettuce, and endive. Numerous compounds will reduce ozone injury or weather fleck on tobacco. Various fungicides and such materials as ascorbic acid, powdered clay, kaolin, and diatomaceous earth have been evaluated. It was recently shown by the U.S. Department of Agriculture that the application of *N,N′*-diphenyl-*p*-phenylenediamine protected tobacco from ozone fleck without evidence of injury to the plant by the applied chemical.

Research is revealing many difficulties in using chemical treatments to prevent air pollution injury. For example, treatments may be washed off by rains or sprinkler irrigation and thereby require frequent application. The chemical residues from the treatment may be hazardous to consumers. Because of this concern over residues, research has not yet produced a satisfactory chemical treatment to prevent air pollution injury to crop plants.

Applied research has developed a practical method of reducing or preventing certain types of air pollution injury to plants in greenhouses. A number of greenhouses in California are equipped with carbon filters to remove ozone and other oxidants. At present, the method is expensive to install and the filters may need to be replaced after a few years, or even a few months, of operation. Evidence of air pollution damage in greenhouses in the eastern United States is increasing.

Preliminary studies show that cultural procedures may affect the extent of air pollution injury. Irrigation tends to accentuate the damage. Levels of mineral nutrients appear to modify the adverse effects of air pollution. The complexity of current observations, however, offers no clear-cut conclusions.

Research underway pertaining to the injury, and the abatement of injury, of these airborne chemicals on crops, trees, and animals obviously is inadequate.

Smoke From Wild Forest Fires

As indicated in appendix II (Organic Wastes), wild forest fires during the average year emit hundreds of thousands of tons of hydrocarbons and millions of tons of particulates into the atmosphere. Abatement of this smoke production has importance in air pollution control besides the urgent need to minimize decimation of our forests.

The Forest Service began research on forest fire control in 1923. The three Forest Fire Laboratories conduct research on the development of (*a*) fire danger prediction systems; (*b*) aerial fire control methods; (*c*) low-cost fire-retardant chemicals; and (*d*) infrared fire detection and mapping techniques.

The importance of the application of these research findings is indicated by the reductions in fire damage in the National forests from 602,000 acres in 1924 to 92,000 acres in 1963. In 1964, the average expenditure for fire protection on Federal.

State, and private forest lands was $10,800 per fire. This figure represents only the cost per acre of fire protection and does not include any of the losses inherent in forest fires, such as timber value, erosion and sediment control, recreation, and esthetic values.

Research is also underway to develop alternatives to prescribed burning of slash. Various mechanical, chemical, and biological methods have been evaluated. Chipping has been used near urban areas, but it is prohibitively expensive for most forestry operations. A more feasible procedure for eliminating slash than by prescribed burning is highly desirable.

Airborne Dusts

The duststorms of the 1930's stimulated serious attention to research on basic causes and effects of wind erosion and development of conservation practices to avoid soil blowing. Between 1935 and 1941, soil surveys and serious research on wind erosion were undertaken at Swift Current, Canada, and at the California Institute of Technology. Wind tunnels were constructed at Swift Current, at the California Institute of Technology, at Brookings, S. Dak., and at Amarillo, Tex., to study wind erosion problems continually, not just when they occurred in the field.

Following World War II, special funds were appropriated under the Research and Marketing Act of 1946 to establish a cooperative wind erosion research project at Kansas State University. The most significant research finding thus far emanating from this project has been the computer analysis of a large mass of field and laboratory data that enables a delineation of the factors having major influence on soil blowing. The incorporation of these factors into a wind erosion equation provided an extremely useful management tool in planning and installing conservation practices to control wind erosion. Current research is providing information on basic wind erosion mechanics and processes, soil physical properties that influence erosion, wind erosion climatic factors, prevailing wind erosion directions, effectivness of shelterbelts and strip crops, performance characteristics of tillage machines, and effectiveness of a number of vegetative and nonvegetative surface films in controlling wind erosion.

Research is underway on seeding methods, species and varieties of plants adapted to soil stabilization, and management practices and forage systems designed to maintain satisfactory cover on range and pasture sites.

Many species of trees and shrubs have been and are being tested for persistence and suitability as windbreaks at several locations in the Great Plains.

From these studies, the species rated the highest for windbreaks include juniper, ponderosa pine, honeylocust, Russian olive, Siberian elm, American plum, common chokecherry, and Siberian peashrub. Research in the Northern Great Plains has shown that use of windbreak plantings has conserved both soil and water. Under experimental conditions, wheat yields have been increased from 18.9 to 27.2 bushels per acre.

Results of research related to soil blowing have been extensively used by action agencies such as the Soil Conservation Service and the Federal Extension Service. For example, the wind erosion equation is used by the Soil Conservation Service to provide technical guidance on ranch planning in the Great Plains and on the vegetable-growing areas of the Great Lakes and along the Atlantic seaboard.

Wind erosion research has contributed importantly to the effectiveness of today's conservation and other advanced farming methods in reducing the threat of future "Dust Bowls" in the Great Plains. One of the best testimonials to this point was the experience of farmers in Kansas during the drought of the mid-1950's, which records show was as bad as that of the 1930's. Erosion was not nearly as serious as it was 20 or 25 years earlier. Esthetic impact is difficult to measure.

If world food demands impose the need for expanded wheat production under intensive operations in the Great Plains, the recurrence of another drought period such as the ones in the thirties and fifties may well reveal inadequacies in our present technology to cope with soil blowing. If these contingencies come to pass, research on wind erosion control will have difficulty just keeping technical effectiveness from going backwards. Current research is directed toward meeting problems that are expected to become more serious.

Airborne dust, other than that from soil blowing, emanates from processing of farm products, such as cotton ginning, feed grinding and mixing, and most harvesting operations. The dust varies from small particulates of the product being processed to fine powders of organic material including spores and soil that may be attached to or intermingled with the product. Depending on circumstances, the dust may fall out quickly or may be carried long distances by wind.

Research has led to relatively efficient collecting devices for larger particles. Cyclones—mechanical dust removers—are widely used on feed grinding and mixing equipment; when properly designed and used they will collect all but very fine dusts. If more stringent requirements for dust removal are imposed in the future, new techniques will need to be developed.

Cotton ginning presents a special problem in that the lint fly is mingled with other dust and both are exhausted with air used to transport cotton through the gin. Research to date has greatly improved screens for collecting the lint fly. One major accomplishment was the development of a self-cleaning screen to permit continuous operation and to permit maximum effectiveness of the screen. Current studies are investigating wet and dry inertial separators, electrostatic collectors, special screens to collect very fine particles, and methods to measure air pollution quantities and distributions from cotton gins.

The general problem of control of fine particles suspended in turbulent conveying media, such as air, is being studied by the U.S. Department of Agriculture in one of its pioneering laboratories. Research emphasis is directed toward developing a mathematical formula to characterize the complex system of fine particles. This would aid in their measurement, classification, and control.

Sediment

Conservationists in the United States have been concerned over excessive delivery of sediment from cultivated land to streams for over 200 years. Around 1750 Jared Eliot of Connecticut was writing on the seriousness of soil erosion and stream sedimentation. John Taylor of Virginia published a vigorous essay in 1813 on ways to reduce soil erosion, to control gullies, and to prevent streambank erosion and stream sedimentation. Many leading agriculturists made a contribution, but let us especially consider the work of E. W. Hilgard.

Sediment Delivery

Hilgard must be regarded as the most distinguished soil scientist the United States has produced. From 1855 to 1873, he was State Geologist of Mississippi. In 1860, he published a book entitled "A Report on the Geology and Agriculture of the State of Mississippi"—a contribution that is now regarded as one of the "classics" in history of American agriculture.

Hilgard noted in this book that the brown loam soils in north-central Mississippi were some of the most fertile cotton-producing soils in the South. But he warned that these soils were prone to what he called "running," and that unless proper "husbandry" practices were followed, the soil would run off the fields into the streams filling up the channels.

Soon after Hilgard's report was published, the Nation erupted into a violent holocaust. During the war years and the turbulent years of the Reconstruction, little, if any, thought was given to the problems of soil erosion and attendant sedimentation.

That which Hilgard warned might come to pass, did come to pass.

By the turn of the century, the U.S. Department of Agriculture and several State agricultural experiment stations were providing technical advice on field management practices to reduce soil erosion and the movement of sediment from fields to streams. Several States began measuring soil and water losses from different kinds of lands in the early 1900's.

But the decade beginning in 1928 stands out as the period when the soil and water conservation movement began to flourish in this country. This era saw the establishment of soil and water conservation programs within the U.S. Department of Agriculture in both research and operations, which have evolved as major bulwarks in the conservation development of the Nation's land and related water resources.

Research was begun and has continued on the mechanics of erosion and factors influencing erosion processes; mechanics of sediment transport; principles of sediment deposition in stream channels and on flood plains; rates and processes of reservoir silting; sediment burden of streams in relation to erosion processes in contributing watersheds; and development of methods and systems for control of erosion and sediment problems.

It has been clearly shown that rates of erosion and resulting sediment delivery have been greatly accelerated by man's use and management of lands, vegetation, and stream channel systems. It is also a well-accepted fact that stabilization of the sediment source by proper erosion control measures is the most direct approach to solving most sediment problems. Where the sediment is derived from sheet and rill erosion on agricultural, forest, or rangelands, certain agronomic and silvicultural practices are known to effectively reduce sediment yields. For instance, changing cultivated fields from row crops to small grain may reduce soil loss to sheet erosion by from 60 to 90 percent, depending on cover conditions, soils, and seasonal distribution of rainfall.

Rotation of crops to include meadow in the cropping sequence may reduce average soil loss from fields by 75 percent. Such practices as mulching stripcropping, and contour cultivation have been shown to be highly effective in reducing soil erosion on farmlands.

Graded cropland terraces may reduce erosion on fields by 75 percent, and in combination with crop rotations, mulching, minimum tillage, etc., can reduce to practically nothing soil loss from cultivated cropland fields. Converting croplands to good grasslands, pasture, or woodlands can reduce soil erosion by 90 percent or more.

At Riesel, Tex., sediment yield from a 132-acre watershed with good conservation practices (including improved rotations, increase in acreage of permanent grass, and graded cropland terraces) is only 12 percent of that from an adjacent 176-acre watershed without conservation practices. On paired watersheds of 400 acres at Rosemont, Nebr., land treatment measures started in 1957 have reduced sediment yield by about 50 percent.

The effectiveness of watershed management practices on National forest lands as stabilizers of erosion and for control of floodborne sediment has been clearly demonstrated. Improved grazing practices, fire protection, contour trenches, and seeding of perennial grasses have successfully prevented debris-laden flows from the Wasatch Front north of Salt Lake City, Utah. Adoption of research-derived criteria for location and construction of logging roads and skid trails has minimized soil disturbance and sediment delivery from timber harvest operations. Forestry research on the abatement of wild fires has made a major contribution in diminishing sediment delivery from forested lands.

Where the primary source of sediment is erosion from gullies or stream channels, various types of engineering works can effectively reduce the amount of sediment delivery to downstream points. On the 145-square-mile Buffalo Creek Watershed, for instance, streambank erosion control measures reduced sediment delivery by 40 percent. During the same period, sediment delivery by other streams tributary to the City Harbor of Buffalo, N.Y., but without stream channel erosion control practices, increased by about 10 percent.

Mathematical equations of sediment-streamflow relations, criteria for designing vegetation-lined waterways and for streambank erosion control measures, ratios between sediment delivery and watershed erosion, and information about the properties and distribution of sediment in reservoirs are also products of this research in the U.S. Department of Agriculture.

About 10 years ago, data from all of the cooperative soil erosion studies were brought together at the Indiana Agricultural Experiment Station where further cooperative research using a digital computer reduced the data to a state permitting meaningful evaluation of the key determinants in soil loss, or sediment delivery. A "Soil Loss Equation" evolved from this comprehensive analysis of the accrued data.

The findings showed that erosion can be related to the energy available for dislodgment and transport of soil particles. The energy sources are (1) falling raindrops and (2) the elevation differences of sloping topography, which impart energy to runoff water. Effective control measures include using crop or residue covers to intercept the falling raindrops and promote water intake, planting sod crops and crop row barriers to reduce runoff velocity, and modifying the topography to reduce slope steepness and length.

The soil loss prediction handbook (*136*), based on the results from 35 locations in the United States, has been used widely by the Soil Conservation Service and educational institutions in their programs.

The data from these studies are used effectively by educational institutions in teaching conservation courses and by action agencies in explaining to potential cooperators the need for and the advantages from application of the practices to these lands.

These findings point out the need for application of effective conservation practices to land areas and show the tremendous reductions that can be made in sediment yield. In addition to preservation of the soil resource for food production, such measures are necessary to preserve the storage capacity in water reservoirs; to protect the beauty and utility of recreational areas, particularly those that are water based; to reduce highway maintenance costs; and to mitigate the damage inflicted during urban and industrial expansion.

Slopes once scarred by gullies have been healed by establishment of grasses and legumes. Contour stripcropped fields have added to the beauty of the rural landscape.

Clarifying Silted Water

Investigations of the ground water acquifer of western Texas and Oklahoma and eastern New Mexico have shown that natural recharge is so small that pumping is essentially a mining operation. Depletion of this aquifer exceeds 4 million acre-feet annually. Natural recharge is about 75,–000 acre-feet a year. Simple arithmetic reveals the future of the aquifer. During the average year, about 1.5 million acre-feet of runoff water is collected in shallow playa lakes that have almost impermeable lake bottoms. This water, which is almost always wasted by evaporation, is a potential source for recharge through reverse operation of irrigation wells.

A study of recharge through multiple-purpose wells showed a drastic reduction of well pumping rates caused by clogging of the acquifer pore space by the clay and silt in the playa lake water. Pumping of the wells removed little of the sediments. The need to clarify the water before recharge thereby became urgent. Numerous chemical flocculants have been studied in an effort to develop an economical clarification system. The flocculation potential of polyelectrolytes has been intensively investigated for several years under cooperative research with the Government of Israel through authorization in P.L. 83–480 (*116*) in Israel. From these studies a model clarification system has been developed and tests made on the Texas High Plains. Early results indicate 90 percent of sediments can be removed; however, considerable research remains to be done before commercial operation is warranted.

Résumé

The vast magnitude of sedimentation problems is mitigated by their subtle nature. Many people are so accustomed to seeing muddy water that they become indifferent to its presence.

Sediment in the waters of many of our streams and their associated reservoirs can never be eliminated, but abatement of this water pollutant should go forward to the full extent practical. There must be ever-continuing improvement in technology that will warrant economically feasible plans and procedures for curbing and controlling the sediment burden entering and being transported by our streams.

Plant Nutrients

Major concern over the effects of plant nutrients in surface waters as a precondition to eutrophication is rather recent. Research on the behavior of such nutrients as phosphorus and nitrogen in soils and soil solutions has been underway for over a century.

In 1834, at the age of 20, John Bennett Lawes was given the management of the family estate. This family farm was called Rothamsted. It covered 250 acres near the village of Harpenden, England. While at Eton and Oxford, Lawes became interested in the new science of chemistry. Working in his home laboratory, he discovered that treating bone black with sulfuric acid made the product more effective as a phosphatic fertilizer. This suggested using the same treatment on apatite and other mineral phosphates. In 1842, he obtained a patent for, and began manufacturing, superphosphate.

In 1843, Joseph Henry Gilbert, a chemist, joined Lawes at Rothamsted. They started their historically famous soil fertility experiment that is still underway. The effects on crop yields of chemical fertilizers providing nitrogen, phosphorus, and potassium were evaluated with comparable levels of plant nutrients provided in barnyard manures. The tremendous value of chemicals as sources of soil fertility soon became apparent.

Phosphorus

Research on the field application of phosphatic fertilizers has been underway in the United States for over 80 years. A number of the State agricultural experiment stations—Illinois, Pennsylvania, Ohio, and New Jersey, for example—initiated this early research. As time went on, there also developed an extensive program of laboratory studies towards understanding the chemical behavior of phosphate in soils.

Research showed that some phosphorus is present as a natural component of soil-forming minerals in all soils. The amount in the 7-inch plow layer ranges from less than 100 to as much as 4,000 pounds per acre (of soil to the plowed depth). The average content runs about 1,000 pounds per acre or about 0.05 percent of the 2 million pounds of soil in an acre to plow depth. To illustrate, the Clyde, Brookston, and Claremont soils of Indiana and Ohio averaged 2,540 pounds per acre, whereas the Norfolk and Tifton soils of the Atlantic Coastal Plain averaged only 340 pounds per acre.

Much of the mineral phosphorus content in soils is not only insoluble in water, but unavailable to plants. The part of the phosphorus that is not actually present as crystals of insoluble phosphates or occluded within grains of other minerals is adsorbed very tenaciously on the surface of the soil colloids. Phosphate derived from water-soluble fertilizers is rapidly converted to insoluble forms.

Much research has been done on thousands of soils as to the soil chemical factors that control phosphorus availability. In acid soils, freshly applied fertilizer phosphate is rapidly converted to various forms of aluminum phosphates, some of which are crystalline. With the passage of time these compounds disappear, as the phosphate is converted to forms of iron phosphate by reaction with the iron oxides that are an almost universal component of the soil. In virgin (undisturbed) soils most of the mineral phosphate is present as poorly defined but highly insoluble iron phosphates.

In neutral and alkaline soils the principal forms present are basic calcium phosphates. At pH values above 6 these are very stable and highly insoluble. In addition to the mineral forms, significant quantities of phosphorus can be present in organic forms, in amounts ranging from 5 to 75 percent of the total depending upon the character of the soil. These are also very stable compounds; the availability of this kind of phosphorus depends mainly on its rate of conversion to mineral forms.

A marked step forward was made possible in studying the phosphate chemistry of soils in the middle twenties by discovery of the ceruleomolybdate reaction in which traces of phosphate reacting with molybdenum in the presence of a tin catalyst produce a bright blue color that is proportional to the concentration of phosphate. This colorimetric technique made possible assay of phosphorus in soil solutions that contained only 0.1 p.p.m.

A tremendous step forward in research and understanding of the behavior of phosphate in soil solutions was made in the midforties when a radioactive isotope of phosphorus, P^{32}, became available from atomic research. Use of this isotope enabled the researcher to distinguish between the phosphorus that was inherent in the soil and that which was applied as a fertilizer. Phosphate ions that entered into crop plants, into drainage waters, or became residual in the soil itself could be traced. The great mass of chemical evidence that has been attained from research on soil phosphorus shows very conclusively that phosphate applied to soils does not move downward into the ground water or drainage water except in very minute amounts. Studies of soils in lysimeters have shown this very clearly. For example, in lysimeter studies at the Illinois and Wisconsin agricultural experiment stations (*68*, *107*) phosphate content of the percolate was not even measured because there was such a minute trace.

Cooperative research by the U.S. Department of Agriculture and the South Carolina Agricultural Experiment Station (*9*) involving lysimetric studies of a Lakeland sand is of special interest. If phosphorus would percolate downward through the soil and into the effluent from any soil, it would do so in Lakeland sand. Phosphate was added to the soil in the lysimeters at rates varying from zero to 288 pounds of P_2O_5 per acre. A number of different crops were grown on the soils so treated. The amount of phosphate that accumulated in the leachate was measured over a 5-year period following fertilizer application. In the lysimeter that received no phosphate fertilizer, the total loss of P_2O_5 over the 5-year period was 1.48 pounds per acre. The four lysimeters that had received 288 pounds per acre of P_2O_5 at the beginning of the study, lost an average of 1.42 pounds of P_2O_5 per acre for the 5-year period. This study on a soil which was amenable to maximum leaching provides little evidence that phosphorus enters into drainage water as a result of field application of phosphate fertilizer.

The excellent experiments on soil loss from erosion carried on by the Missouri agricultural experiment station (*84*) were very significant in revealing the large losses in phosphorus that would take place from fields by soil erosion. An experiment was carried out on a Shelby loam soil with plots 90 feet long, having a 3.86-percent slope. Where corn was grown continuously, the loss of phosphorus by erosion was 18 pounds a year. That is, more phosphorus was lost by erosion in 1 year than would be absorbed by corn plants producing a 75-bushel crop. Even where a good rotation was practiced, the loss of phosphorus by erosion was found to be 6.2 pounds per acre. However, under continuous bluegrass, only 0.1 pound of phosphorus per acre was lost by erosion simply because grass cover provides such excellent protection against soil losses. This early research presented clear evidence that if phosphate is getting into streams from farmers' fields, it is getting there by soil erosion. However, such phosphorus riding on soil particles is highly insoluble in the water of the stream.

Other studies have shown similar results. Studies (*98*) at the Alabama agricultural experiment station indicated that 82 percent of the phosphate applied to a fine sandy loam soil in Alabama over a period of 26 years was lost by erosion, amounting to a total loss of 1,430 pounds per acre. Research at the Virginia agricultural experiment station measured nutrient losses by erosion from a silt loam soil on different slopes (*94*). During a 5-year rotation of corn, wheat, and clover, 610 pounds of phosphorus per acre were lost from a 5-percent slope. The loss of phosphorus was twice as great on a 15-percent slope. Direct measurement of the amount of soil eroded showed that most of this loss took place during the growth of the corn.

The U.S. Department of Agriculture has long-term studies underway to measure the soluble unadsorbed phosphate in water from the runoff of variously treated watersheds in the Appalachian foothills. This study will provide some information that is urgently needed on the sources of phosphorus in the streams of a watershed.

Nitrate

Research in the U.S. Department of Agriculture has not ignored the movement of nitrate from fields into surface and ground waters. Nitrate salts are extremely soluble, and are readily transferred by water movement. However, this simple rationalization by no means implies that the nitrogenous fertilizers applied to farmers' fields are the source of nitrate found in surface and ground waters.

Nitrate salts have accumulated to high levels under natural conditions. The high level of nitrate salts in the vast accumulation of "caliche" that took place in geologic times on what is now the Plateau of Tarabaca in northern Chile stands as stark testimony to the enormous level to which natural nitrate accumulation can occur.

Hilgard (*55*) discovered during his studies on salinity at the University of California during the latter part of the 19th century that there were a number of locations in California and Nevada where nitrate accumulated in the caliche. He reported that a sample of caliche from the Colorado Desert of southern California contained 80 percent sodium nitrate, and that a caliche deposit near White Plains, Nev., contained 50 percent sodium nitrate.

Headden (*53*) studied the naturally occurring "nitre" spots of eastern Colorado during the early years of this century. He even found nitrate in ground water 80 feet below the surface. In 1910, when he first reported this observation, virtually no chemical nitrogen fertilizer was used in Colorado. Headden concluded that nitrate was being formed currently by the biological oxidation of nitrogen fixed in those spots by nonsymbiotic microorganisms. Seliakov (*101*) came to a comparable conclusion to explain nitrate accumulation in the saline soils of Russia.

Nitrate formed in soils by natural processes in humid climates would be leached out by rain, whereas they would accumulate near the surface under arid climates. It is important to recognize these early studies showing that nitrate may be formed naturally and may move in the direction of soil moisture movement, including percolation to ground water.

The previously mentioned cooperative research (*9*) between the U.S. Department of Agriculture and the South Carolina agricultural experiment station involving the fate of plant nutrients added to Lakeland sand in lysimeters is especially pertinent. Lysimeter No. 16 grew no crop and received no nitrogenous fertilizer except the 25 pounds of nitrogen per acre received in rainfall over a 5-year period. Nitrogen recovered in the percolate totaled 153.9 pounds for the 5 years. One could only hypothesize that nitrogen was being mineralized in this fallow soil, and readily being leached out in the absence of growing crops.

Lysimeters Nos. 19, 20, 21, and 22, each received 679.1 pounds of total nitrogen over the 5-year period as fertilizer, manure, and rainfall additions. Millet was grown on each of these lysimeters. Nitrogen in the leachate from these four lysimeters averaged 18.1 pounds for the 5-year period. It would be difficult to conclude from this experiment that adding fertilizer to a cropped field contributed to the nitrogen found in the percolate moving downward to the ground water.

Lysimeter studies were carried out at Cornell University using a Dunkirk silty clay loam and growing timothy grass continuously for 8 years. In one set of treatments, the annual nitrogen additions in pounds per acre were 93, 124, 155, and 217; and the annual nitrogen losses in the leachates were 0.2, 0.2, 0.3, and 1.9 pounds, respectively. These nitrogen losses to deep percolation under grass cover were amazingly small.

The Kentucky agricultural experiment station carried out a lysimeter experiment for 11 years using Maury silt loam that received no nitrogen fertilizer. Various forage crops were grown. The average annual nitrogen losses in the leachates, in pounds per acre, from the various cropping treatments were as follows: uncropped 74, Korean lespedeza 58, alfalfa 9, and bluegrass 5. Kind of cover may have a tremendous effect on deep percolation of nitrogen even though no chemical is applied to the soil.

Cooperative research between the U.S. Department of Agriculture and Purdue University (*74*) has shown that appreciable nitrogen losses can occur in surface runoff if ammonium nitrate is broadcast over the surface of both fallow and sod before a runoff-producing storm.

Since the advent of high analysis fertilizers in the 1930's, considerable research has gone into designing fertilizer applicators on planting equipment so that the more concentrated fertilizers will not "burn" the germinating seed, the fertilizer applied will be protected from runoff losses, and the minerals will be placed where they will be maximally utilized by the growing crop. The California Agricultural Experiment Station studied the nitrogen and phosphorus contents in tile drainage effluent from irrigated areas in the San Joaquin Valley (*63*). The amount of phosphorus entering the drains was insignificant. The nitrogen content of the drainage effluent varied from 1.8 to 62.4 p.p.m. One area under study during 1962 consisted of 150 acres in cotton and rice that had received application of 23,500 pounds of nitrogen. Assay of the drainage water indicated that 14,800 pounds of nitrogen were lost in the drains. That is, 63 percent of the nitrogen applied went down the drain. This finding is important in that it shows that there may be plenty of room for improvement in efficiency in nitrogen use under irrigation.

Research in Hawaii (*85*) has provided evidence that water in an aquifer under an irrigated sugar plantation receiving up to 300 pounds of nitrogen per acre over a 2-year period may have an appreciably elevated nitrate content.

The University of Missouri has made extensive studies to explain the high nitrate content in certain crop plants and in numerous samples of ground water. The research findings indicated that leachates from feedlots were the main source of nitrate (or nitrite) in most contaminated aquifers. The studies revealed that fertilizer nitrogen has been of little importance in water contamination, but could become important in the future. These studies are being continued.

It has been known for many years that certain well waters in California contain 100 p.p.m. of nitrate or more, and that many of them contain more than 10 p.p.m. One well near Riverside, which yields water containing about 100 p.p.m. of nitrate, has been used as a source of irrigation water for over 30 years without material change in nitrate content (*66*). The University of California has research underway to ascertain the sources of nitrate found in California wells.[7] Special attention is being given to the 10-square-mile basin occupied by Grover City and Arroyo Grande. This basin

[7] Stout, P. R., and Burau, R. Extent and Significance of Fertilizer Buildup in Soils. Presented at Amer. Assoc. Adv. Sci. Symposium, Washington, D.C., Dec. 29, 1966

offers an unusual opportunity to study complete soil profiles through which nitrate transfer can be traced from soils to underlying water tables. The highly permeable subsoils of this basin facilitate nitrate transmissions from uncultivated soils downward to the ground water table within two or three seasons under natural rainfall. Nitrification occurs very rapidly in soils that have received sewage effluent devoid of nitrate. Concentrations of 90 to 130 p.p.m. of nitrate have been found in water percolating to the underground reservoir from well-aerated permeable soils. This important research is being continued.

The U.S. Department of Agriculture has initiated cooperative research with the Colorado agricultural experiment station toward gaining information on the deep percolation of nitrate under various land uses in the valley of the South Platte River. Analyses have been made on 129 cores varying in depth from 10 to 65 feet, as limited by bedrock or water table depth. Quantity of nitrate in transit to the water table is emphasized, but other water contaminants are also measured. Cores from beneath native rangeland and irrigated alfalfa contain insignificant amounts of nitrate. Those from cultivated dryland fields contain significant amounts of nitrate below the root zone even though rainfall in the area averages only 15 inches a year. Slightly larger amounts of nitrate are found under irrigated fields of corn and sugar beets. Preliminary evidence indicates that about 20 to 30 pounds of nitrogen as nitrate per acre are lost to the water table during the average year.

Highly variable amounts of nitrate are being found under cattle corrals. The amount appears to depend on the corral management, corral age, and the water content of the profile, which affects denitrification. As much as 5,000 pounds of nitrate nitrogen per acre has been found in a 20-foot profile. Nitrite is detected in the cores from some corrals. Nitrate was not found in cores where reducing conditions predominate, indicating that nitrate is destroyed in profiles under corrals lacking oxygen because of high microbial activity. Corrals with good manure management from the esthetic, "public nuisance," and animal health standpoint appear to be the worst in relation to subsurface contamination with nitrate (*108*).

Samples from water tables beneath corrals frequently contained nitrite, ammonia, organic carbon, and phosphorous. Samples were redolent with a very offensive odor.

Inorganic Salts and Minerals

Problems in agriculture related to the accumulation of salts in soils, surface waters, and ground water are as old as the arts of irrigation that apparently began some 7,000 years ago in the valleys of the Tigris and Euphrates (*18, 60*).

When earth materials weather, small amounts of soluble salts are released. Under humid climates, such solubles are leached away; under arid or semiarid climates these solubles tend to accumulate at the surface as a result of evaporation. Water transports solubles from one part of the landscape to another. For example, a desert storm abets such salt accumulation in a playa basin. Irrigation water brings solubles from miles away and abets their accumulation in the irrigated fields unless they are leached away through a proper drainage system.

Following the transfer of E. W. Hilgard from the University of Michigan to the University of California in 1875, a real beginning occurred in the United States on research on salinity problems. Hilgard's work in California (1875–1906) on the kinds of salts that prevail in salted soils and waters, their distribution in the soil profile, and the relative tolerance of different vegetative species to salts still stands as a monumental contribution.

By the turn of the century, or soon thereafter, most of the agricultural experiment stations in the Western States had initiated research pertaining to the salinity or "alkali" problem associated with irrigation agriculture. The U.S. Department of Agriculture started investigations in this area with the establishment of the Office of Western Irrigation Agriculture in 1905.

W. P. Kelley of the University of California was one of numerous leaders in salinity research during early decades of this century. Based on his research, Kelley set forth in 1934 five primary points that must be considered in the management of salt-affected soils:

1. The adequacy of the drainage conditions.

2. The chemical composition of the soluble salts.
3. The content of adsorbed sodium on the soil.
4. The nature and content of calcium minerals in the soil.
5. The composition and adequacy of supply of available irrigation water.

The Bankhead-Jones Act of 1935 authorized the establishment of certain regional research laboratories. The directors of the agricultural experiment stations of the 11 Western States decided on the establishment of a salinity laboratory. This came into being at Riverside, Calif., in 1938.

The U.S. Salinity Laboratory has carried on a continuing cooperative research program with the agricultural experiment stations of the 18 Western States on salt-affected soils, salts in irrigation and drainage waters, and the reactions of economic plants to salty water and soils.

Research findings have been made available through publication in scientific journals and summarized in agricultural bulletins and information bulletins for use by farmers. Information has gone directly to engineers and agronomists employed by action agencies such as the Soil Conservation Service, U.S. Bureau of Reclamation, water and drainage districts, and pollution control boards. USDA Handbook 60 (*126*), which summarizes much of the findings up to 1954, has been translated into four languages and is widely used internationally as a text and reference book.

Irrigation Water Quality

Studies have been underway for a number of years, and are continuing more intensively, on developing sound criteria for assessing irrigation water quality. Experience has shown that a single-valued criterion of water quality for irrigation under average conditions requires a high degree of subjective judgment in its use. Research data must be accrued to enable quantitative assessment of irrigation water quality with reference to soil properties, climate, irrigation management, and salt tolerance of plants.

The research approach underway to meet this objective is to determine "the potential leaching fraction" for a given salt-affected soil, taking into account soil infiltration rate, evapotranspiration and drainage rates, and the critical water management practices, irrigation frequency, and duration. On calculation of the potential leaching fraction, the maximum permissible salt content of an irrigation water could be calculated by reference to the maximum permissible limits of salts in the soil solution for specific crops.

From the maximum permissible salt content of the soil solution for the specific crops to be grown, one can determine the fraction of the total amount of irrigation water of a given quality that must be allowed to drain.

The above statement ignores the effect of composition of irrigation water; the tendency of high sodium waters and, to some extent, of high bicarbonate waters to increase the exchangeable sodium percentage in the soil is an additional complicating factor.

Another aspect of water quality that needs further study is its relationship with hydraulic conductivity. The initial use of high salt water for reclamation of sodic soils, with the salt concentration of the water decreasing gradually with time, tends to maintain a higher conductivity and hence enhances the passage of leaching water. This can result in drastically reduced time requirements for reclaiming sodic soils.

The research on water quality will not only provide more rational characterization of water quality, but will also permit more efficient use of water having a quality which is partially impaired by a salt burden.

Soil Chemistry

Much research has been underway over the years, and is continuing, on cation exchange reactions in salt-affected soils. Knowledge of such chemistry is essential for making sound recommendations on the management of saline and sodic soils.

It is known that calcium ions are adsorbed on clay particles with a much higher energy of retention than potassium ions are, and that potassium ions are retained with a higher energy than sodium ions. The physical properties of soil colloids are in turn affected by the nature of adsorbed cations. Calcium-saturated soil colloids flocculate readily, whereas those colloids predominantly saturated with sodium tend to be highly dispersed. Soil with appreciable levels of adsorbed sodium tend to be intractable and impervious to water. Soils begin to take on the characteristic of "sodium soils" when about 10 to 15 percent of the base exchange capacity becomes saturated with sodium. Thus, the base exchange characteristics become an exceedingly important attribute in predicting the manner in which waters varying in salt content will move into, through, and out of soils. The behavior of soils with respect to adsorbed cations also varies with the nature of the mineral providing the adsorption surface, that is, whether it is kaolinite, montmorillonite, or vermiculite.

"Slick spots" are a common problem in many areas in the Western States. These are areas in fields that were at one time salt-affected soils—specifically sodic soils. The soils became highly dispersed and relatively impervious to water. Hence, these "slick spots" are usually manifested as barren spots in a cropped field. Understanding the principles of base exchange phenomena aforementioned has been necessary in developing field technology for reclaiming these salt-affected soils.

Various amounts and kinds of soil amendments have been used over the years as aids in the reclamation of salty soils. Research results have shown that if the soil is afflicted with an accumulation of neutral salts and has a low level of adsorbed sodium on the soil colloids, then leaching with good water is all that is necessary for reclamation. Soils containing appreciable levels of adsorbed sodium, but also containing calcium and minerals such as gypsum or calcium carbonate can be reclaimed by adding sulfur, sulfuric acid, or other acidifying amendments before leaching. If a soil contains considerable adsorbed sodium but little or no calcium, then it is necessary to add gypsum to the soil before leaching. Understanding the principles of base exchange reactions in soils is fundamental to developing soil tests and predictive equations in support of field management decisions on the use of amendments for reclaiming salt-affected soils.

It has long been held that weathering of soil minerals is the main process in the production of soil salts. Recent studies involving spectrographic analysis have indicated that negligible amounts of chloride and sulfate salts are released during the weathering of primarily igneous materials. Current evidence suggests that too little consideration has been given to the role of accumulation of fossil salt in soil as the origin of solubles.

Soil Water

The only way that salts can move into, through, and out of soils is by the vehicle of water. Consequently, studies on the physics of water retention and movement in soil become fundamental to an understanding of salt behavior. Soil colloids retain water molecules tenaciously. Water molecules closely attached to the surface of the clay may be held with energy forces equivalent to thousands of pounds per square inch. Research studies show that when the water content of the soil drops to the level called "permanent wilting percentage," the water is held on the surface of the clay with a force equivalent to about 200 pounds per square inch. When soil is holding about all the water it can against the force of gravity—a water content referred to as "field capacity"—the particle surfaces are retaining the water with a force equivalent to about 5 pounds per square inch.

To understand water behavior in soils and its role as a salt vehicle requires basic knowledge and means of measuring the energy status of water in soils. Attaining such information, as well as designing apparatus that would make meaningful measurements, has been a key objective of scientists working on salt-affected soils for the past 30 years. The problem of measuring the energy of soil moisture by an inserted instrument is illustrated by the fact that the relative humidity of the soil atmosphere in a soil at field capacity is about 100 percent, whereas the relative humidity in the soil atmosphere at the permanent wilting percentage is about 98 percent. Thus, an exceedingly narrow range in relative humidity prevails over the range of soil moisture content available for crop growth. This situation is the basis for the tremendous difficulties experienced in making psychrometric measurements of the energy of soil water. Over the last few years, rapid strides have been made in perfecting such instrumentation for field work.

Another fundamental need in determining salt content of soils was instrumentation that would measure salt content in situ without the tedium of taking the soil into the laboratory to make appropriate extractions and measurements. During the past few years rapid progress has been made in developing a salt sensor that should be practical for field use.

Plant Tolerance

Irrigation agriculture must provide for improved growth of crop plants or it has no justification for existence. Thus, when soils or irrigation water have an undue burden of soluble salts, it is essential to know how much salt various crops will tolerate at different stages of growth. Research has shown that certain barley varieties are quite tolerant to irrigation water containing 20,000 p.p.m. of dissolved salt. Sugar beets are very sensitive to salt at the seedling stage but highly tolerant after the young plants have become well established. Beans are very sensitive to salty soils. Most horticultural fruits are sensitive to salty soils, but there are exceptions.

A study undertaken to ascertain the effects of various rootstocks in permitting grapes to be grown on salty soils showed that the rootstock tremendously affected the amount of chloride that accumulated in grape leaves. It was also found that if the chloride ion accumulated to appreciable levels in a grape leaf, it could cause necrosis, or death, of the leaf. When grapes were grown on a rootstock known as "Salt Creek," only one-fifteenth as much chloride accumulated in the leaves as when grown on "Cardinal" rootstock. Consequently, grapevines growing in soils having appreciable chloride salts would show serious injury if grown on Cardinal roots, whereas the same varieties would show virtually no injury when grown on Salt Creek roots.

Research is underway in the selection of genetic lines of Pima cotton that are more tolerant to saline conditions of the Southwest. Pima S–3, recently released for commercial production, appears to be considerably more tolerant to saline conditions than the current commercial variety.

Limited research has shown the feasibility of developing forage grasses that are superior with respect to establishment, persistence, and yield on saline soils. Grass varieties differ markedly in salt tolerance. Evidence indicates that there are good possibilities in selecting within species for improved salt tolerance.

Research on the nature of salt tolerance and selection or development of varieties superior in salt tolerance, will provide valuable information and planting material in the future. As economic pressures on water supplies force agriculture to use more and more water of impaired quality with respect to salt loading, salt tolerant crops will increase in importance.

Decreasing Salt in Drainage Water

Plants preferentially absorb water and leave the dissolved salts in the soil. This preference by plants for water over salt increases with increasing salinity of the water. Since this discrimination in plant absorption is a basic plant characteristic, it would appear that little can be done to alter the fact that drainage waters from irrigated areas will be higher in salt concentration than the original irrigation water, and approximately in inverse proportion to the change in water volume during the passage of the water through the plant root zone. Since virtually all of the salt in the drainage water was endogenous to the irrigation water, no substantial decrease in total salt burden of the water is possible without adversely affecting the agriculture of the area. In fact, increasing the salt tolerance of plants—thereby enabling them to concentrate the water still further—will only result in a still greater increase in the salinity of the drainage water. However, the reduction in volume of the drainage effluent may be decidedly beneficial if alternative methods for disposal of drainage effluent other than by return to streams or reusable water reservoirs are developed.

Not all evapotranspiration is beneficial or unavoidable. Excessive irrigation, by keeping the soil surface moist for longer periods, promotes surface evaporation. In only rare cases is the resultant lowering of soil temperature of definite benefit to the crop. Therefore, improved irrigation efficiency will not only conserve water but will also decrease the volume of drainage water and the quantity of salt that must in some way be removed from the crop fields. Research on planting techniques for furrow-irrigated crops has produced planting methods that do not require preplanting irrigations for thorough leaching of salt out of the plow layer. This, again, conserves water and reduces nonbeneficial evaporation of water from the soil. The elimination of weeds in fields, and of phreatophytes along canals and field borders, will further conserve water and decrease the magnitude of the saline water disposal problem.

The removal of drainage waters from irrigated lands, which prevents rising water tables and a buildup of salt in the soil, is essential for the maintenance of the project. The collected drainage waters, although commonly returned to rivers, may—with efficient irrigation management—be so saline that alternative methods of disposal should be considered. Since some crop plants are 10 times as salt tolerant as others, the drainage water, although too saline for general use, often has productive potential for crops with especially high salt tolerance. Bermudagrass pastures and seed crops of some other grasses can be grown with waters too saline for general agricultural use. The further concentration of the original drainage waters by using them on a second salt-tolerant crop may be an important step in disposing of large volumes of saline waste waters.

Salinity Reconnaissance

There is a pressing need for rapid and effective methods of evaluating conditions in extensive land areas. Such information is needed in planning irrigation districts, drainage districts, conservation districts, and river basins. Remedial measures are more expeditiously applied as knowledge of the nature and extent of the problems increases. The occurrence and intensity of soil salinity, the prevalence of moisture excesses or shortages, and disease infestations are kinds of problems where extensive evaluation is helpful. The use of remote sensing techniques appears to offer unusual advantages.

Limited research in this area has been underway for several years by the U.S. Department of Agriculture in the Lower Rio Grande Valley of Texas. The earlier studies using aerial infrared color film sensitive to wavelengths in the range of 0.5 to 0.9 micron showed tonal contrasts that correlated well with measured soil salinity. Recent results reveal an excellent correlation between leaf temperature of cotton plants and salinity in the 0- to 5-foot profile.

The Department of Defense and the National Aeronautics and Space Administration have developed information through their research and development programs that makes possible the use of optical and thermal techniques in aerial mapping of large areas and in detection of environmental conditions important to agriculture.

Little is known, however, of the specific effects of plant and soil environmental factors on the optical characteristics of land cover and of their relation to specific agricultural problems. This phase is now receiving direct attention in the research and development programs of the U.S. Department of Agriculture and several land-grant universities. Fundamental studies seek to establish the mechanisms whereby these environmental factors affect the optical properties of plant materials and of the soil. From this information, photogrammetry techniques and identification and interpretation procedures are being developed for use in the solution of many land-management problems involving salinity and the status of soil-moisture conditions.

Organic Wastes

The Chinese developed procedures for full utilization of agricultural wastes centuries ago (*69*). The peasants diligently collected all wastes—human, animal, and plant—made "patties" out of them, and allowed them to dry in the sun. The patties were then stacked until distributed to the fields at the proper time. Although this old Chinese art provided for full use of organic wastes, the procedure has never found favor in the United States.

The point to be emphasized is that organic wastes can be used, but we rightly insist on using technology that takes into account health hazards, social acceptability, and economic feasibility.

Research that pertains to organic wastes may have one or more of the following six objectives:

1. To better characterize organic wastes.
2. To improve evaluation of the effects of organic wastes in the environment.
3. To minimize production of organic wastes.
4. To minimize adverse effects in the management of organic wastes.
5. To develop waste management and disposal procedures and facilities with high economic feasibility.
6. To develop technology with higher economic feasibility for utilization of these wastes.

Animal Wastes

Research was underway in the State agricultural experiment stations on the characterization, handling, and utilization of animal manures before the turn of the century. The Cornell (New York) station reported on such research in 1891 (*93*), and the Ohio station in 1907 (*110*). Much of the early research was oriented towards the use of manure as a fertilizer. An excellent summary of this information is found in Ohio Agricultural Experiment Bulletin 605 (*96*). The conclusion was reached that the crop production potential of manure is largely derived from its nitrogen, phosphorus, and potassium contents. The nitrogen in the urine was evaluated as being equally as available as that in mineral fertilizers, but the availability of nitrogen in solids of barnyard manure was considered to be only 25 to 50 percent of that in chemical fertilizers depending on the kind and nature of storage. Availability of phosphorus and potassium in manure was evaluated as about the same as that in mineral fertilizers.

In further review of available evidence, the U.S. Department of Agriculture (*32*) finds that on soils of good tilth, manure has value only for its plant nutrient content; but on soils in poor tilth, manure has a value above and beyond its nutrient content.

Marked improvements in the techniques for making fertilizer from atmospheric nitrogen were made in the period before World War II. During the war, the Federal Government built numerous plants for the manufacture of fixed nitrogen for munitions. At the war's end, these plants became available for making farm fertilizers at a relatively low price. The price has remained comparatively low ever since, whereas other farm costs have advanced appreciably. This has led to the situation in which nitrogen from chemical fertilizers is cheaper than that from manure, even if only handling charges of the latter are taken into account. This simple economic fact deters use of manure for land improvement and contributes to the problem of disposing of wastes that accumulate from large operations.

The Illinois Agricultural Experiment Station (*129*) has studied the economic value of manure handling from hog lots. The report on this study states:

> Spreading solid manure on cropland rather than dumping it in a disposal area is still a profitable practice because there is little difference between spreading and disposal costs.

However, liquid handling systems for manure are of increasing interest for those raising hogs in confinement systems. The Illinois report also states:

> The most profitable practice for the average farmer who raises hogs in confinement is to dispose of the liquid manures in a lagoon and use commercial fertilizer on his fields.

A report (*86*) of a study at Purdue University on the economics of handling manure is also of interest. Three statements are pertinent:

> In general, the scale and efficiency of the operation and prevention of dilution of the manure determine if the manure can be spread in the fields at the cost equal to or less than the value of the nutrients used by the crops.
>
> Aerobic and anaerobic treatment of manure in special low-cost facilities designed for use on the farm seem to be practical solutions.
>
> No profitable method of industrial utilization of livestock manure can be forseen.

The high moisture content of manure is a major factor in its bulk handling cost. A number of State agricultural experiment stations—for example, Michigan, Nebraska, and New York—have research underway to develop an economical procedure for dewatering manure.

Efficient systems of handling manure analogous to sewage-handling systems are being developed at a number of State stations—for example, Massachusetts, Minnesota, Ohio, and South Dakota. The Pennsylvania station has carried on outstanding research for using sewage effluent on the land. Technical Bulletin 675 (*58*) reports on use of sewage effluent for irrigation of cotton and pasture. The New Jersey station has developed a plow-furrow-cover technique that tends to conserve the value of manure, while minimizing its adverse effects in the environment.

The use of lagoons for disposal of manures is under study by the U.S. Department of Agriculture and a number of State experiment stations (*33*, *34*). Many are poorly designed, overloaded, and misused. The South Dakota station has reported adversely on lagoons. The U.S. Department of Agriculture is also studying the possibilities of growing grasses hydroponically in lagoon and other effluents to remove the plant nutrients (N, P, & K) and trace elements. This procedure would keep these nutrients from reaching and supporting aquatic plant growths in receiving streams and also help provide additional livestock feed.

Several experiment stations in the Midwest are making improvements on the Pasveer system—a system developed in Holland to handle sewage from small cities by artificial stirring to improve oxidation in a ditch. Promising reports on adapting this system for animal wastes have appeared, even though animal wastes are much more concentrated than sewage effluent.

The Georgia and Ohio stations are investigating the treatment of poultry manure-litter with micro-organisms. The treatment permits birds to be replaced on the same litter and provides an odor-free and fly-free environment.

Dilution of Organic Wastes in Streams

The adverse effects of animal wastes, sewage, and processing wastes moving into streams are conditioned by the flow of the stream. Consider the Connecticut River. Average annual flow of this river at Hartford is 10.4 billion gallons per day. During September and October 1930, the river reached a low flow of 1.9 billion gallons per day; and the maximum was 207 billion gallons per day in March 1936. Let us assume that organic wastes from sewage, industry, and agriculture dumped into this river in the Springfield-Hartford area is equivalent in biochemical oxygen demand (BOD) to that from the raw sewage of a population of 3 million people. That is, it is assumed that the daily BOD load dumped into the river is 500,000 pounds.

Under average annual flow of the Connecticut, the added wastes would induce a BOD in the stream of 6 p.p.m. (Water with 5 p.p.m. BOD is considered to be on the verge of pollution.) Under 'ow flows such as occurred in late summer of 1930 and 1966, the specified waste load would induce a BOD of 31 p.p.m. Under a spring flow of 65 billion gallons per day, this waste load would induce a BOD of 1 p.pm. (Water at 1 p.p.m. BOD is considered relatively pure.)

The flow of the Connecticut is relatively stable. But consider the Bad River in southwestern South Dakota. This stream drains a watershed of 3,107 square miles and has an average daily flow of 114 million gallons per day. The Bad is dry 3 or 4 months every year. Peak flow has been recorded at 1.9 billion gallons of water a day. There is high variability in the amount of organic wastes that a stream such as the Bad could assimilate.

Engineers concerned with assimilation of wastes in streams are interested in minimizing degree and duration of low flows. Research and development programs on watershed management in the U.S. Department of Agriculture and land-grant universities are directly related to nature of streamflow.

Foresters have been interested in the relation of forested watersheds to streamflow for over 100 years. A commission appointed by the Wisconsin State Legislature in 1867 pointed out the relationship between forest cover and streamflow. The American Forestry Congress in 1886 adopted a resolution relating to the management of public lands "with a view to maintaining and preserving a full supply of water in all rivers and streams." Research in the National forests pertaining to water yield began in Colorado in 1910. It became immediately evident that reductions in forest cover brought about increased total streamflow because of reduced transpiration and increased interception of precipitation at the ground surface. More recent research separating water yield into seasonal parts indicates the highest percentage increase from reduced cover occurs during the normally low-flow season. A moderate level of research relating forest cover to water yield is in progress in most of the major climatic and vegetation zones.

In the Rocky Mountains of Colorado, studies have shown that removal of half the lodgepole pine-spruce-fir forest by strip and block cutting from a watershed in the snow zone produced about a 25-percent increase in total annual streamflow. Most of this increase came mainly during the spring freshet, but streamflow was also found to be higher during the summer and autumn following treatment.

Cutting woody vegetation in the mountains of southern California produced an annual water yield of 1.3 acre-feet per acre of riparian areas, and 0.11 acre-feet per acre of upland deep soils. In both cases, the streams, which had formerly dried up in the summer and fall, flowed continuously after treatment.

At the Coweeta Hydrologic Laboratory in North Carolina, water yield increased 17 acre-inches per acre during the first year after all trees and shrubs had been cut. Maintenance of clear-cut conditions sustained an increase of 11 acre-inches in water yield from the experimental watershed for more than 15 years.

Clear-cutting the mature hardwood cover on a watershed at the Fernow Experimental Forest in West Virginia decreased the annual number of low-flow days (less than 50 gallons per acre per day) from 79 to 24 during the 4 years following cutting. More recent clear-cuttings increased water yield 6 inches in the 1965 growing season—by far the driest growing season of record. Attaining this increase during a drought is remarkable.

One-third of the United States is forested. These forests, with associated range and alpine areas, yield about three-fourths of the Nation's streamflow. More than any other lands, the management of our forests is important to the quality and quantity of water. Research results indicate that if studies are continued and improved watershed practices are applied to suitable areas, the amount of high-quality usable water available to the Nation can be increased by 14 million acre-feet annually. Such a bounty would exceed the average annual flow of the Connecticut River, 11.5 million acre-feet, and approach that of the Colorado River, 15 million acre-feet. Cost of producing this extra water from forest lands is expected to be about $10 per acre-foot—3 cents per 1,000 gallons.

Replacing forest with grass may not increase water yield. Research at the Coweeta Hydrologic Laboratory showed that establishing well-fertilized grass in place of forest produced no increase in streamflow. With loss in fertility and resulting poorer grass production, streamflow increased slightly.

At the Coshocton Hydrologic Field Station in Ohio, establishing a farm woodlot on a 44-acre watershed reduced water yield. By the 19th year after the trees were planted, runoff was 5.32 inches below what it would have been had it not been forested. This finding is the inverse of the results for clear-cutting forests.

Estimates (*40*) indicate that phreatophytes (deep-rooted, water-loving plants growing in flood plains) nonbeneficially use some 25 million acre-feet of water annually from the subsurface flow of the streams in the Western United States.

Cooperative research involving the U.S. Department of Agriculture, the Bureau of Reclamation, and the Arizona, New Mexico, and Wyoming agricultural experiment stations is underway to develop economical methods of eliminating phreatophytes. Salt cedar is one of the worst pests among phreatophytes. Studies indicate that applications of 2,4-D and 2,4,5-T will kill a high percentage of the top growth, but regrowth from the roots takes place (*111*). Research indicates that a more effective chemical method of controlling these plants is urgently needed.

Forestry research pertaining to the abatement of wild forest fires is important in the modulation and continuity of flow of streams arising in forests. When the surface mulch of the forest floor is burned, rate of infiltration of rainfall and absorptive capacity of the soil is greatly impaired. Runoff during the storm becomes excessive, and reserve moisture in the burned-over soil is proportionally lessened.

A forest fire started near Yucaipa, Calif., on July 4, 1950, and burned some 650 acres of chaparral-covered foothills. On July 6, while mopup crews were still on the fire, an intensive thundershower dumped three-fourths of an inch of rain over the burned and surrounding area. The high runoff from the burned area caused a flood that blocked roads, yet little or no water flowed from adjacent unburned areas.

On a burn, snow cover melts faster during spring than it does under forest trees. This impairs modulation of streamflow. Also, frost will penetrate into the soil of a burn and thereby accentuate runoff. For example, at the Hubbard Brook Experimental Forest in New Hampshire, the soil seldom freezes in the deep forest, whereas the soil on a burn would freeze.

The importance of improved technology on watershed protection for modulation of streamflow is indicated by the fact that preliminary plans for a program for cleaning up the Potomac River include costly structures to be installed primarily to avert low flows.

Plant Residues on Farms and Ranches

Farm wastes coming under the category of plant residues do have uses: bedding for poultry and livestock; mulch; soil organic matter; a small amount in ensilage; and some use in manufacture of corrugated cartons, insulating boards, etc. By far the greatest use is as a mulch.

Spreading plant residues over the ground has been referred to in English as "mulching" since 1802. Horticulturists have long been interested in this use of plant residues. In the early years of this century, the preferred culture of apple orchards in New England was that of using a deep mulch under each tree. Use of stubble mulching for erosion control and economy of operation was attempted at a number of locations on the Great Plains soon after the turn of the century (*77*).

The first intensive research in this practice was started under cooperation between the U.S. Department of Agriculture and the Nebraska agricultural experiment station in 1937. Cooperative research on this use of plant residues was underway in Idaho, Iowa, North Dakota, South Carolina, Texas, and Washington by the early forties.

The research proved conclusively that adequate residue cover is an effective use for this waste in controlling wind and water erosion (*139*).

Use of plant residues as a mulch affected the chemical, microbiological and physical character of the soil surface.

Leaving crop residues on the surface may increase or depress yields. Proper residue management requires maintaining an adequate supply of soil nitrogen, controlling weeds, and adapting suitable cropping sequences.

Research has developed machinery capable of effectively managing residues on the soil surface and of planting field grains and soybeans directly into deep mulch without prior tillage.

Research on chemical weed control has greatly abetted research on the feasibility of stubble mulch farming.

Plant residues do sometimes aid in the carryover of crop diseases and harmful insects. Research has not yet solved these problems inherent in the use of mulches.

Trash in Forests

As pointed out in "Organic Wastes" in appendix II, some 25 million tons of logging debris are left in the woods annually. This is a serious fire hazard. Research is underway to develop ways of disposing of this trash alternative to controlled burning, but the probability of discovering an economically feasible method is not bright. Burning costs only $1 per ton; chipping costs $12 a ton.

Processing Wastes

In "Organic Wastes" in appendix II, data were presented indicating that the annual effluent of organic wastes from the pulp, paper, and wood fiber industry was equivalent in BOD to that of the raw sewage from a population of 216 million people. It is obvious that research towards developing processes that would lessen such waste production would be an important contribution to abatement of stream pollution.

Over the past 25 years, many of the processing steps in the manufacture of pulp paper and wallboard have been studied towards better recovery of byproducts and consequent decrease in stream pollution. In recent years, pulping factories have begun to use wood chips from sawmills and veneer mills. This use of a byproduct is now involved in 25 percent of all pulp produced in the United States. In kraft pulping, chemicals are now recovered and oxygen-depleting substances are removed by sedimentation to minimize stream pollution. Wastes from the older sulfite plants are still a problem.

In newly built sulfite mills, use of the magnesium-base pulping process developed by forest products research eliminates much of the polluting effluent (*123*). A new polysulfide modification of the kraft process results in greater pulp yields, less waste, and reduced air and water pollution.

Cheese whey fermentation processes that lessen amount of polluting effluent have been developed, and are in industrial use. The first process that can successfully dry the acid cottage cheese whey has been developed recently (*51*). This process lessens waste effluent and is being rapidly utilized.

A technique for recovering sugar from pear processing wastes has been developed, enabling the recovered syrup to be used for canning.

A process for recovery of feed and fertilizer values from chicken feathers was developed and is in general use (*28*).

Processes for decreasing the amount of wastes from wool scouring have been found (*41*, *42*).

The cost of farm and ranch produce and, particularly, timber products is such that every effort must be made to improve technology that increases product yields and reduces wastes. Since these wastes have potential economic value for production of boards, paper, animal feeds, and chemicals, the research problems are not so much ones of waste disposal or elimination for esthetic reasons, as they are of finding and developing products of high economic value. Thus, a large part of the product development research in the U.S. Department of Agriculture and the State agricultural experiment stations ultimately contributes to pollution abatement.

Infectious Agents and Allergens

A real milestone in civilized progress occurred in 1864. Louis Pasteur announced as a result of his beautiful experiments on fermentation that very minute organisms were the active agents in the process. Organisms—yeasts—involved in the development of good wine were found to be quite different from those that cause wine to go bad.

In 1865, Pasteur isolated bacilli of two distinct diseases that were killing the silkworms and ruining the silk industry in southern France.

Pasteur became the first distinguished research investigator on the diseases of farm animals. He isolated the causative organisms and developed vaccines for chicken cholera, animal anthrax, and hydrophobia.

Thomas J. Burrill of the University of Illinois became fascinated with Pasteur's findings while traveling in Europe in the early 1870's. He was the first to show that a plant disease—fire blight of pears and apples—is transmitted by bacteria (*21*). Even before the discoveries of Pasteur and Burrill, DeBary in Germany had shown that microscopic fungi caused rust and smut diseases of plants.

Animal Disease Agents Contaminating the Environment

Before 1843, animal diseases were a minor problem in the United States. By 1883, the year before the establishment of an organized animal disease eradication program, there were 146,388,329 domestic animals on farms, valued at $2,338,241,519. Hog cholera killed $25 to $30 million worth of hogs annually. Sheep raising was precarious in many sections because of scab and parasitic diseases. Tuberculosis and brucellosis were spreading. Anthrax and blackleg were on the increase in most States. Texas fever was feared by cattle raisers. The causes of most of these destructive diseases were unknown, or in dispute, and livestock owners were largely defenseless. Nothing was known of the extent to which a contaminated environment abetted transmission.

Contagious pleuropneumonia was such a problem that our export cattle and sheep were denied admission into Great Britain. Our pork was prohibited in most of the markets of Europe.

The Bureau of Animal Industry of the U.S. Department of Agriculture was established in 1884. The wording of the act indicated that the first duty of the Bureau was to take charge of the eradication of pleuropneumonia—disseminated by contaminated air—in cooperation with authorities in the States where the disease existed. The disease was eradicated in 5 years at a cost of $1,509,100.72 (*122, p. 2*) in Federal moneys.

D. E. Salmon, the first Chief of the Bureau of Animal Industry, U.S. Department of Agriculture, isolated *Salmonella* bacteria in 1885. There are over 1,000 strains of these bacteria that cause salmonellosis in man and animal. This infectious agent, transmitted by water and food, is still very much with us.

To find the cause of tick fever was the next task of the Bureau of Animal Industry. While studying the cause and control of a cattle fever at the turn of the century, Department scientists discovered that ticks were carriers of the disease. To the average citizen this might seem to be a bit of routine information, but it was much more than that. It was the first positive proof that arthropods could carry a disease from one animal to another.

Brucellosis organisms may contaminate the environment. The disease is widespread and costly; it mainly affects cattle, swine, and goats. The predominant clinical signs of the disease in pregnant females are abortions, birth of weak calves, retained placentas, and vaginal discharge, often followed by a temporary or permanent infertility. Exposure to infection takes place by ingestion of contaminated feed and water. Treatment of brucellosis in cattle has not been successful. It can be prevented only by sanitation, good herd management, or vaccination, or any combination of them that may be necessary (*75*).

Cattle, poultry, swine, and other animals may be affected by tuberculosis. Theobald Smith discovered that the human tubercle bacteria are not the same as bovine tubercle bacteria. Tubercle bacilli usually enter the body via contaminated food or water. Sometimes they are breathed directly into the lungs. Control of the disease in cattle includes environmental sanitation and the prevention of contamination of healthy animals. A Federal-State program started in 1917, in which cattle were tested with tuberculin, infected animals were killed, and an indemnity paid for slaughtered animals, has successfully reduced bovine tuberculosis from 4,900 per 100,000 to 70 per 100,000 (*62*).

Anthrax is a disease of all warm-blooded animals, including man. It is characterized by acute septicemia. The cause is a spore-bearing rod, *Bacillus anthracis*. The spores are very resistant and have been known to survive for many decades in the soil, in water, or on hides, and then grow and produce disease when introduced into a suitable medium. The first vaccine for anthrax, made by Pasteur in 1879, was widely used in many parts of the world for many years. Improved products are available today.

Tetanus is caused by *Clostridium tetani* and they or their spores may be in old farming areas, especially ones which were heavily manured (*90*). The disease is common in people and horses. Active immunization against tetanus was introduced in 1931 (*92*).

Blackleg causes greatest losses in cattle-raising and cattle-feeding areas in the Central West and Far West. Occasionally, sheep and goats contract the disease. The spores of *Clostridium chauvoei* survive in soil for many years (*49*). An effective immunizing product against this disease was developed by researchers in Kansas (*99*).

The larvae of the parasite known as *Dictyocaulus viviparus*, which cause verminous pneumonia in cattle, may survive several months in the soil (*95*).

Swine influenza is an acute, highly contagious, infectious disease caused by the concerted activity of a bacterium, *Hemophilus influenzae* var. *suis*, and a filterable virus. Swine influenza would die out except for an ingenious mechanism for survival. Eggs laid by female lungworms in the lung of swine sick with influenza contain the virus. The eggs are coughed up, swallowed, and passed in the feces. Earthworms ingest the lungworm eggs and the eggs hatch in the earthworm. The lungworms develop through several stages and finally imbed themselves in the hearts and gizzards of the earthworm. A single earthworm may harbor 2,000 lungworm larvae which are freed on digestion of the earthworm. Swine root out and eat the earthworms with relish, thus setting the stage for the influenza to infect the animal (*102*, *103*). Sanitation of the environment is the only means of control.

Listeriosis, an infectious disease, is caused by a bacterial organism that affects sheep, cattle, swine, chickens, and other animals. In large domestic animals, the disease is characterized by central nervous involvements—encephalitis and paralysis. The exact mode of transmission of listeriosis under field conditions is not well known. It may spread by contact and by contaminated feed and water.

Swine erysipelas is present in the United States wherever hogs are raised. The organism, *Erysipelothrix rhusiopathiae*, may live in the soil as a saprophyte and can multiply under favorable conditions of moisture in a soil rich in humus. Antibiotics alone and antiobiotics with a specific immune serum are useful in treating swine erysipelas. Biologics are available to the veterinarian (*104*).

Pullorum disease is an infection afflicting the egg-producing organs of the hen or turkey. It is transmitted from the hens to the chick through the egg. Pullorum disease may be spread among chickens and turkeys through breathing or consuming contaminated dust, down, or other material in the incubator, shipping box, brooder, or pen. It is also transmitted through consumption of contaminated litter, feed, or water. It is controlled by detecting and eliminating adult carriers, because the disease is largely eggborne (*135*).

Paratyphoid is spread from bird to bird by consumption of litter, feed, or water contaminated with infected droppings (*134*).

People can get ornithosis (psittacosis) through contact with sick birds (*57, ch. 10*). Infectious sinusitis in turkeys may be spread from one generation to the next through infected eggs and by direct contact or indirectly by contaminated air and dust (*115*). The disease is controlled by detecting and killing infected adults.

Infectious bronchitis of chickens is spread by direct or indirect contact with infected birds. The air in the poultry house becomes contaminated with the virus attached to dust and this may spread the disease far. It can enter all except specially constructed poultry houses (*65*).

Coccidiosis is caused by microscopic protozoan parasites, which have been known to survive in the soil and elsewhere for many months (*132*). Numerous species of coccidia are known and distinct species account for the economic disease in cattle, sheep, and poultry. In general, there are effective methods of treating the disease (*1*).

Blackhead of turkeys and chickens is caused by a microscopic, single-celled animal, *Histomonas meleagredis*, that attacks the ceca, or blind gut, and the liver. Occasionally the bird ingests the naked organism but usually a second parasite, the cecal worm, *Heterakis gallinae*, is involved. The protozoan spends part of its life cycle in the eggs and larva of the cecal worm. The cecal worm egg is sturdy and may survive in the soil for a year or longer. Recently, U.S. Department of Agriculture scientists learned that eggs of cecal worms are often eaten by two or three earthworm species (*112*). This leads to a concentration of cecal worms and blackhead parasites in the earthworms, which are readily eaten by poultry.

Turkeys also may get hexamitiasis by consuming food, water, or soil contaminated with droppings of infected birds. Research has provided no satisfactory treatment.

A number of worms are parasitic to cattle, swine, and poultry. Many of these can live for long periods in the soil (*122*). For example, the eggs of large intestinal roundworms of swine can live up to 7 years in soil. Threadworms of sheep may develop into adult free-living males and females that can give rise to a large number of infective larvae in the pasture. Sanitation is the preferred method of control.

Salmon poisoning is a rickettsial disease of dogs and other canines, such as foxes, that eat uncooked salmon or trout parasitized by the intestinal fluke *Nanophyetus salmincola*. This fluke carries the rickettsial micro-organism. The disease is usually fatal. The disease-carrying fluke requires two intermediate hosts to complete its life cycle—a freshwater snail and a fish. In streams, each fluke egg hatches into a miracidium, a free-swimming form that enters the snail, *Oxytrema plicifer*. There the fluke passes through two more stages, emerging from the snail as larva that penetrates the body of salmon or other fish of the same family. In the fish, fluke larvae encyst in the muscles and internal organs. Research has disclosed that the fluke and infective rickettsial micro-organisms survived in migrating salmon for as long as 4 years after fish were experimentally infected (*113*).

Tremendous research progress has been made in the development of insecticides and miticides that control arthropods transmitting animal diseases in the environment. (See appendix III, "Agricultural Chemicals," p. 76.)

Plant Disease Agents Contaminating the Environment

Most plant diseases contaminate the environment in one way or another. This whole area of research is too vast for detailed consideration in this report, but a few examples of how air, water, and soil are contaminated by plant disease agents are in order.

Black shank of tobacco appeared near Quincy, Fla., about 1915, but was not identified until some years later. The fungus disease, *Phytophthora parasitica* var. *nicotianae*, can spread rapidly into new areas and is a serious threat wherever it occurs. It almost always appears first in a low place in the field. About midsummer a few plants wilt. In the early stage one or more of the large lateral roots are blackened and killed. Then the entire root system and the base of the stalk decay and the plant dies.

Black shank is spread by moving contaminated water, soil, or plants. The disease spores can contaminate ponds or streams into which infested fields drain. In some areas, once a field became infected it remained so, although a rotation of 5 or 6 years might reduce the infection to a trace. In another locality the disease has never persisted. The story of developing plants resistant to black shank begins with the work of W. B. Tisdale at the Florida agricultural experiment station when he intercrossed and selected many varieties in order to develop a resistant commercial shade tobacco (*24*).

A combination of planting resistant varieties of tobacco and rotating crops is the best control in many areas where tobacco is grown (*46*).

Stem rust of wheat is an example of a plant disease that may be spread, with disastrous results, by contaminated air. For example, in 1953, 60 percent of the wheat crop in Minnesota and some neighboring States was lost. The loss that year for the whole country was about a quarter of the wheat crop.

The fungus, *Puccinia graminis tritici*, causes stem rust of wheat, barley, and many wild grasses and is itself a plant. As any other plant, the fungus germinates, grows, and fructifies. It multiplies by countless billions, mutates, and hybridizes continuously to form types that may attack varieties of grain previously resistant or immune to the rust disease. Thus, countless kinds were made in the past and more are continually being made (*106*). Control of the disease has been possible through a continuous program of breeding work to develop resistant varieties of wheat, oats, and barley.

Red stele disease of strawberry is an example of a plant disease fungus that can live for many years in soil even if strawberries are not present. The fungus spreads through the soil by microscopic swimming cells known as zoospores. Flood and drainage water can carry the spores long distances and thus infect other areas. The disease can be spread by moving soil on machinery or planting stock, and such. Several strains of *Phytophthora fragariae*, the fungus causing red stele, exist. The disease is controlled by breeding resistant varieties of strawberry plants (*61*).

The Texas agricultural experiment station was established in 1888, and work started the first week in March, with "not much being done, however, until the last week in the month." After deliberate consideration it was thought best to take up, first, a study of a practicable and economical method of cattle feeding, and second, "a study of the disease of the cotton plant known as 'Cotton Blight' or 'Root Rot' " (*48*). Bulletin No. 4 of the station dated December 1888, is "Root Rot of Cotton, or 'Cotton Blight' " (*91*). The general characteristics, the infectious nature, and the treatment of the disease were discussed. The statement was made "It will be somewhat difficult to treat this disease." Experience over the past 80 years in the Blacklands area of Texas has proved that this comment was an understatement.

Now we know that more than 2,000 species of wild and cultivated plants are attacked by the soil inhabiting fungus *Phymatotrichum omnivorum*, which causes cotton root rot. The disease has been one of the more difficult to control. The search for cotton varieties resistant to the disease has yielded negative results. The greatest promise of practical control of root rot appears to lie in the use of organic manure, particularly in the form of legumes. The use of organic manures, plus rotation, early fall plowing, and early maturing varieties, should provide satisfactory control of root rot (*14*).

Cabbage yellows is a disease caused by a fungus, *Fusarium oxysporum f. conglutinans*. The fungus can exist indefinitely in soil. It may be disseminated in soil moved by wind, water, animals, and man. It is most destructive throughout the Corn Belt and as far north as central Wisconsin. Yellows was so destructive in 1910 that research was undertaken at the Wisconsin agricultural experiment station on the disease. All attempts at practical control were unsuccessful but, by selection, a resistant variety, Wisconsin Hollander, was obtained and released in 1916. Through selection and hybridization, yellows resistant varieties to suit most seasons and market requirements have been obtained. The work of breeding new varieties to meet changing requirements continues (*130*).

White stringy root rot of conifers is a disease caused by the fungus *Fomes annosus* Fr. and is present throughout softwood forests nationwide. It had been observed rotting white pine roots in the early part of the century but was of small concern. The disease has been a source of considerable loss in continental Europe where planting has been an important method of reforestation for generations. Scientists of the U.S. Department of Agriculture reported in 1944, as a result of studying white pine plantings at Biltmore, N.C., that 75 percent of previously thinned plots had root and butt rots. The rots were caused mostly by *F. annosus*.

The disease frequently becomes established when a healthy conifer stand is thinned. Airborne spores of the fungus inoculate freshly cut stumps. The spores germinate and the fungus grows into the stump roots. Roots of healthy trees in contact with infected stump roots become infected. Also, sporophores are produced on the stump, thus a foci for dissemination of airborne spores is established. Once tree roots are infected, the fungus may survive below ground for 50 years or more (*12*).

Based on British experience, creosote has been recommended for control of *F. annosus*. However, cooperative research of the U.S. Department of Agriculture with the Missouri agricultural experiment station suggests other materials such as urea, sodium tetraborate decahydrate, and borax are superior to creosote for control (*13*). The stumps must be treated after each thinning.

Allergens

Any weed-control practice performed before flowering will prevent pollen formation. There is no research underway that is designed specifically for the control of plant species, such as ragweed and bermudagrass, that produce allergenic pollen. Much has been learned about problem species, however, through observations incidental to other research projects.

Information is available for the control of ragweed, for example, but that knowledge has not been put to use in a widescale control operation. Since the seed is disseminated by wind and can remain viable in soil for long periods of time, areawide treatments would be necessary for adequate control.

The prevention of pollen production by troublesome weed species would alleviate much suffering and save many thousands of dollars in medical expenses.

Agricultural Chemicals

Insecticides

Paul Müller of Basel, Switzerland, was awarded the 1948 Nobel Prize in Physiology and Medicine in recognition of his outstanding work in development of DDT as an insecticide. Müller's product first showed its dramatic power when used to control an infestation of Colorado potato beetles in Switzerland in 1939. During the war years, researchers in the U.S. Department of Agriculture determined the value of DDT for controlling a number of disease vectors, and the insecticide was used extensively by the Armed Forces to control arthropodborne diseases. Millions of illnesses were prevented; thousands of lives were saved (*71*). No adverse effects on humans were recorded.

Following the war DDT and a number of similar insecticides were developed for agricultural pests. Extensive use of DDT to control insect pests of field crops and forests sometimes has resulted in the direct kill of small numbers of fish and storage of DDT in the tissues of survivors; sprays used to kill bark beetles that transmit Dutch elm disease fungus have led to contamination of earthworms in the soil with DDT and robins feeding on the worms were sometimes killed; eagles and other predatory birds were found with DDT in their tissues. Wildlife conservationists became concerned, not only over possible adverse effects of DDT but also over other broad spectrum pesticides, including endrin, aldrin, dieldrin, heptachlor and toxaphene.

Rachel Carson's book, "Silent Spring," shocked the general public. People began to wonder if Müller's discovery had not created many more ominous problems than it solved. Objective evaluation (*64*, *133*) has made a strong case that development of DDT was indeed a tremendous contribution to man's welfare.

Retention in the Environment.—The U.S. Department of Agriculture began laboratory studies on the persistence of DDT in soils in 1943 (*38*). Soil samples were collected from 85 different locations infested with the Japanese beetle and treated with 25 pounds of DDT per 3 acre-inches. The average results for all soils, based on bioassay, were as follows:

Persistence after years indicated:	*Percent DDT remaining*
1	97
2	90
3	79
4	64
6	56
8	44

Persistence tended to be greater in sandy than in fine-textured soils, and to be inversely related to organic matter content of soil. In soil containing 29 percent organic matter, the persistence after 3 years was 24 percent, whereas in soil containing 0.7 percent, the persistence was 94 percent.

The high degree of persistence of DDT in soil found in this laboratory study has been confirmed many times.

Comparable studies (*39*) showed that chlordane was somewhat persistent in soil but not nearly so persistent as DDT. A number of problems related to the persistence of chlorinated hydrocarbon insecticides were discussed in the 1952 Yearbook of Agriculture (*17*).

Research toward characterizing the resistance to degradation of such insecticides as the chlorinated hydrocarbons still is under intensive study at the Wisconsin and other State agricultural experiment stations. The Wisconsin (*72*, *73*) work has shown that the 10 most important factors that influence the persistence of insecticides in soils are the chemical specificity of the insecticide itself, the soil type, soil moisture, soil temperature, wind or air movement, cover crops, soil cultivation, mode of application of the insecticide to the soil, the insecticidal formulation, and soil micro-organisms. Studies show that the most important factor among these is the chemical nature of the pesticide itself. The chlorinated hydrocarbons have a very low solubility in water and tend to be adsorbed on clay particles and organic matter. Accordingly, these substances are very resistant to downward leaching. The Wisconsin studies showed that a silt loam soil retained 84 to 96 percent of these insecticides in the surface 3 inches even after 17 months.

Cooperative studies between the U.S. Department of Agriculture and the Georgia agricultural experiment station showed that the nature of the soil could have a marked effect on the amount of chlorinated hydrocarbon insecticide removed under extended leaching with water. When 40-gram samples of six different soils were eluted with 1,600 milliliters of water, the results were as follows:

(*a*) In general, lindane was the one most readily leached; 54 to 88 percent of this chemical was removed from the six soils.

(*b*) No trace of endrin was found in the leachate from three of the soils, but 51 to 95 percent of that added to the other three soils was leached.

(*c*) Dieldrin showed wide variability in behavior among the six soils. Only 1 percent of the dieldrin was leached from Magnolia sandy loam, whereas 65 percent was removed from Lakeland sand. Results from the other four soils were scattered in between these extremes.

(*d*) Aldrin was very resistant to leaching. Only a trace was removed from five of the soils, and 16 percent from the Lakeland sand.

(*e*) Heptachlor also was very resistant to leaching: none was found in the leachate from four of the soils, and only 15 percent from the other two.

When one considers this divergent heterogeneity among six sandy soils found within a 50-mile radius of Tifton, Ga., one can surmise what the results would have been had a wide range of soils from all over the United States been studied.

In experimental plots in Texas where DDT, benzene hexachloride (BHC), toxaphene, and dieldrin were applied to soil and plowed to a depth of 6 inches, about 20 percent of the amount applied was found present after 4 years, except for BHC (1.5 percent of the amount applied was recovered). When granular dieldrin was applied at the rate of 10 pounds per acre (5 p.p.m. to plow depth) to three kinds of soils, the residues recovered after 1 year were 14.2 p.p.m. dieldrin in the sandy soil, 4.7 p.p.m. in the medium-textured soils, and 2.3 p.p.m. in fine-textured soils.

Experience has shown that whenever root crops—potatoes, carrots, sugar beets—are planted in soil containing aldrin or dieldrin, one can expect to find residues of aldrin or dieldrin in these root crops. Research information on the persistence of insecticides in soils may be vital to a determination whether major crops, such as alfalfa, sugar beets, peanuts, and soybeans, can be planted without hazard of contamination.

Samples of well water and surface water from the grounds of two U.S. Department of Agriculture laboratories were analyzed by gas chromotography. Chlorinated hydrocarbon insecticide had been used in experimental spraying of livestock for the control of insect pests for 17 years at one laboratory and 2 years at the other. No insecticide was found in any of the water samples.

Analyses for DDT and its metabolites in samples of water from creeks and rivers in areas of Idaho that had been sprayed to control spruce budworm showed less than a 0.0002 p.p.m. of DDT in 66 percent of the samples. Less than 2 percent of the samples exceeded 0.0013 p.p.m. of DDT.

Cooperative research in Oregon and Washington indicated that spraying forests for control of the Douglas fir tussock moth with DDT at three-fourths of a pound per acre resulted in a general increase of DDT and its isomers in the food chain of fish and animals. The highest residue, 1.2 p.p.m., was found in trout and the lowest, 0.02 p.p.m., in herbivores.

The U.S. Department of Agriculture has carried on a monitoring program to ascertain whether insecticides are accumulating in soils and related waters as a result of agricultural use. The findings are typified by results from a study near Greenville, Miss.[8]

[8] IVERSON, L. K. MONITORING OF PESTICIDE CONTENT IN WATER IN SELECTED AREAS. Presented at Amer. Assoc. Adv. Sci. Meetings. Washington, D.C., Dec. 27, 1966.

This involves 1 square mile in which there is a slough. This slough retains water draining from 300 acres of surrounding cultivated land. The rotation followed on this cropland involves soybeans, corn, and cotton. Insecticides are used on these crops whenever necessary for pest control. Although other chemicals were found in trace amounts, endrin residues have shown an interesting sequence of analytical peaks which have some significance.

The treatment history of this study area shows that an average of 7.5 applications of endrin at 0.3 pound per acre had been applied to cotton fields since 1956. During 1965, when the following data were obtained, the 37-acre cotton field in the 300 acres being studied received weekly applications of endrin from July 14 to September 3. Endrin residues in the soil of the watershed area under study averaged 0.30 p.p.m. in the spring of 1965 and 0.32 p.p.m. in the fall following the treatment period.

One part per million equals approximately one pound per acre in the surface 3 inches of soil. In the 9 years endrin has been used on this acreage, a total of approximately 22.5 pounds per acre had been applied and residues remaining in the soil amounted to approximately 0.3 pound per 3 acre-inches, or approximately the amount applied in a single application.

Development of Improved Insecticides.—The public concern regarding certain insecticides that may impair the quality of our environment is being met through research on the development of improved insecticides with a higher degree of degradability, and with minimum toxic effects to humans, farm animals, fish, wildlife, and beneficial insects. Most every State agricultural experiment station, as well as the U.S. Department of Agriculture, has research underway on use of less persistent organic phosphorus and the carbamate insecticides in place of the chlorinated hydrocarbon insecticides.

Following availability of the chlorinated hydrocarbon insecticides in the forties, research and use experience soon began to show that these insect killers were highly persistent in soils and in water. Of even greater concern, it was found that insecticides such as DDT, dieldrin, and heptachlor would accumulate in animal tissues. Meat and milk showed high residues when the livestock consumed feeds containing substantial residues of these materials. When animals were sprayed with chlorinated hydrocarbons to control flies, ticks, lice, and other livestock pests, the insecticides were absorbed through the hide, and residues appeared in meat and milk. Once present in animals the residues persisted in the tissues for some time, slowly decreasing for weeks or months. They were not readily degraded in animal tissues. Wildlife biologists found that the residues would magnify in animal tissues through food chain organisms and even result in death of animals at the top of the food chain.

Research showed that organophosphorus compounds and carbamates degrade more rapidly in soils and water and on plants. Even more important, these types of insecticides were found to degrade rapidly in animal systems, thus the problem of residues in meat and milk was largely avoided, and the problem of biological magnification in wildlife was prevented. Unfortunately, the organic phosphorus compounds as a class are generally more toxic than the chlorinated hydrocarbons to man and animals that have had acute exposure. Both classes include materials that are highly toxic to beneficial insects.

Zectran and stabilized pyrethrins appear, from current research, as possible substitutes for DDT in the control of forest defoliators such as the spruce budworm.

Research on aerial spraying of forest insecticides indicates that the addition of fluorescent particles to the spray provides an excellent means to track deposits.

Many changes and adjustments in recommendations and registrations have been made as the result of research on the biodegradable properties of insecticides in soils, water, plant tissues, and especially in livestock. As a result of these findings, the use of DDT and certain other persistent insecticides on dairy animals and on crops grown for dairy foods was discontinued by the late forties. Their use on beef animals and on forage for beef animals was greatly restricted.

To protect forage crops as well as livestock from insect attack, such insecticides as methoxychlor, malathion, and carbaryl, have almost completely replaced the persistent tissue-accumulating chlorinated hydrocarbon insecticides. This has greatly alleviated the problem of residues in meat, milk, and poultry products.

Scientists in industry, as well as in public-supported research institutions, recognize that biodegradable insecticides must eventually replace the nondegradable types in situations where wild and domestic animals can become exposed to the insecticides used.

Basic research on degradability, fate, and metabolism of the newer insecticides is accelerating the solution of the residue problems brought about through the use of persistent insecticides. In spite of the progress made, there is still extensive use of the persistent insecticides in agriculture for controlling insects on nonfood crops, soil insects, and medically important insects.

Alternate Methods of Pest Control.—Although use of conventional chemical insecticides for insect control has received much research attention in the past, most of the current research on insects in the U.S. Department of Agriculture and the State agricultural experiment stations is oriented to the development of ways to control insects by various biological or physical means, or by developing highly selective chemicals such as insect attractants to which only the target insect will respond. Thus, it is hoped to eventually achieve control of most of the important insect problems without creating the adverse effect on other organisms that is so characteristic of broad spectrum chemical insecticides.

The chief biological methods for the control of insect pests are by the use of other insects (parasites and predators) or microbial pathogens. Foreign exploration for insect parasites and predators in the native home of pests accidentally introduced into the United States constitutes one of the important lines of research that has been emphasized for more than 70 years.

The first successful introduction of a foreign predator to control an insect involved the introduction of the vedalia beetle in 1889 to control the cottony cushion scale on citrus.

The gypsy moth was accidentally introduced into Massachusetts in 1869. Without natural enemies, it became a ravaging pest of forest, ornamental, and fruit trees. In 1905, the State of Massachusetts and the Federal Government began to introduce natural enemies of the gypsy moth. The control of this insect by predators was not at first highly successful. Alternative hosts for the predators were not present in this country. However, continued research on gypsy moth parasites has developed a situation in which the gypsy moth is now a relatively manageable pest in most States even though major control programs are occasionally needed.

The success of early efforts to control insect pests by introducing beneficial insects has led to the introduction of a wide range of parasites and predators. The results of this research approach have ranged from highly successful to complete failure.

Imported parasites and predators for control of balsam woody aphid and larch casebearer have exerted control in some areas. Control of these two pests is especially encouraging.

The continuing worldwide search for beneficial insects has produced parasites of such recently introduced pests as the cereal leaf beetle and the imported fire ant.

In the past, most research on biological control agents was allocated to the collection and release of biological agents with the expectation that such agents would survive and multiply on their own, and thereby play a vital role in control of the target pest. In recent years, more effort has been allocated to the mass production and sustained release of biological agents for direct control of the pest.

Insects are subject to infection by a wide range of disease organisms, including bacteria, viruses, fungi, and protozoa. Most of the research on biological control of pests has involved microbial agents. Several hundred kinds of insect pathogens have been found to cause diseases in insects. Research with laboratory animals and human volunteers has indicated that certain insect viruses are not harmful to warmblooded animals, and generally do not even adversely affect closely related insects.

Research on the nutritional requirements of insect pests has contributed to a capability to artificially produce pests en masse. This, in turn, enables production of parasites, predators, and pathogens in enormous numbers as needed. For example, cooperative research between the U.S. Department of Agriculture and Canadian insect pathologists has enabled the production of a virus disease of the European pine sawfly. The control of the Douglas fir tussock moth with polyhedrosis virus has been brought to the pilot-plant stage.

Insect attractants have been recognized since the thirties, when considerable work was done on attractants for bark beetles. Only in recent years has a widespread interest developed in exploring this profitable area of research. Insect attractants produced by plants (food or ovipositional lures), by insects themselves (sex lures), or synthetically by organic chemicals offer a remarkably simple means of detecting insects and possibly of controlling them, when used in conjunction with insecticides or chemical sterilants.

An attractant for the gypsy moth was synthesized several years ago. This substance has been found to be valuable in making surveys of gypsy moth populations and significantly reducing the cost of the surveys.

Eradication of the Mediterranean fruit fly by the use of a protein hydrolysate bait containing malathion is one of the most significant recent developments. Early programs to eliminate medflies cost millions of dollars; eradication in 1966, at Brownsville, Tex., cost $200,000 and took only 44 days from the time the outbreak was discovered. The last eradication effort was aided materially by the use of another attractant, a synthetic chemical called "medlure." The synthetic attractant provided an effective means of detecting medflies so that the bait spray could be applied before the pest had spread over wide areas.

A bait containing peanut oil and a toxicant, mirex, is now used to control imported fire ant. This bait-insecticide combination permits the control of this insect by the use of only a few grains of insecticide per acre. This bait, which is harmless to fish and wildlife, replaced heptachlor, a persistent residue-forming insecticide that created hazards to wildlife.

Methyl eugenol, a powerful synthetic attractant for males of the oriental fruit fly, can be used in conjunction with an insecticide to eradicate this insect.

Insect repellents have been used successfully for protecting man from attack by disease-carrying and pest insects. Considerable research on repellents for livestock has been conducted with some success. No effective repellents for agricultural insects have been found.

Varieties or strains of plants that are resistant to the attacks of specific insects may be selected or developed. This approach to insect control has been recognized for many years. In 1860, the grape industry in France was threatened by a root-feeding aphid from America. The problem was solved by grafting European grapes on resistant rootstock from the United States. The first research on this approach to insect control in the United States was initiated at the Kansas agricultural experiment station about 1920. In 1928, a sorghum variety resistant to chinch bugs was released to growers.

Cooperative State-Federal research involving plant breeders and entomologists has developed varieties of wheat that are highly resistant to the Hessian fly, one of the major pests of wheat in the United States.

Excellent progress has been made in the development of resistance in field corn to the European cornborer.

Alfalfa varieties have recently been developed that are highly resistant or almost immune to damage by the spotted alfalfa aphid. This introduced pest threatened the alfalfa crops in the Western States about 10 years ago.

Tree resistance to insect pests has been studied by forest entomologists since about 1945. Most interest has been focused on developing strains resistant to tree-killing bark beetles. Pine oleoresin constituents associated with resistance to the western pine beetle have been identified. This is an important step toward selecting resistant strains. A hybrid pine has been found that is resistant to the pine reproduction weevil.

Crop varieties resistant to specific insects are not readily attained. Ten or more years of research is usually required to develop a satisfactory strain. Farmers generally need solutions to insect problems as quickly as possible. Research resources are generally inadequate to carry on both immediate and long-range solutions to problems.

Self-destruction of insects by methods involving sterility and other genetic principles offers a new approach to the control of insects since it was first investigated about 1950. The screw-worm fly, one of the most destructive insect pests of livestock, is now controlled by the release of radioactively sterilized males. This success has increased efforts in exploring the feasibility of inducing sterility to control other major pests. Included are tropical fruit flies, codling moth, boll weevil, pink bollworm, tobacco hornworm, gypsy moth, locust borer, and the European pine shoot moth. Sterilization offers promise as the primary means for controlling certain insects, but its greatest value will be in integrating it with other procedures for controlling insects.

Research has shown that insect sterilization can be accomplished in three ways—by the use of atomic radiation, by use of chemicals that sterilize insects, or by achieving genetic sterility by crossing genetically incompatible lines.

Bioenvironmental methods of controlling insects continue to offer promising lines of research. The approach has a long history since such methods were among the few ways of controlling insects before the development of most modern insecticides.

Cultural control methods that are desirable agronomic practices are often readily adopted. When such measures are based on a modification of necessary farm operations, they are cheap methods of control. Fall plowing results in high mortality of overwintering forms of the corn earworm and the European corn borer, and thereby reduces the number of adults that emerge the following spring.

Infestation of the grapeberry moth has been greatly reduced by burying the overwintering cocoons under a layer of soil so that the moths are unable to emerge and make their way to the surface in the spring.

A mechanical method of controlling cotton boll weevils is being developed. It involves picking up and destroying cotton squares that have been punctured by weevils, killing the larva, and breaking the life cycle.

Burning trash in sugarcane fields has destroyed as many as three-fourths of the overwintering sugarcane borers.

Destruction of tobacco stalks after harvest reduces the number of late-stage tobacco worms, tobacco budworms, and corn earworms.

Production of mosquitoes, horseflies, deerflies, and other pests that breed in aquatic and semiaquatic habitats can be minimized and in some cases prevented by proper alterations of the environment and by appropriate water management procedures.

Logging western pine on a selective basis—"sanitation salvage"—prevents the tree-killing western pine beetle from getting a foothold in the stand. This approach was the basis for studies in California showing that the trees most susceptible to attack could be identified by visible characteristics.

The insecticide era brought about curtailment in the study and practical use of many cultural practices for insect control. Yet, with insects becoming resistant to many insecticides and the emergence of many problems resulting from insecticide residues, there is a resurgence of interest in research towards improving cultural control. In some cases, cultural and bioenvironmental methods may eliminate the need for using insecticides or may reduce the number of applications required. This would contribute to the avoidance or amelioration of contamination in the environment.

Electromechanical devices for capturing and destroying insects are receiving more and more research attention. The attractiveness of various wavelengths of radiation for stimulating responses in insects has been known for many years. Until recently, practical usefulness of the approach has been quite limited. Extensive early work on light traps for such insects as the European cornborer, tobacco hornworm, and codling moth failed to provide practical results. In 1952, cooperative research between the U.S. Department of Agriculture and the Texas agricultural experiment station revealed that the pink bollworm moth was readily attracted by radiation in the near ultraviolet region (black light).

The Indiana agricultural experiment station found that insect traps equipped with black-light lamps were effective in reducing losses due to cucumber beetles.

Recent results of a 3-year experiment showed that using three black-light traps per acre in a large-scale experiment, integrated with other control procedures, reduced tobacco hornworm populations and greatly curtailed the need for insecticides.

The more favorable results experienced recently with electromechanical devices arise from a new concept in experimental design. Traps are used in sufficiently large areas to provide treatment of the total population, or a large segment of the population, to limit the influence of immigrating insects. The favorable results have renewed research interest in practical black-light techniques. This has stimulated research on other forms of electromagnetic radiation as a means of trapping insects for destruction.

Herbicides

About the earliest research on selective herbicides in the United States took place at the North Dakota agricultural experiment station during the first years of this century (*15*). Inorganic chemicals such as common salt, iron sulfate, copper sulfate, and sodium arsenite were evaluated and found to have promise for selective weed control under selected conditions.

Following this initial work, interest in use of selective herbicides to control weeds did not thrive in the United States until the forties. During the period 1934–42, scientists at the Boyce Thompson Institute reported the results of their research on the responses of plants to synthetic growth regulators. In 1942, they were the first to report (*138*) that 2,4-dichlorophenoxyacetic acid had properties of a growth regulator when applied to plants in very dilute concentrations. Two years later, a report from research in the U.S. Department of Agriculture (*76*) indicated that an application of 2,4-D killed dandelion, plantain, and other weeds in a bluegrass lawn.

From this point, research on a wide array of organic chemicals for use as possible herbicides boomed. Commercial use of 2,4-D and related chemicals expanded rapidly during the sixties.

Persistence in the Environment.—In the summer of 1959 a tolerance of zero was established for the herbicide amino triazole. Research had shown that this compound might be capable of producing cancer in test rats when it was fed at high levels. Under the Delaney amendment to the Federal Food, Drug, and Cosmetic Act a tolerance of zero was mandatory.

The registration and recommendations for the use of amino triazole for weed control in cranberries specified that the chemical be applied only after the berries had been harvested. Some growers did not follow these recommendations.

On November 9, 1959, the seizure of lots of cranberries containing illegal residues of amino triazole was announced. Large blocks of cranberries were seized, and the market for cranberries was demoralized within 24 hours.

Cranberry growers vigorously denounced the manner in which the seizure action was taken. Regardless of the pros and cons of the situation, the public was alerted to the problem of the use of pesticides in the production of foods.

U.S. Department of Agriculture and the State Agricultural experiment stations are continually carrying on studies on how different herbicides might contaminate soil, water, and crops. This research begins well before the first experimental label is granted and usually continues as long as the herbicide is used.

Scientists are concerned with several problems involved in the persistence of herbicides in different kinds of soil: Nature and capacity of the adsorption complex, photodecomposition, chemical reactivity, microbial degradation, vapor transfer, and leachability.

Adsorption of a herbicide by a soil (*30*) is determined by the specific surface of the soil, organic matter content, the nature of the clay mineral, moisture status, temperature, nature and degree of base saturation, and structure and polarity of the herbicide molecule. Specific surface of soils may vary from 300 square centimeters per gram for a sandy soil to over 30,000 square centimeters per gram for clay. Adsorption of organic molecules such as herbicides is also determined by the nature of the adsorbing surface. For example, montmorillonite clay, kaolin clay, and colloidal organic matter differ in their adsorbing specificity. There is wide diversity in the extent to which the adsorption mechanism of a soil affects persistence and deactivation of the many different herbicides.

Amino triazole forms relatively stable complexes with metal ions in soils (*109*). Formation of the complex detoxifies the herbicide.

Hydrolysis and oxidation of herbicides in different soils under varying conditions have received a modest level of research attention (*50*). The wide diversity of conditions involved in this research has not opened up a path to sweeping generalizations (*44, 78*).

Probably one of the most important factors responsible for the detoxification of herbicides in soils is the soil micro-organisms. Their importance in the detoxification process is readily apparent when one compares the persistence of a herbicide in sterile and nonsterile soils (*128*). With few exceptions, herbicides in the latter are detoxified far more rapidly than in the former. Soil bacteria, fungi, and actinomycetes have been implicated as the most important agents in the degradation process. Soil micro-organisms either possess constituent enzymes or can be induced to form enzymes to catalyze the breakdown of many diverse organic herbicides. Many of these micro-organisms have been isolated and identified, and in a few cases, the enzyme responsible for carrying out the initial detoxification reactions have been isolated and characterized. It is largely because of the activity of these soil micro-organisms and other dissipation mechanisms that most herbicide residues in the soil are not showing a progressive buildup.

Phytotoxic residues of herbicides may persist longer in soils when the herbicides are applied in combination than when each is used individually.

The degree to which a herbicide is soluble in water or is adsorbed on soil particles determines leachability of the herbicide by rain or irrigation water (*127*). Obviously, the amount of water moving through the surface soil is an important determinant in the amount of herbicide leached away.

Klingman (*70*) has summarized research information on persistence of herbicides in soils. For some uses, 2,4-D is not completely satisfactory because it lasts only 1 to 4 weeks. On the other hand, simazine applied as a soil sterilant may persist for 2 to 4 years or more. The evidence does indicate that the adverse effects of persistence of herbicides are those upon succeeding crops.

Cooperative research by the U.S. Department of Agriculture and the Arizona, California, and Mississippi Agricultural Experiment Stations was carried out over several years on the presistence of herbicides in cotton fields. Use of repeated annual application of dichlobenil, trifluralin, diphenamid, DCPA, monuron, diuron, and linuron on weeds in cotton caused no buildup of the chemicals to levels harmful to cotton. By contrast, treatment of the cotton fields with diuron, trifluralin, linuron, prometryne, or dimethyl 2,3,5,6-tetrachloroterephthalate (DCPA) resulted in residue accumulations that were toxic to succeeding crops of barley, milo, oats, soybeans, and sugar beets. This research confirmed the need for existing restrictions on the use of several herbicides.

Potentially the most serious problems associated with the use of herbicides are their (1) downward movement in the soil to depths of 4 to 15 feet where degradation mechanisms are relatively ineffective, and (2) movement from large watersheds into drainage systems and our major water resources.

Inactivation and dissipation rates of herbicides in soils vary widely. Cereals planted in the fall after crops have received summer applications of 1 to 4 pounds per acre of such herbicides as atrazine, simazine, and diphenamid have been injured by phytotoxic residues. Injury to soybeans, sugar beets, oats and forage grasses and legumes has been encountered in some instances 10 to 12 months after application of atrazine to corn. Tobacco, cotton, peanuts, and soybeans have been injured by fenac residues 1 to 2 years after application at rates used for selective weed control in corn.

Certain of the benzoic, phenylacetic, and picolinic acid herbicides persist in soils for several years. These same chemicals, especially 2,3,6-TBA and fenac may often move downward in soils through volatilization and percolating water. In the arid areas of the Great Plains, phytotoxic residues of the benzoic and phenylacetic acids have been detected at depths of 4 to 12 feet in certain soils. Single applications of these herbicides are used to control deep-rooted perennial weeds such as field bindweed (*Convolvulus arvensis L.*) at rates of 4 to 40 pounds per acre. However, when these herbicides move 4 to 12 feet downward in the soil, they are not readily degraded and thus pose a potential problem, if these uses should become extensive.

Although low levels of phytotoxic residues of the substituted urea and *s*-triazine herbicides and some of the phenylacetic and benzoic acids have persisted from one season to the next, data from many sources indicate that accumulation of excessive residues has not occurred and is extremely unlikely. Inherent phytotoxicity of herbicides provides a natural indicator for residues and serves as a defense against their accumulation when used for selective weed control in crops.

There is little evidence of adverse effects of herbicidal residues on fruit trees and shrubs. Research in New Jersey underway over 5 years has revealed no undesirable residual effects from annual applications of a number of different herbicides on apple, peach, blueberry, and cranberry plantings.

Movement in the Environment.—The winds carry mists and dusts. And the wind does not discriminate because of chemical specificity. Mists or aerosols or dusts containing pesticides are carried at the same rate as those that are uncontaminated.

Water moving downstream is an effective vehicle. The amount and physical character of suspended material transported depends on velocity of flow. Gravel and even sand settle out as flow retards. Colloidal material of clay and organic matter may even stay suspended in still waters. Colloidal materials can readily be carriers of pesticides. Concentration of herbicide in true solution in a stream does not vary in relation to rate of flow. A herbicide with low degradability in water actually becomes a good tracer.

Consider the following study. Cooperative research between the U.S. Department of Agriculture and the Washington agricultural experiment station revealed that six applications of acrolein could be quite effective for control of aquatic weeds which clog irrigation canals. An average concentration of only 0.1 p.p.m. (weight basis) in the water during exposure periods averaging 48.4 hours at intervals of 3 to 4 weeks in 1965 controlled pondweeds for 10 to 20 miles from the point of application in a canal with an average flow of 2,023 cubic feet per second (4,000 acre-feet per day). Control was still adequate from 20 to 50 miles downstream. Pondweeds in many branch laterals were adequately suppressed, particularly those within 20 miles of the point of application. The concentration and total quantity of acrolein required for pondweed control were much less than in previously used methods of application. Acrolein will kill most species of fish at concentrations required to kill aquatic weeds in irrigation canals. Fish production should not be attempted in canals that are to be treated with acrolein.

Temperature of the water very much affects loss of acrolein during transport. In July, with water at 70° F., 32 percent of the acroleine was lost during the first mile of canal flow when the chemical was introduced at 0.1 p.p.m., whereas 42 percent was lost when introduced at 0.6 p.p.m. (weight basis). In cooler water in September—about 61° F.—the losses of acrolein in the first mile of flow were only 20 percent when the chemical was introduced at either of the above concentrations.

Some of the more seriously adverse effects from use of herbicides have occurred as a result of untoward air transport. To counteract the inadvertent introduction of these chemicals into the atmosphere during application, research is underway to (*a*) develop invert emulsions to reduce spray drift, (*b*) develop granular and pelleted formulations to minimize volatilization and drift during aerial applications, (*c*) incorporate the herbicide directly into the soil, (*d*) combine with invert materials to retard volatilization and photodecomposition.

Development of Improved Herbicides.—There is a continuing need for herbicides that are more efficient in destroying the target weeds, carry an appropriate degree of degradability, have a minimum toxic effect on crop plants, and have no adverse effects on humans, farm animals, wildlife, or fish.

Research has shown that chloroxuron is much more toxic in acetone than in water, and that surfactants enhance the activity of many herbicides. In both cases, the enhanced activity means that effective weed control can be obtained with less herbicide.

Degradability in soil is much more rapid for 2,4-D, a chlorosubstituted phenoxyacetic acid, than for fenac, a chlorosubstituted phenylacetic acid. The faster degradability of 2,4-D has been used to advantage in the control of witchweed.

Development of Alternate Methods of Weed Control.—Edwin Markham in his sad little poem "The Man With the Hoe" sought to portray a human soul engaged in the very essence of drudgery. Those of this latter day who have "chopped" cotton or sugar beets know well Markham's meaning.

Mechanization of this art has largely removed the drudgery and evolved effective and economically feasible practices. Mechanization is not new. Jethro Tull invented the horse hoe before 1822. George Esterly patented a straddle-row cultivator pulled by horses in 1856, and a tractor-mounted cultivator became available in 1918.

An important landmark in mechanical weed control was the report of Cates and Cox in 1912 (*23*) that the principal virtue of cultivation was to kill weeds. They found that there was no merit in plodding down the rows and cutting off roots if there were no weeds to kill. Later work has shown that if the soil crusts over following a rain and impairs soil aeration, breaking the crust has beneficial effects beyond weedkilling.

Research underway in the U.S. Department of Agriculture and a number of State agricultural experiment stations indicates that nonchemical weed control still has a place. This method of weed control is still predominant in the production of most crops. Use of shallow tillage tools such as the rotary hoe early in the season has been found to be satisfactory for weed control in soybeans, peanuts, and many other crops.

Flame cultivation has been developed as an economical and practical means of controlling midseason and late-season annual broad-leaved weeds and grasses in the cotton row. It requires the application of a carefully controlled flame to the drill row of cotton plants at a rate that does not injure the crop while killing the more delicate weeds.

Chemicals can be used to artificially stimulate seed germination. Such stimulation has the potential of providing an even-aged weed population that is less difficult to control. Recently, two unknown germination stimulants of witchweed were isolated from cotton roots. An unidentified alkali-labile corn root exudate was also found that would stimulate germination of witchweed. Witchweed is an exceedingly serious pest along the middle Atlantic seaboard.

The biological control of plants was firmly established in the thirties following the introduction of a moth, *Cactoblastis cactorum*, from Argentina into Australia for the control of pear cactus in that country. The snail, *Marisa cornuarietis* and two fish genera have since shown promise for the control of submersed water weeds.

The control of Klamath weed (*Hypericum perforatum*) in northern California, Oregon, and Washington by beetles of the genus *Chrysolina* is a good example of biological control of weeds. By 1944, over 2 million acres of California rangeland were infested with this weed. Release of the beetles in California began in 1945. As soon as beetles became abundant, collecting programs were organized at county levels so that ranches could assist in distributing the insects. In 4 years it became evident that good control was being obtained. In 7 years, the weed was under control. In 1956, Klamath weed was removed from the list of noxious weeds in California.

Fungicides

Persistence in the Environment.—The adverse effects of fungicides upon our environment are not widespread. Where harmful effects have been noted or suspected, the heavy metal component of the fungicide was usually involved. Many fungicides contain copper, zinc, mercury, iron, or manganese. The literature pertaining to the persistence of these metals in soils and their adverse effects on plants has recently been reviewed.[9]

Apple orchards in England with a long copper-spray record were found to contain in the surface mat more than 1,500 p.p.m. of copper. The surface soil in old vineyards in France was found to contain up to 845 p.p.m. of copper. In sandy soils used for citrus in Florida, copper concentrations in the surface layer were found to exceed 50 p.p.m. This level was sufficiently high to be toxic to citrus seedlings. Clover and alfalfa plants are particularly sensitive to copper in the soil.

Research has developed copper fungicides that hold the copper in a chelated, less available, form. Zinc and manganese can accumulate to toxic levels in soils, but the evidence indicates that application of fungicides containing these metals is usually not at fault.

Mercury found in soils usually comes from fungicides. Mercury vapor can be toxic to plants and the effects are usually noted in greenhouses where ventilation is low.

Research has shown that the unfavorable effects of heavy metals on plants can generally be alleviated by (1) increasing the soil pH above 6, such as by liming, (2) adding organic matter to the soil, (3) applying an iron chelate either foliarly or to the soil, and (4) applying phosphatic fertilizers if the *p*H is managed properly.

Alternates to the Use of Fungicides.—Seeking ways and means to alleviate the ravages of plant diseases is as old as the arts of agriculture. Through crop rotation, cultural practices, sanitation, and elimination of alternate hosts, many a plant disease is controlled or partially kept in check, thereby reducing or eliminating the need for fungicides. Breeding varieties that are resistant to diseases has been the most effective approach towards controlling disease without resorting to the use of chemical fungicides.

Brown rot can be exceedingly destructive in a crop of peaches. The sources of infection are spores formed by "mummies"—infected peaches that dried on the tree before dropping—that come into direct contact with the soil. Peaches rotting on the ground rarely form mummies. Thus, studies have shown that field sanitation during pruning or harvesting should be that of preventing many mummies on trees from dropping to the soil and becoming sources of infection.

Bacterial blights of beans can spread very rapidly over a field when the vines are wet from dew or a shower. Cultivating and harvesting damp

[9] LAGERWERFF, J. V. HEAVY-METAL CONTAMINATION OF SOIL. Presented before the Amer. Assoc. Adv. Sci. Meetings, Washington, D.C., Dec. 29, 1966.

vines can spread the infection in a few plants to a whole field. Thus, proper cultural and harvesting practices become important in disease control.

Clubroot can be a serious disease of cabbage. However, studies have shown that it can largely be kept in abeyance by maintaining the soil reaction close to neutral or slightly alkaline by liming.

Potato scab requires the opposite treatment for control from that indicated for cabbage clubroot. Potato scab is kept in abeyance if the pH of the soil is maintained below 5.2.

The need to use chemical fungicides is sometimes avoided by eliminating the alternate host of a plant disease. The fungus causing the cedar rust of apples must alternate its life cycle between parasitism on pome fruits such as apples, crabapples, quinces, hawthorn, serviceberry, and the overwintering hosts of several species of juniper. This cedar rust in apple orchards can be largely controlled by eliminating appropriate species of cedar within a mile or so of the orchard.

Stem rusts of wheat and other cereals have caused tremendous damage in grain production in the United States. An important alternate host is the stem rusts for the common barberry. An extensive program of eliminating wild barberries in the wheat-growing areas of the United States has done much to eliminate sources of infection for stem rusts.

White pine blister rust became a serious menace to white pines in the United States during the first quarter of this century. The disease organism must have alternate hosts such as provided by gooseberries and currants. An extensive program of eliminating the susceptible species of alternate hosts has done much to hold in abeyance the threat of white pine blister rust.

White pine blister rust is also attacked by another approach to biological control. It has been found that the hyperparasite *Tuberculina maxima* inactivates many of the cankers formed from infection over white pine blister rust but not enough to provide effective control of the disease. Research has also shown that certain fungi compete well with oak wilt fungus in the bark of killed trees or with the disease agent *Fomes annosus* in old pine stumps and roots. Research is underway towards finding how to stimulate the protective organisms.

Plant breeding and selection has long been an effective approach towards developing strains of economic plants that would avoid the ravages of plant diseases without the use of chemical sprays and dusts. Mildew-resistant cantaloups have been developed. Wilt-resistant varieties of watermelons have been produced. Sugar beets resistant to leafspot have been developed. These are just a few examples of plant diseases that would normally be controlled by the fungicides if the plant did not carry disease resistance. There are a tremendous number of examples of plant breeding for disease resistance wherein use of fungicides was not feasible and thus resistance of the crop plant was virtually the only hope; for example, use of fungicides in forests is of questionable economic feasibility. Great progress has been made in research towards eliminating the need for such chemicals in the forest by developing hybrids of forest trees that are immune or highly resistant to white pine blister rust, fusiform rust, brown spot, littleleaf, mimosa wilt, and chestnut blight.

In fact, one could summarize by saying that the contributions of agricultural and forestry research towards controlling ravaging diseases without use of chemicals has been one of the great contributions of all research endeavor.

Socioeconomic Evaluation

The solution of waste disposal problems lies in part outside the influence of the market system. The price system works effectively for many of the quantitative aspects; however, it is difficult to attach monetary significance to esthetic values which are diminished by offensive odors or unsightly surroundings. Despite these difficulties, it is essential to consider esthetics when attempting to answer questions such as: What level of waste treatment do we want? How much can we afford to spend? How much are we willing to pay for specific levels of quality improvement?

The analyses of alternative systems of alleviating waste problems are seriously hampered by the general lack of information. A number of studies are underway at State agricultural experiment stations and within the U.S. Department of Agriculture. These studies will enhance the decision-making process and contribute to the optimal economic and social solutions to waste problems. These studies are related to pesticides, water quality, plant nutrients, and organic wastes.

Pesticides

A wide variety of chemicals, varying in degree of toxicity, are available for use in controlling agricultural pests. Little information is available regarding the economic impact of the use of the various chemicals and associated practices in the production of specific crop and livestock commodities in the different agricultural regions of the United States. Reports are being compiled to determine the increased crop productivity due to pesticides and to evaluate alternate methods of pest control. Information in these reports will facilitate evaluations of the contributions of pesticides to agricultural production.

Economists in the U.S. Department of Agriculture are tabulating and analyzing data from the Pesticide and General Farm Survey for 1966. In the evaluation of problems concerning the chemical pollution of our natural environment, comparison of the 1966 data with the 1964 data will indicate trends in the intensity of pesticide use by geographic areas, types of farms, and specific crops and livestock.

As in the 1964 survey, the 1966 questionnaire includes information on the use of pesticides in agriculture, and related information on farm organization and operations. About 10,000 farmers were interviewed. In contrast to the previous survey, these farmers represent all the economic strata. The farmers with low sales were excluded in the 1964 survey.

Statistical data from the 1964 nationwide pesticide survey show the quantities of selected pesticide ingredients applied to crops and livestock by region, by type of farm, by economic class of farm, and by type of pesticide.

The basic economic questions inherent in the pesticide issue concern the effect that restrictions on the use of toxic chemicals in the control of agricultural pests will have upon production costs, farm incomes, and the supply and quality of food and fiber produced. Information obtained in the 1966 nationwide survey can be useful in evaluating approaches for reducing contamination from chemicals.

Water Quality.—The U.S. Department of Agriculture and the land-grant universities have initiated economic research related in some degree to land and water quality problems. The studies include evaluation of erosion control, water quality, and the impact of high-salinity irrigation waters on land values.

Recent research objectives are concerned mainly with waste disposal and management. They include studies on the accumulation, movement, and adverse impacts of pesticide residues on soil and water resources and ways to reduce these effects; economic analysis of pesticide residues and agricultural waste problems in a watershed of river basin planning complex; a study, cooperative with the Oregon State University, of legal-institutional approaches for pulpmill waste disposal where control needs involve mill and recreation interests; and a study of the Federal Water Pollution Control Act to determine the implications of the act for agricultural and other rural resources.

Plant Nutrients.—There is a continuing research program in the economics of fertilizer use. These studies provide current information on the amount and type of commercial fertilizers used in agriculture and returns from their use. They show that, over the period 1960–64, farmers received an average return of $2.50 for every dollar spent on fertilizer. Projections of fertilizer use to meet 1980 production needs do not consider any harmful effects associated with the use of commercial fertilizers. Economic questions related to the impact of restrictions on fertilizer use could be evaluated in terms of production costs, farm incomes, and the supply and quality of food and fiber produced. These economic studies have a primary interest in farm production, and only secondarily in nutrients that may impair the quality of surface and ground waters.

Organic Wastes.—Cooperative research on the economies of size and livestock operations and materials handling is underway at the University of Illinois, University of Minnesota, and Colorado State University. Current studies consider the economics of waste disposal only as a part of the overall feeding operations.

New and different methods of materials handling and livestock confinement are an important part of modern major feeding operations. Concentrated milking and feeding operations permit economies as the size of the operation increases. But, as such operations become larger, conventional methods of waste disposal become less adequate. Modern livestock waste disposal systems are primarily limited to large hog and livestock feeding operations. They are also an important part of a few specialized dairy and poultry operations in areas near large metropolitan centers. Pertinent economic aspects of alternative means of waste disposal and regulation of disposal methods include effects of disposal methods on production costs, farm incomes, and the supply and quality of food produced.

Many firms processing agricultural commodities have serious problems in disposing of their byproducts or wastes. Most of the past research has been directed at developing new products, or uses for existing products, or finding a low-cost method of disposing of the wastes. Industries with the most acute waste problems include dairy, meat, poultry, cereal milling, and wool scouring processors. Waste materials from these industries include offal, blood, bones, feathers, grease, starch, and water. Research conducted since the late 1950's to help put these wastes in a more marketable form has been highly successful.

In response to the President's message concerning the Water Quality Act of 1965 pertaining to our "rivers flowing red with blood from slaughter houses," new methods for handling packinghouse wastes are being investigated. Two methods which currently look favorable are (1) treating these wastes with polyelectrolytes, and (2) converting them into a protein supplement by a phosphoric acid digestion method.

Research Accomplishments.—Numerous marketing research reports have been published during the last 10 years in an effort to find new markets or develop new products for the wastes from industries processing agricultural products. Results indicated that (1) spent sugarcane can be used for making paper; (2) hide trimmings and fleshings can be converted to a high-protein feed; (3) irrigation is a low-cost disposal method for poultry and dairy sewage; (4) drying of blood in poultry and meatpacking plants increases returns; (5) development of hydrolized feather meal increases returns to poultry processors; (6) citrus pulp is an economical feed; (7) recovery of wool grease is economical in some instances; and (8) alternative methods and their costs are available to the cereal starch industry for controlling stream pollution.

Detailed studies of waste treatment methods for canners of tomatoes, corn, apples, peaches, cherries, beans, and mixed products were completed in 1958. Results indicate fruit and vegetable canners can adequately control their effluent by screening, biological treatment, lagooning, or spray irrigation.

In 1964, farmers spent, on the average, about $300 for pesticides (*11*). This did not include pesticides used for treating seeds, stored crops, or storage buildings, or in farm households, farmyards and gardens. Expenditures ranged from a high of $882 per farm in the Pacific States to $119 in the Northern Plains. Ninety-four percent of the farmers surveyed used some pesticides. The proportion of farms using pesticides did not vary appreciably from region to region or among different types of farms. Farmers with the highest sales, that is $40,000 or more annually, accounted for 43 percent of the money spent on pesticides. Eighty-five percent of the pesticides were used on crops, and 11 percent were used on poultry and livestock.

Many firms processing agricultural commodities have put the recommendations of marketing research into action. The best examples are the recovery of blood, offal, feathers, and grease from livestock and poultry industries. Other examples are the installation of irrigation systems for using waste water from the poultry and dairy industries. Currently, 14 tanners and hide dealers have installed processes for converting hide trimmings to high-protein feed.

Although past and current research does assist in making decisions in regard to waste disposal, the efforts are inadequate to provide optimal solutions to waste disposal problems. There is an urgent need for national and regional surveys of rural waste problems. Likewise, studies should be initiated to identify economic and social implications of selected problems. Alternatives for alleviation of waste problems should be evaluated to provide essential information for arriving at rational compromises between production efficiency and environmental quality.

APPENDIX IV

Problems in Waste Management Needing Attention in Agriculture and Forestry

As America's technological giant continues to grow, it becomes ever more ravenous for better information. In doing so, this giant also casts a powerful spotlight over broad areas of ignorance—untilled fields that should be producing food for the giant.

The development of digital computers opened up a capacity to effectively digest vast quantities of complex data towards attaining an optimal solution to sophisticated problems. As an example, these computers are the sine qua non in advanced planning for river basin development. They enable the programer to take into account all pertinent inputs, both stochastic and determinative; all prevailing constraints; and all desirable attainments on development. This provides for a realistic appraisal of alternatives in social and economic objectives. The capacity of the computer to handle such programs has often focused onto the serious dearth of accurately accrued data, both physical and economic.

Experience has amply shown that an advancement in one area of science or technology may have wide ramifications in many other areas. In the process, the demands for pertinent technical and economic information snowball.

When Fritz Häber of Germany synthesized ammonia from atmospheric nitrogen in 1910, one can rest assured that he gave no thought that his discovery would cause massive problems on animal waste disposal in the United States. Following World War II, synthetic nitrogenous materials for fertilizers were produced so abundantly and so inexpensively that it became cheaper for the farmer to supply plant nutrients to his fields from the bag than from barnyards and feedlots. Endless problems arose as to just what to do with huge accumulations of a socially unattractive product.

World War I gave a major impetus to the work of organic chemists in new products. By the end of World War II, a whole array of organic compounds began to appear that worked miracles on controlling pests of people, crops, livestock, and forests. Unfortunately, some of these chemicals had other repercussions in the environment. A myriad of new problems arose concerning their use and abuse.

When Henry Ford developed the assembly line in 1912 and initiated mass production of a low-cost car, he opened the door to literally putting the United States on wheels. Unfortunately, a gaseous exhaust system was also associated with the wheels. The effects of air pollution emanating from millions of automobile exhausts upon human health and comfort, and plant and animal life, have become of prime concern in our efforts to improve environmental quality.

Because of a successful test at Los Alamos, N. Mex., on July 16, 1945, our atmosphere will probably never again be free of radioactivity.

Past experience reveals that technological progress usually spawns whole families of unforeseen problems. Research must not only seek answers for the problems of today, but also anticipate the key questions that will loom up in the future.

The need for sound information relative to production, management, use, and control of wastes is so vast that no one responsible for direction of research in this area will ever emulate the U.S. Commissioner of Patents in the early 19th century who resigned from his post on concluding that everything that could possibly be invented, had been invented. As a consequence, the director of research pertaining to wastes must carefully evaluate all the possibilities and place his resources on the most promising ones.

Radioactive Substances

The need for additional information on how to cope with radioactive contamination of the environment depends on things to come; things largely unknown but rife in speculation. If the problems were confined to the effects of natural radioactivity found in the effluvium from uranium mines, the need would not be serious. If we are to be prepared to counteract accidental releases of radionuclides from research laboratories or nuclear power plants, then we must be confident of available decontamination procedures. If radioactive fallout should increase substantially by (*a*) accidental release from underground tests; (*b*) breaking of the ban on atmospheric testing now in effect by the U.S.S.R., the United States, and the United Kingdom; or (*c*) intensification of atmospheric testing of nuclear explosions by nations respecting no bans; then, our problems will be much more serious.

If nuclear warheads should become the last resort in deciding international disputes, then we are going to need a great deal more information on decontamination and other defensive procedures than we have. One suspects that the United States is better supplied with these warheads than with countervailing information to cope with those that might come to us.

We need far better information on the duration and effects of retained fallout particles on plants in order to improve validity of prediction of radiation doses to plants and animals. Information is especially needed on heavy fallout conditions. We need to more fully evaluate the forces tending to dislodge fallout particles from plants. These forces include wind, rain, shaking, and brushing. Characteristics of leaves that affect ease of dislodgment need far better evaluation. Distribution of retained particles on plant surface needs to be measured.

The foregoing information is needed to develop more expedient and practical procedures for decontaminating forage in the field. This capability is urgent. Research will probably find certain crops are far more easily decontaminated under field conditions than others. A sprinkler irrigation system could have new uses, but it would be necessary to know optimal time of sprinkling during fallout.

Radically new techniques are needed to reduce the thickness of surface soil that must be removed to decontaminate soils. For example, it should be possible to develop mechanical methods for removing thin plastic coatings that have been allowed to harden on contaminated soil surfaces.

Much research information is needed on the physiological specificity of different varieties of crop plants to (*a*) exclude most entities in radioactive fallout from absorption by the roots; (*b*) exclude these entities from entry into the vascular system even if absorbed by the fine roots; and (*c*) exclude these entities from foliar absorption. A crop plant that would not absorb radioactive materials under heavy fallout would indeed be the nonpareil in a nuclear emergency.

Chemical Air Pollutants

Improved Technology for Evaluation of Damages From Airborne Toxicants

Evidence of significant damage by airborne toxicants to farm crops, ornamentals, and forest trees continues to grow each year. There is no question that vegetation is very sensitive to air pollutants. Adverse effects occur around every industrial and populated area. For example, in Metropolitan Washington, D.C., an ozone-sensitive variety of tobacco only makes half as much growth in prevailing air as when grown in the same environment but with carbon-filtered air. Even a resistant variety of tobacco accumulated one-third less dry weight in the prevailing air.

Losses due to various airborne toxicants are difficult to estimate and reliable data are very limited. Estimates published in 1956 (*83*), 1961 (*81, p. 444*), and 1965 (*5, pp. VII–280*) show that photochemical air pollution causes millions of dollars of damage annually to crops in California and that the amount of damage has been increasing rapidly. In 1959, there was an estimated 12 to 20 percent loss to cigar-wrapper tobacco growers in the Connecticut Valley (*54, 97*). In 1965 and 1966, ozone-induced weather fleck caused significant damage to Florida shade-grown tobacco (*27, 29*). The damage was more general over the area in 1966 and resulted in greater economic loss. It was estimated that fleck damage in 1966 averaged at least one leaf per plant for every acre planted.

In view of the gross evidence of mounting losses from these airborne toxicants, there is an urgent need to improve the validity of the techniques available for assessing damages, particularly chronic damages. Valuable information can be obtained by comparing plant growth in ambient versus carbon-filtered air. If adverse effects in the ambient air are noted, it is essential to ascertain the entities that are responsible. Further information is needed to enable identification of the specific effects of each toxicant on the many different plant species of concern.

Physical facilities must be available that enable controlled exposures of plants for long periods to low levels of toxicants. Methods of identifying and measuring specific air pollutants must be improved. Physical and biological data must be so accrued as to be amenable to sound economic analysis.

The potential exists for improving the design of physical facilities towards improving assessment of losses to agriculture, including the relative significance of each specific pollutant. Parallel field studies will be needed to check the validity of laboratory findings for field conditions.

Effects of Airborne Toxicants on Plants, Including Interactive Effects

That air-polluting chemicals damage leaves and blooms of salable plants is an established fact. But little is known of the actual physiological mechanisms by which these harmful effects take place. A better knowledge of how these toxicants alter the biochemistry of leaves is a prerequisite for the development of counteractive measures.

The potential for improving procedures to ameliorate air pollution damage has not been adequately developed. Ozone fleck in tobacco has been partially diminished by ozone-resistant varieties. However, plant resistance is relative. The floor for injury of a resistant variety may be exceeded if pollutant concentration increases. Cultural practices and use of chemical protectants promise some control of air toxicant damage.

The best way to alleviate air pollution damage to agriculture and forestry would be the use of technology to eliminate industrial and automotive sources. The prospects for this happening are dim. Therefore, the highest promise for alleviating the damage now being inflicted on crops, ornamentals, and trees is to foster adequate research for resistant varieties as strains, and for effective chemical protectants from the adverse physiological changes that air toxicants induce.

Development of Tolerant Species, Varieties, and Breeds of Plants

There is an urgent need for information on tolerance of species, varieties, and breeds of plants, if profitable production of sensitive species, such as pines, citrus, tobacco, and leafy vegetables, is to be maintained in certain areas of the country. The situation is already acute in southern California. It is becoming increasingly serious in the densely populated stretch from Boston, Mass., to Richmond, Va. Information on tolerance of ornamentals is especially needed by city planners and landscape architects.

The apparently unlimited potential for developing plants more tolerant to air toxicants should be exploited more fully. Systematic studies to develop tolerant vegetation have just begun. Evidence shows that white pine trees can be selected that are resistant to ozone and other toxicants.

The effort needed to develop tolerant plants is large because of the tremendous number of plant species involved, and the need to genetically combine yielding ability, quality characteristics, and resistance to diseases with tolerance to airborne toxicants.

Adequate physical facilities will need to be provided for maintaining a controlled level of toxicant in progeny evaluation studies.

Evaluation of Air Cleansing of Toxicants by Foliage

Plant species vary considerably in their reaction to toxic substances in air. For example, a few parts per billion of fluoride in the air are extremely toxic to gladiolus, corn, sweetpotatoes, prunes, and apricots; but other species such as alfalfa are tolerant and may accumulate levels about 500 p.p.m. without injury. Other toxicants such as sulfur dioxide cause injury to pines, alfalfa, cotton, and grains at relatively low concentrations; but citrus, privet, and apple are very resistant.

When sulfur dioxide enters leaves, it is converted to sulfite. Then sulfite is slowly oxidized to sulfate, which reduces the sulfite toxicity by a factor of about 30. Consequently, if sulfur dioxide is not added to the system too rapidly, a large amount may be added without resultant toxicity. More information is needed on the extent to which sulfur dioxide may be a source of sulfur nutrition of crops on sulfur-deficient soils.

It is known that plants exposed for several days to about 1 p.p.m. of nitrogen oxide become greener, although somewhat stunted in growth. This suggests that some plants may be able to use nitrogen from this toxicant.

Conifers appear to be more efficient in air cleansing than maples because they have greater leaf surfaces and are not deciduous.

Much more information is needed about the relative rate at which plants remove toxicants from air during different seasons. It is important to know if plants are as effective at night as during the day in this removal. Would certain chemical sprays aid removal of air toxicants by plants without resulting injury to the plants? Developing such information would be especially important for growers near urban areas and for metropolitan planners.

Research on the air-cleansing capacity of foliage is just beginning and needs to be expedited.

Development of Protective Chemical Treatments

Antioxidants and antiozonants protect plants from ozone injury. Lime dusts reduce fluoride injury.

On cigar-wrapper tobacco, zineb is used commercially for the control of a pathogenic disease, but it also reduces the amount of ozone fleck. More effective chemicals than zineb are available, but the problem of residues remains to be solved.

Little information is available about the use of chemical protectants against other airborne toxicants. But current information indicates that the development of chemical protectants is a promising area of research.

Rapidly growing plants are generally the most sensitive to air pollutants. Seedlings sometimes appear to be more sensitive than older plants. Plants supplied with adequate soil moisture are much more sensitive than those subjected to soil moisture stress.

The interrelated effects of nitrogen metabolism, carbohydrate metabolism, and organic acid metabolism in plants on their resistance to toxicity appear to be very complex. Certainly these effects are now poorly understood. Research information is needed on these indicators of plant nutrition to develop guides for better mineral fertilization practices under conditions of chemical air pollution.

Development of Information and Procedures To Lessen the Hazard and Intensity of Forest Fires

Forest fires contaminate the air by producing tremendous quantities of smoke and hydrocarbons. For example, every commercial airport in the State of West Virginia was closed for nearly a week in 1964 because of smoke from forest fires.

Research into forest fire control is constantly producing improved procedures that reduce the total acreage burned and, consequently, the smoke and hydrocarbons produced. Such research has had high benefits in relation to its costs. It is certainly in the national interest to take every step possible to reduce the hazard of forest fires and their tremendous effluent of smoke and hydrocarbons.

Develop Improved Procedures To Diminish Forest Fires Caused by Electrical Storms

Lightning causes more than 7,500 forest fires during the average year. Such fires are exceptionally expensive to control because, unlike man-caused fires, they often occur in inaccessible country. In the Rocky Mountain States, lightning sparks more than 70 percent of all forest fires. Smoke from these fires has severely curtailed air operations as far east as New York and Boston.

Cloud-seeding techniques offer a strong potential for reducing or eliminating lightning-caused fires. In recent field trials, heavy overseeding with silver iodide gave a one-third reduction in cloud-to-ground lightning. The urgency in preventing forest fires, not only to avoid contributions to air pollution, but also to protect watersheds and conserve timber stands, indicates that appropriate research move forward as rapidly as possible.

Airborne Dusts

Airborne dusts can be irritating, exasperating, and frustrating. They arise from cement plants and lime kilns, cotton gins, and alfalfa mills, natural sand dune areas, unprotected fields and rangelands, highway construction, and suburban and industrial development. Dust clouds emanating from soil blowing on the Great Plains comprise big, dramatic, and usually disastrous events.

Soil Blowing

Masses of soil particles transported by the winds have been known to cause physiological damage to humans and livestock, depletion of the soil resource, abrasion damage to growing crops, increased home and office cleaning, reduced visibility resulting in increased automobile accidents, and many other costly effects. Recent findings have revealed the presence of hydrocarbons from chemical pesticides absorbed on air-transported soil particles.

Reduction of airborne soil particles depends upon control of soil blowing. Although past research has provided information toward understanding the processes, for the development of control practices and means for predicting the extent and probability of duststorms, the potential for improvement in understanding, control, and prediction remains high.

New research must include further study of the wind erosion processes and the definition of principles to form a scientific basis for design of more effective control practices such that the productivity of farmlands will be preserved and pollution of the atmosphere reduced or prevented. The studies must consider various concepts for describing and delineating the influence of atmospheric wind and turbulence on soil detachment and transport; the effect of wind and related atmospheric factors on soil drying and creation of soil surface conditions susceptible to high rates of detachment; the modification of tillage practices and machines to provide effective and lasting crop residues and soil cloddiness conditions to resist soil detachment; the theory of barriers, their effect on the microclimate, and optimum design and orientation based on analysis of wind factors and probabilities; the use of chemicals and petroleum-derived soil stabilants as a part of control systems; the tolerance of crop plants to abrasion for windblown soil particles; the development and selection of better strains and varieties of grasses and crops to tie down soils susceptible to blowing; improved prediction equations for flow conditions; and interrelations of soil erosion rates, dust deposition, soil properties, soil treatments, environmental pollution, and soil renewal.

Windbreaks

Land in the Great Plains is almost constantly exposed to the damaging action of winds. Winter gales remove the snow from open fields on the bare soil; plants become sparse and are sometimes winter-killed. During dry springs and summers, soil blowing and erosion damage from high winds is greatly increased. Strips of trees (windbreaks and shelterbelts) across open areas are a powerful means of amelioration, influencing not only the immediate site but also remoter areas. Crop production is increased by the conservation of soil and soil moisture, and livestock are afforded protection in shelterbelts. Living conditions are improved not only through beautification of the homesteads, but by reduced fuel costs.

Cover is effective in reducing soil movement by wind. Where grasses thin out or disappear due to drought, cultivation, or overgrazing, vast duststorms may result. Brush invades when grass disappears. Grasses stabilize sand dunes, ditchbanks, and roadbanks.

To fulfill the many needs for protective belts of trees and other vegetation, expanded research must focus on the development or selection of suitable species. A wide array of species of trees and shrubs will need to be evaluated to meet the diverse needs of varying climatic conditions. Other needed research information includes that on optimum depth and spacing of plantings; cultural practices to maintain vigor, density, and longevity of plantings; disease and insect control; and the effect of the vegetation on wind movement.

Feedlots

Large feedlots are now under criticism for the dust nuisance they create. These dusts are not only a nuisance to the housewife but of serious concern to those with dust allergies. It is also suspected that dust in these feedlots reduces efficiency of weight gain. Sprinkling is one technique that has been used with some success. However, further study of the problem is needed to develop alternate methods and more economical sprinkling techniques.

Where dusts arise from feed grinding, mixing, and handling, techniques for pneumatic conveying and use of cyclones—mechanical devices to remove dusts from air—offer a means for controlling dust. Cyclones, when properly used, can approach efficiencies very near 100 percent removal. When not properly used, however, their efficiency is very low. Cyclones are presently designed primarily on a trial-and-error basis so that they usually only apply to the special set of circumstances for which they were developed. Research is needed to develop the methodology for the rational design of cyclones so that they can be utilized for control of dusts.

The relationship of weather conditions to dust problems is recognized but needs much further study.

Cotton Gin Dusts

Under average conditions, about 1,000 pounds of trash accrue with each bale of cotton ginned. Some of this is disseminated into the atmosphere as very fine dust. In addition to its plainly irritating effects, it is adverse to the respiratory health of people miles to the leeward of the gin. Burning of the trash at the gin appears to be impractical—the smoke produced is also a nuisance. Returning the trash to the field is inadvisable unless it is decontaminated of insect and disease pests.

People living in the neighborhood of gins are convinced that it is urgent to improve engineering technology to effectively filter the air from ginning operations, and to develop an inexpensive technique to decontaminate gin trash enabling its return to the fields as noninfesting organic matter.

Analogous problems prevail around alfalfa mills.

Sediment

There is no basis at the present time for a really adequate estimate of the impacts of sediment upon the national economy. The Army Corps of Engineers has estimated that flood damage in downstream areas amounted to $538 million annually under 1957 conditions and that potential damage under conditions in 1980 would be about $739 million (*120*). The Soil Conservation Service has estimated the average upstream flood damage in the contiguous United States as being slightly in excess of $1 billion annually (*43*). Any separation of flood damages between water and sediment components can be only arbitrary at best, but it would seem safe to guess that sediment damages associated with floods, considering both upstream and downstream areas, average at least about $500 million a year.

Soil erosion is a natural geologic process which has been accelerated manyfold in most parts of the country by man's use of the land. Reduction of the rate of accelerated erosion is the only positive and permanent cure for the sediment problem. However, the development and widespread application of land management practices to control all erosion is a dream of the future and specific measures for transporting, storing, or otherwise handling sediment will be required in many situations. But before development of more acceptable land use practices can be effectively pursued, increased knowledge of the erosion processes and definition of the basic principles governing the movement and loss of soil must be attained.

This research will involve study of detachment and movement of soil particles by raindrop splash and flowing water, surface sealing and related phenomena that result in decreased infiltration, water intake and movement through soil during freezing and thawing periods, the role of plant cover and crop residues in reducing erosion, and concepts relating erosion to topographic, climatic, and soil factors. Control practices need to be developed and integrated into systems that will reduce runoff a maximum amount and provide for the safe removal of any excess drainage water. The control practices for farms must be compatible with modern farming methods, and for residential and commercial development sites, with efficient construction practices. Attention needs to be given to the development of improved prediction equations.

The potential of land use and management practices for ameliorating sediment problems of watersheds and river basins is one aspect of the problem needing much further study. New concepts and procedures for identifying critical sediment source areas and predicting sediment delivery from such areas as affected by climatic factors, soils, geology, topography and land forms, stream channel characteristics, erosion-control practices, and watershed protection measures are required. Increased knowledge of the physics of sediment genesis and movement in watershed systems is required for isolation and selective treatment of critical sediment source areas.

Criteria for the engineering design of sediment traps and debris basins are inadequate. A better understanding of the mechanics of sediment transport in tortuous channels of alluvium, and the resistance of cohesive materials in channels to hydraulic forces is necessary for design and maintenance of stable stream channel systems.

Additional information on rates and processes of sediment deposition in reservoirs and water detention structures, on floodplain lands, and in estuaries and harbors will also be required for effectively coping with sediment problems.

Little or no information is available on the role of sediment as the transporting agent for residues of pesticides and other chemicals in streamflow. The affinity of sediments, particularly clays and organic fractions, for pesticides must be defined and, if significant, measures for keeping such wastes from streams must be developed. More economical and effective techniques to stabilize streambanks are required. New technology to stabilize eroding soil in developing urban areas, on roads and highways, and on other construction sites is a new requirement of great urgency.

Increasing demands for greater quantities of water of improved quality may soon require that positive steps be taken to stabilize and control critical sediment source areas in urban, agricultural, and forested environments. In urban areas, erosion from construction and development sites is a potent contributor to the sediment content of streams. Studies have shown that erosion in the Washington, D.C. metropolitan area is a primary source of sediment polluting the Potomac River estuary and will have to be controlled before this portion of the Potomac River can be restored to its natural beauty and used for its full potential.

Economically feasible erosion-control techniques are needed for use in suburban development and preparation of industrial construction sites. Better means of channeling and trapping uncontrollable sediment delivery from these sites must be developed.

Soil erosion by water, the dominant problem on 179 million acres of cropland, is feasible to treat with measures that reduce soil losses (*25*). Highly mechanized farming on large tracts, monoculture, and intensive culture, all focus on the need for new technology that will provide for more economically feasible systems of erosion control under these systems.

More than 40 million acres of forest and related rangelands are eroding because of disturbances or destruction of cover. They produce an estimated 100 million tons of sediment each year. Approximately 90 percent of this sediment is produced by roads, logging skid trails, and burned areas. Not only are these lands reduced in productivity, but they are sources of sediment-laden floods and mudrock flows, which destroy crops, homes, roads, and other improvements, and impair water quality for irrigation, industrial, and domestic use.

Research towards diminution of forest fires, gully development, and overgrazing of rangelands would contribute very much to reduction in sediment delivery.

Strip mining for coal and minerals has become more economic with the advent of large, powerful machinery. Tremendous spoil banks and barren areas are formed. These piles of raw earth materials are usually highly erodible. Revegetation of these barren areas is frequently very difficult because of high acidity and low content of mineral nutrients.

Revegetation is difficult on gullies, spoil banks, roadbanks, strip mine areas, overgrazed rangelands, forest burns, and other badly disturbed, unstable, or deteriorated sites where growing conditions are severe. Adapted species, varieties, or strains must be found or developed to revegetate and stabilize these critical sediment source areas. This will require extensive research on selection, evaluation, and culture of promising plant materials. Revegetation may involve a succession of species, with the first cover probably involving plants that can become established quickly under conditions of low fertility and drought.

Engineering modification of barren surfaces and addition of specific soil amendments will need research attention for effective revegetation of many of these deteriorated sites.

Plant Nutrients

Concern is growing over the eutrophication of lakes and rivers. The enrichment of these waters with plant nutrients, particularly nitrogen and phosphorus, enables the growth of algae and other water plants that are the base of the eutrophic process. These nutrients may come from many different sources: Domestic sewage, including the phosphate in detergents; processing wastes; garbage and refuse dumps; animal wastes; land runoff; and land drainage.

More and more evidence is appearing on the prevalence of nitrate in ground waters. Possible sources include fertilization of farmland, feedlots and barnyards, septic tanks and other domestic sewage, processing effluent, and natural sources such as niter spots in semiarid regions.

When phosphorus or nitrate is found in water, the relative importance of possible sources of origin is largely conjecture. This provides fertile ground for arguments. To the extent possible, conjectures should be replaced by sound information.

Very little modern information is available on the phosphorus content of runoff from land varying in geochemical characteristics, treatment with chemical amendment and fertilizers, cultural practices, and hydrologic conditions. The data available indicate that total quantities of phosphorus in water derived from either surface or subsurface land runoff are at levels that are completely insignificant in terms of agricultural production, but may be approaching significance for growth of algae which respond to as little as 0.05 p.p.m. of phosphorus in the growth medium.

Far more study is needed on the method of determining phosphorus content of water in terms of biological significance. Trying to interpret the significance of values for total phosphorus content of river water is analogous to grinding up a whole cow and then testing a bit of the resulting hamburger to see if the animal had ketosis.

The development of suitable analytical procedures may help us to distinguish at least four different states of phosphorus in water samples: (*a*) That which is in true solution as orthophosphate; (*b*) that which is in solution in a nonpolar form as an organic polyelectrolyte; (*c*) that which is adsorbed on the surface of suspensoids; and (*d*) that which is a component part of the mineral of the suspensoid. Information is especially needed as to the degree of liability of phosphorus in entities (*b*) and (*c*) in terms of growth of water plants.

It is urgent that we rapidly alleviate the grave dearth of qualitative and quantitative information on the phosphorus in runoff and drainage water from agricultural and forested lands as affected by soil type, fertilizer practices, cultural practices, vegetative cover, and climatic conditions.

The lability of phosphorus in bottom sediments in streams is little understood in terms of its availability for growth of algae even if it is available to bottom-rooted plants. We need to know how turbulence in stirring up bottom sediments, presence of organic matter, prevalence of aerobic vs. anaerobic conditions, and the activity of metallic ions such as iron and aluminum, affect release of phosphorus adsorbed on sediment particles.

In terms of eutrophication of surface waters, we also need information on nitrogen and potassium moving from the land into streams, even though need for information pertaining to these two elements does not appear to be as pressing as that for phosphorus.

Whereas phosphorus appears to be the nutrient that limits the growth of free-floating plants, such as algae, different circumstances may control the growth of bottom-rooting plants which have direct access to the phosphorus reserves in the bottom muds. Evidence shows that when nitrogen supplies are adequate, the growth will be controlled by the supply of potassium in the water. The extent to which this is supplied from fertilizers is not known.

Nitrate is found in ground water and there is concern on the readiness with which this anion may be reduced to nitrite and cause methemoglobinemia in babies or nitrite poisoning in ruminants. There is evidence that nitrate in ground water does not come from fertilizers applied to fields; and there is evidence to the contrary. Supplementary information to fully explain this apparent contradiction must be attained.

Nitrate is formed naturally in soils. In arid or semiarid regions, it accumulates near the surface as caliche or as "brown alkali"—niter spots—in the surface soils. No one has adequately explained whence this nitrate came. Under the right hydrologic conditions, it may be leached into ground water. If it is formed in humid regions, it is so leached.

Evidence is at hand that nitrate does enter the ground water system in leachate from cattle pens and feedlots. In a restricted locality such downward movement of nitrate may be appreciable, but little is known of the total contribution of this source to overall content of nitrate in an aquifer.

Domestic sewage is certainly a source of nitrate in ground water. This may be the main source of such nitrate in rural communities. Certainly there is need to replace unwarranted supposition with irrefutable evidence.

As nitrate and associated entities move downward from the surface soil to the water table, there is much need for information on the prevalence of conditions for the formation of nitrite at various horizons as well as in the ground water.

Inorganic Salts and Minerals

Inorganic salts and minerals in the effluent from certain metallurgical and chemical industries, and the acidic drainage from many operating and abandoned mines, can seriously impair the quality of water. All fish may be killed. Use of an afflicted stream for recreation areas in forests or in other parts of upstream watersheds may be seriously impaired. Such water is generally unusable for irrigation and livestock. Agricultural and forestry leaders planning and developing upstream watersheds for optimal social benefits need far better information on possible measures for coping with these seriously harmful mineral additions to streams.

A number of metallic salts and related materials have been added to soils over the years as (*a*) insecticides or fungicides, (*b*) micronutrient supplements, or (*c*) inadvertently as impurities in fertilizer. Lead arsenate was the main insecticide used to control codling moth in fruit trees for many years. This metal salt accumulated to relatively high levels in soils of apple orchards of the Northwest. On orchard removal, succeeding crops have been injured. Calcium arsenate used to control cotton insects accumulated to toxic levels in some cotton soils. Copper compounds, for example, bordeaux mixture, have long been prime fungicides. Copper may be found in some vineyard soils at relatively high levels. Copper or zinc salts need to be added as supplemental minor elements in some soils. Evidence from a few areas suggests that the practice may be overdone. Some ores used for fertilizer production may carry undue quantities of boron, arsenic, zinc, or fluorine. These impurities are usually not harmful.

Serious losses from soil contamination by mineral salts have not occurred. Enough warning lights are on the horizon, however, to signal the need for more adequate information on the action of these contaminants in soils and the availability of counteractive measures.

The heavy salting of highways to facilitate traffic movement following snowstorms has caused serious damage to right-of-way vegetation and has increased silt damage to streams when erosion followed killing of the vegetation. This type of damage has been felt by adjacent property owners—both rural and urban. It has been particularly serious in part of New England. In humid areas, rainfall eventually remedies the damage.

Research is needed to assess the problem and adjust findings of saline soil and water research for irrigated lands to solution of the highway salinity problems.

Mineral salts have long been serious contaminants in the soils and associated waters of irrigated areas in arid regions. With competition for water increasing in the water-short sections of this country, one can expect that the needs of irrigation agriculture will not rank high. If waters of varying quality are available, agriculture will undoubtedly have to get along with that which is less than the best. All indications the world over point to greater need for information on the evaluation and management of salt-affected soils and waters.

Water available for irrigation use varies widely in quality. Previous use or treatment (softening) of the water can affect its quality for irrigation. More elastic criteria are needed to characterize water quality for this use as modified by climate, soil characteristics, management practices, drainage, quantity of water available, and kind of crops grown.

Advances in atomic power plants for generation of electricity and in processes for desalting sea water have prompted feasibility studies of plants to produce both low-cost power and water. Cost estimates for the water imply a level currently acceptable to irrigation users. Advancing technology should in time provide water well within the economic reach of many irrigation users. As this water is essentially free from any dissolved chemicals, its use on saline and sodic soil may present problems of water intake and leaching of salts already in the soil. Research must be conducted on the use of such water for irrigation in areas now successfully irrigated with water containing relatively high amounts of salts, such as the Imperial Valley where each acre-foot of Colorado River water imports 1.2 tons of dissolved salts. The first use of the pure water may be as a dilutant of current supplies or particularly for the high-salt-content flows leaving irrigated fields as tile drain effluents.

Salts in, or previously in, soils affect their physical and chemical characteristics. The interrelationships are complex. An increasing body of knowledge is needed on the chemistry, mineralogy, and microbiology of the hundreds of different kinds of soils affected by salinity. Better means of assaying these salty-soil problems are needed as related to their irrigation by waters varying widely in chemical characteristics.

Salts move in soils only with water as the vehicle. Information on the physical state of water in these soils is fundamental to understanding the principles of salinization and desalinization. With recent breakthroughs on techniques for measuring the energy state of water in soils, research on water retention and movement can be and must be expedited.

Genetic lines of many crops vary greatly in their response to saline and sodic soils. Indications of this variability have been found in cotton, cereal grains, grasses, and fruits. Plant breeding research to develop lines with superior salt and alkalinity tolerance should be expedited.

Far more definitive information is needed on the biochemical and physiological mechanisms in plants that determine their tolerance to various salt-affected soils. Unfortunately, little information is available on the effect of climatic conditions in modifying inherent salt tolerance of crops. Such information is essential to crop and soil management in soils subject to salinization. Increased knowledge of salt rejection by biological membranes could be extremely helpful in desalting sea water. It is also essential to plant breeders working to develop varieties and strains with higher salt tolerance.

Fence lines sometimes show wide differences in salinity damage. Even with identical water supply, identical soil, and identical crops, diverse management practices by different operators on either side of the fence may be the difference between success and failure. Accordingly, much better practical information is needed to unerringly predict the combination of management practices for maximum production efficiency under a given set of conditions pertaining to salty soils or waters.

Hard experience in the Western States has revealed that successful irrigation requires effective drainage. Accumulating salts must be continually leached out. This is the only practical means known today for maintenance of irrigated agriculture in many areas and for reclamation of areas already salted out. Excess leaching wastes water and plant nutrients. For most efficient use of water and maintenance of a favorable salt balance in the fields, better mathematical expressions are urgently needed for the calculation of leaching requirements, drainage requirements, and the proper salt balance.

Fields and irrigated areas already seriously impaired by salinity must be treated with the most economic reclamation procedures available. It is essential that more research attention be given to minimizing the cost of amelioration procedures on salinized lands for redeveloping productive soil-water-plant systems.

The return flow from an irrigated area is almost invariably saltier than the incoming water. The salt that comes in must go out, but part of the water carrying the salt in is lost in evapotranspiration from the field. Hence, Nature's principles dictate that there be a corresponding concentration of salt in the outflow water. If the drainage return flow enters a stream, the downstream users accuse the irrigation project for contaminating the water. One of the most pressing needs for information in irrigation agriculture is the development and evaluation of other procedures for disposal or reclamation of return flow—procedures that seek to maximize beneficial use of total water available, while minimizing contamination for downstream users.

Experience has already shown that one of the prime contributions the United States can make in the Food for Peace Program is sound technical information on the management of salt-affected soils in the irrigated areas of the world.

Organic Wastes

It is most fortunate for 20th century man that there were conditions in prehistoric times under which a vast production of organic wastes from prolific vegetation was not completely oxidized, but accumulated under water as muck and peat to become a wealth of coal and oil eons later.

It is most fortunate for 20th century man that there are conditions now by which a vast production of organic wastes is rather rapidly oxidized by bacterial activity, conflagration, or other means back to CO_2 and H_2O. Our problems with organic wastes arise because oxidation does not take place as rapidly or as acceptably as we would like.

New, more extensive, or more useful information is needed on the production, handling, and disposal of organic wastes, including animal wastes, reclaimed sewage effluent, crop residues, forest slash, and processing effluent.

Animal Wastes

Production of farm animals has become big business. There are highly mechanized dairies carrying 400 head; feedlot operations handling 10,000 cattle; and automated poultry enterprises caring for 100,000 fowl. An operation involving 400 milk cows produces about 14 tons of solid wastes and 4.5 tons of liquid wastes daily. An outfit with 10,000 cattle on the feedlot produces 260 tons of solid wastes and 100 tons of liquids daily. A poultry enterprise with 100,000 birds produces 5 tons of wastes daily.

Economic studies indicate that fertility value of these wastes to the land is not equivalent to cost of hauling and spreading. If allowed to accumulate, these wastes emit offensive odors, afford breeding areas for flies and other vermin, and provide concentrated sources of pollution for surface and ground water.

There are many possibilities for improved management, handling, disposal, and reclamation techniques in meeting animal waste problems. These problems are rather new on their present scale, and consequently, have received relatively little research attention.

There is a pressing need to develop basic design criteria that are amenable to some adjustment to meet the widely varying constraints associated with different enterprises in different parts of the country. Elements of the problem include characteristics of manures, removal of manure from livestock and poultry quarters, storage, transport, feasibility of use on land and disposal by burning, use of lagoons or similar facilities, or burying. Disposal problems include handling carcasses, milk-room wastes, and silage effluents.

Most of the present methods for handling livestock and poultry wastes are no longer economically justifiable nor esthetically acceptable. New methods and systems are essential. Engineering competence will be needed to evolve a completely new family of agricultural equipment and processes.

The possibility of using livestock and poultry wastes as a culture medium for the propagation of organisms antagonistic to known plant pests and diseases should be evaluated. If the use of manure as a culture medium for the production of organisms antagonistic to plant pests and diseases were practical, this would justify the higher costs of spreading manure on the fields. The value of manure in soil sanitation has not been fully appreciated. The possibilities of combining agricultural and industrial wastes as an effective soil amendment to reclaim marginal or badly eroded land needs much more consideration. For example, industrial wastes such as fly ash and cinders, would improve the structure of some soils by providing better aeration of the root zone. Organic wastes provide some fertility and may appreciably improve the structure of intractable soils.

Procedures for disposal of carcasses by incinerating need to be improved to alleviate their nuisance in producing odors, smoke, and fly ash. Incineration is often necessary to control dissemination of diseases.

Much information is needed on the effect of materials used for litter and bedding on bulk water absorption and other properties of manure.

Plant molds exist that are known to be toxic to poultry and, presumably, livestock. Specifically, there is a mold that infects peanuts and is toxic to poultry. Peanut hulls are one of the best materials that can be used for poultry litter, but the presence of this mold renders it useless. The hulls become a liability instead of an asset.

Chemical analyses of manure from beef cattle on different diets in feedlots would provide useful information towards developing potential uses and methods of disposal. More information is needed on the effects of feeding and management of dairy cattle on the chemical nature of the solid wastes.

Emanations from large livestock feedlots must be evaluated in terms of esthetics as well as health.

Much effort should be allocated to identify the odor-producing organisms prevalent in manures and to develop techniques to destroy such organisms.

The massive amounts of manure that accumulate under certain operations permit houseflies to reproduce prolifically. These flies create serious health problems in addition to irritating man and animals.

Treatments of manure that would keep flies and other vermin from using it as a breeding ground are especially needed.

Even when it is feasible to spread manure on cropland, it may be done only during certain periods of the year. More acceptable procedures for storage and distribution without emission of offending odors and possibility of contamination of runoff waters are needed.

Encroaching suburbs in many rural areas are forcing farmers to change and improve procedures for handling animal wastes, but the cost-price squeeze that continually hovers over farmers demands that any changes in handling procedures be made at the lowest cost possible.

Use of Reclaimed Sewage and Industrial Effluent

Effluent from industry and domestic sewage is now a costly waste disposal problem. Possibilities exist in many regions of the United States for utilizing these waste waters for agricultural purposes. Criteria need to be established for agricultural use of such waters in irrigation. In addition to the nature and content of organic constituents, water use for various crops on different soils will be affected by such water quality aspects as total dissolved solids, suspended solids, acidity, and content of metallic elements. Since demands for irrigation water are seasonable, storage or other uses of such waters may need to be developed.

Evidence indicates that the best way to reclaim sewage or industrial effluent is to permit it to percolate downward through soil. Overirrigation should be explored as a means of purifying water and recharging aquifers.

Crop Residues

A major use of crop residues is as a part of stubble-mulch farming to protect fallow lands against the erosive forces of wind and water. Under some conditions such mulches appear to depress crop yields. Also, the mulch may harbor diseases and insects and form sources of reinfection. Additional information is needed so that the soil-protecting aspects of mulch may be realized without undue losses from the adverse effects.

The process of microbial decomposition of crop residue is accompanied by great changes in the microbial populations in the soil. There is ample evidence that plant pathogens are sometimes suppressed or eliminated during this surge of microbial activity (*79*). If the basis for this biological control (*79*) of disease organisms was known so that the residue could be treated or amended to augment this response, it would be one of the most important breakthroughs in soil microbiology. Much research effort is being placed on this problem throughout the world, but so far with little success. Since it is known, however, that the disease-controlling effect can be modified by simply changing the C/N ratio of the residues, there is definite hope that accumulating knowledge will lead to useful biological control practices.

It is also known that certain decomposing crop residues have a toxic effect on subsequent crops, particularly in the seedling stage. Detailed knowledge on the chemistry and biological effects of residue decomposition may reveal many unsuspected harmful or beneficial effects on crop growth. Eventually, it may be possible to manage the decomposition of crop residue, not only to reduce harmful effects, but even to stimulate crop response.

Another possible side effect of improved management of crop residues is the detoxification of pesticide residues in soil. Many pesticide materials are adsorbed or complexed by the organic matter in soil and the enhancement of microbial activity should be advantageous in favoring decomposition of those pesticides that are susceptible to microbial degradation.

The straw from grass seed harvesting is presently burned in the field along with remaining stubble. The emitted smoke and hydrocarbons often create a serious air pollution problem in the immediate locality. Other ways of handling this residue need to be found—ways that will also provide disease and insect control.

In some grain production areas, and in many areas in some years, straw production is too great for efficient use of equipment under stubble-mulch farming. Progress in breeding varieties of cereals with short straw without sacrificing yields needs to be expedited.

In rangeland renewal operations, the prevailing brush is frequently bulldozed, chained, or otherwise mechanically removed. Evidence indicates that the brush residue may be distributed over areas newly seeded to grass, thereby reducing moisture losses and aiding emerging grass seedlings. This possibility needs to be vigorously exploited as a means of utilizing brush residue in meeting the urgent demands for grassland restoration.

Forest Slash

The millions of tons of forest slash produced each year provide a serious fire hazard, a serious air pollution problem when burned, and a source of insect and disease infestation when not burned. Thus, there is an urgent need to develop new technology for slash disposal. Mechanical means involving chipping, crushing, or mastication are far too expensive at the present time. Expediting slash disintegration by chemical treatment has not given positive results. Likewise, fungal inoculation to hasten decay appears to offer little hope. There can be marked improvement in burning techniques that reduce atmospheric pollution. This approach appears very promising and research to this end should be expedited.

Processing Wastes

It can be conservatively estimated that over a billion pounds of milk goes into sewers annually from fluid milk processing plants; over 20 billion pounds of whey and buttermilk containing over 1 billion pounds of solids result from cheese and butter production. Over 500 million pounds of biochemical oxygen demand are produced in cannery wastes (dry weight). Neither the farmer nor the processor has a direct interest in water pollution from farm products. Costs for additional treatment of these wastes must be borne by the consumer or the general public through taxation.

In the forest products field, processing losses annually include nearly 400 million cubic feet of logging residues and 230 million cubic feet of coarse wood residues at manufacturing plants. Progress in use of manufacturing wastes has been phenomenal; wood waste burners have almost disappeared and 25 percent of all pulp is made of chips from sawmill and veneer mill residues. Yet, the pulp industry indicates that its wood requirements in 1967 will expand by 10 million cords over those of 1966. The need for better utilization of the resource continues to grow.

Because of the potential economic value of agricultural and forest product wastes for chemicals, pulp, and other manufactured products, the first priority of research should be in new product development using available residues.

The potential for improving processes so that less waste results, or less deleterious wastes, is very good. Many steps in processing were developed some years ago when not much attention was paid to stream contamination by effluents. These need to be restudied and changed. Water reuse or countercurrent use should lower both cost and water consumption. Completely new systems are possible; "dry floor" evaporated milk operations illustrate the possibilities.

Progress in pulp and paper manufacturing processes to reduce water pollution has been good, and at newer plants control can be effected. No economical way is as yet available to further reduce the pollution problem at older plants which are not equipped to adopt new and improved processes.

The first step in increasing the efficiency of utilization of waste from processing agricultural and forest products is an evaluation of the waste's physical and chemical properties and a study of potential outlets or uses for these materials. Effluents from some food-processing plants are being used as a source of much-needed irrigation water in some areas. The sugar industry effectively uses filter press mud as a soil amendment and bagasse as a source of cellulose for making paper or for the preparation of furfural. Certain organic wastes from the food- and timber-processing industries are also used as soil amendments. Lignin, making up one-fourth to one-third of all wood, is a byproduct of some pulping processes and may have great potential as a source of chemical products. The livestock-processing industry has made great strides in efficiently utilizing many of its wastes as byproducts. Increasing needs for protein in the future make research on fermentation of carbohydrates more promising.

Where wastes cannot be used directly because of the presence of a detrimental characteristic or component, some minor amelioration processes might be developed to make the waste product more compatible with a potential use. This might include filtration of an effluent to remove harmful solids, dilution of a saline effluent to make it more suitable for irrigation, etc. Some wastes may be converted to satisfactory soil amendments, but in some instances, byproducts of greater economic value may be obtained through the development of new and improved technology. It is important that, where possible, some of the wastes of today be developed into profitable products of the future.

Infectious Agents and Allergens

The latter part of the 19th century has been aptly called the period of "the Great Sanitary Awakening" (*35*). The research of two outstanding medical authorities provided the foundation for this awakening. John Snow demonstrated to the world in 1849 that epidemics of cholera derived from fecal pollution of drinking water. From 1857 onward, William Budd investigated the nature and mode of spreading typhoid fever. Over the past century, civilized people have developed a well-founded awe for the grave consequences that may arise from water and soil contaminated with infectious organisms.

The potato famine of 1846 in Ireland demonstrated with widespread human suffering that a famine caused by an airborne plant disease can be just as ravaging as an outbreak of typhoid fever.

Animal Disease Agents

As our population expands, all phases of our livestock industry—including production, transportation, slaughter, and processing—may be expected to increase in magnitude, with these operations becoming more concentrated geographically. Consequently, greater opportunity will exist for environmental contamination by disease-producing agents of animal sources. In other words, as time passes our pollution problems due to animal wastes will become more serious.

Research is underway but must, in the future, be pursued more diligently on parasitic and infectious diseases of cattle, swine, sheep, and poultry. Many of these disease agents are capable of infecting man as well as livestock; others, in the light of our present knowledge, cause losses only in our livestock populations. All, in one way or another, affect the well-being of man.

The following are a few specific examples of animal diseases that are presently receiving research attention: brucellosis, leptospirosis, encephalitis, tuberculosis, salmonellosis, and ornithosis. This research will have as one of its prime benefits the reduction of sources of environmental contamination by infectious organisms.

Research underway on parasitic diseases will reduce environmental contamination in two distinct ways: First, by reducing environmental contamination by parasite-infested animal wastes through development of methods to reduce parasitism in our livestock population; and second, by reducing the opportunity for environmental contamination by pesticides through development of methods of reducing or eliminating parasitism based on biological control, immunization, improved management, or the more efficient use of better chemicals. Much remains to be done in the field of parasitological research, and adequate facilities and an increase in overall effort are urgently needed.

Research is being pursued to define the toxicological and pathological effects of insecticides, herbicides, fungicides, and other agricultural chemicals on livestock and poultry.

Other current efforts include investigations on the role of endoparasites in the transmission of infectious diseases of livestock.

Important primary considerations in disease research are the adequate control and containment of the disease-producing agents with which the investigator is working. This includes protecting the researcher, protecting the integrity of the experiment, and protecting the surrounding environment from inadvertent contamination.

Although constant effort is being made to meet these requirements, increased research and facilities are needed to further assure the proper handling of infectious or obnoxious aerosols and animal and laboratory wastes associated with research installations.

Research has already accomplished much to reduce the hazards from environmental contamination by disease-producing organisms, and the great plagues of the past are now, in most areas of the world, only a matter of history. Even today, however, this is not invariably true; and in our modern society, constant vigilance against such diseases as bubonic plague and smallpox are recognized as an ever-present necessity. If the pressures and concentration of modern society are not to result in the appearance of new epidemics or even a revival of old ones, we must increase our research efforts to consistently reduce pollution of our environment by disease agents.

Plant Disease Agents

Plant disease organisms continue to contaminate the air, soil, and water of agricultural areas in spite of extensive research to reduce and eliminate them. Such contamination leads to the perpetuation and spread of the organisms, with resultant reductions in yield and quality of crops. For example, the airborne rust diseases of wheat are estimated to cause an average reduction of over 6 percent annually in the potential production of that crop. Ear and stalk rots of corn cause over 5 percent average reduction of the potential corn crop each year. These rots survive on the debris of the previous corn crop. The potential cotton crop is reduced by 12 percent by cotton diseases each year. When such major crops as wheat, corn, and cotton are reduced by plant diseases to the extent noted above, the magnitude of the problem comes into focus, and the benefits to be derived from curtailing these losses become significant.

A great deal has been accomplished and is being accomplished to reduce the waste associated with plant-disease-causing fungi, bacteria, nematodes, and viruses. The reduction has been achieved by applying the results of continuing research programs by the U.S. Department of Agriculture, the State agricultural experiment stations, and private industry.

Chemical controls have been effective for many diseases, especially on high-value crops or when small amounts of the chemical will control the disease on low-value crops. However, this type of control has added to costs of production and in some cases has had undesirable side effects in the form of undesirable residues.

Many diseases are controlled through the use of resistant varieties, and breeding for resistance to diseases is potentially the most effective and efficient method for controlling many crop maladies. However, the evolution of new disease organisms that can attack such varieties remains a constant threat, and control by resistance has not been found or used successfully for numerous destructive diseases.

Neither chemical control nor plant resistance is available for certain diseases, notably those attacking the roots of plants. These are some of our most sinister pathogens because the infected organs are out of sight beneath the soil, and the losses may be attributed to drought, infertility, or anything but disease organisms. The effects of these organisms can be lessened to some extent by various cultural control measures such as crop rotation and sanitation, but these provide only small measures of relief.

Thus, it is obvious that disease controls presently available are not sufficient to prevent all of the waste caused by plant disease agents.

All methods of control discussed should be rendered more effective through diligent research efforts. Chemicals that will not contaminate the environment, but will provide better and more economical control of diseases and nematodes should be developed. Additional effort could provide pesticides with greater specificity, improved modes of action, and less persistence in soil and water. Methods of application must be improved, especially for nematocides and fungicides applied to the soil. Viricides need to be developed to control virus diseases.

To date, the breeding of crop plants for resistance to diseases and nematodes has been largely empirical. Additional research is needed on the nature of such resistance, emphasizing the genetic and biochemical systems of both the host and the pathogen so that resistant crop plants may be bred on a more scientific basis. Extensive exploration for additional resistant strains should be made, particularly in the areas of the world where our crops originated.

Research on the control of plant pathogens that contaminate the soil needs particular attention, since few are subject to control by either chemicals or breeding. The use of crop rotation, soil and water management, and other cultural practices can be made more effective by basic research to understand how the organisms survive in the soil and compete with other soil flora and fauna, and where they may be vulnerable to control by management practices.

Greater attention must be paid to integrated control measures for specific diseases. This type of control brings several methods to bear simultaneously on the problem. In the past we have tended to concentrate on only one type of control. For example, control of the rusts of grain crops has depended almost exclusively on breeding for resistance. This has had disastrous results from time to time when the resistance, frequently consisting of a single gene in the crop plant, has broken down. We need to have available many types of rust resistance, including safe, cheap chemicals and other methods that can be applied for rust control when necessary.

Although the potato blight epidemic in Ireland occurred more than 100 years ago, we still know very little about plant disease epidemics. We need extensive research programs where plant pathologists cooperate with climatologists, meteorologists, and ecologists to work out the basic principles of plant disease development and spread.

Finally, in these days of vastly increased airplane travel and with the supersonic air transport age almost upon us, we must be able to cope with plant diseases that may be introduced from other parts of the world. To prepare for such accidental introduction, we need to study plant pests potentially destructive to U.S. crops. This will require an isolated research facility where plant diseases and their vectors from all parts of the world can be investigated.

Allergens

Bees gathering pollen from flowers do not take all of it. About 1.7 million tons of this delicate dust enters our atmosphere. Allergenic pollens cause mild to severe distress to untold thousands of people. In addition, the cost of prevention and alleviation of allergies caused by pollen is tremendous. The prevention and therapeutics of allergen-induced disease are still more art than science.

It was indicated in appendix III that no research is underway designed specifically for the control of plant species that produce allergenic pollen. Of even more importance is that there is no complete catalog of allergenic pollen. Consequently, the distress caused by pollen cannot even be assessed properly.

Many of the weeds producing troublesome pollen occur naturally in uncultivated wastelands. The only cultural method of control would be repeated mowing or cultivation that would keep the ground bare. Neither method is desirable. Chemical control offers a very real possibility, however. Information on the chemical control of other weed species could be extended to weeds that produce allergenic pollen. Control practices that would significantly reduce pollen incidence in the atmosphere would have to be widespread because pollen is blown for long distances by wind. An additional approach would be to study the prevention of pollen formation.

Improved technology, widely applied, has the potential for significantly reducing the incidence of troublesome airborne pollen, thus alleviating the distress of afflicted persons.

Agricultural Chemicals

Senate Document 85 (*117*) provided an amendment to P.L. 88–573, the act making appropriations to the U.S. Department of Agriculture for fiscal year 1965. Senate Document 85 stated:

> The requested changes for the U.S. Department of Agriculture would provide an additional $29 million to accelerate work on pesticide residues, making a total 1965 request of $69 million for pesticide research, education, and regulation in the Department.

This action by the Congress was eloquent testimony to the interest of the people in problems posed by pesticide residues as possible contaminants of the environment.

Insecticides

The discussions in appendices I, II, and III point out the many complex problems associated with the use of pesticides. Even though progress is being made through research to ameliorate some of these problems, the problem of pesticide residues, both the hazard and the legal issues, continues to be one of major interest.

Toxicologists who have investigated the effects of pesticides on laboratory animals, and even on man, see no evidence that our food supply is not safe. Even though there is no proof that low-level residues in foods constitute a hazard to man, the mere presence of such residues, regardless of infinitesimal amounts, incurs apprehension in some people. In spite of the great benefit derived from pesticides, and the essential role they play in the production of the Nation's food supply, some people hesitate to accept any risks to man that might be involved in their use.

Wildlife conservationists object to the risks of widespread dissemination of pesticides in our environment.

The U.S. Department of Agriculture and the State agricultural experiment stations strive to obtain information needed to assess the risks of pesticides in the environment. Hazards are corrected within the limitations of available information.

Taking the long view, it is more realistic to place major effort on ways to deal with specific insect problems that completely avoid hazards to man and other forms of life. Any system of insect control that has adverse effects on a wide range of organisms will be regarded as objectionable, either because of economic losses from the adverse effects on nontarget organisms, or because of the esthetic value that the public places on such organisms even though they may not be of economic importance. If pesticides were to create hazards to the survival of a species of wildlife, this would be looked upon as a calamity by many. Excessive loss of honey bees is important from the standpoint of economics as well as the viewpoint of the apiarist.

Broad-spectrum insecticides, such as DDT, malathion, or carbaryl, will each control many kinds of destructive insects. Research to develop controls that are insect specific will be expensive, and their use will increase the cost of control procedures as well as reduce potential environmental contamination.

In view of the progress that has already been made, prospects look good for developing completely selective methods of controlling practically all of the major insect pests. The techniques include biological agents, specific insect attractants, insect-resistant crop varieties, self-destruction mechanisms such as sterile males, and chemical insecticides that act on selective physiological systems peculiar to the target insect.

The existing coordinated research program needs to be continued to develop better information on insect population trends, insecticides with higher biodegradability and lower persistence, better knowledge of the chemical behavior of insecticides in soil and water systems, better predictive techniques for forestalling insect invasions, better methods of insecticide application to minimize drift and to reduce rates, and physical attractants to aid in nonchemical control.

Fungicides

During the 1950's, estimates of losses in production potential owing to diseases of pasture and range plants varied from 3 to 9 percent. Comparable figures for fruit and nut crops, and for vegetables, are 2 to 38 percent and 2 to 23 percent, respectively. Many of these diseases are controlled by fungicides or bactericides. In some instances residues of the chemical are present on the crop. Although pollution from fungicides does not appear to be significant, trace amounts of tetrachloro nitrobenzene (TCNB) and dithiocarbamate fungicides have been detected in total diet studies conducted by the Food and Drug Administration. One of the best nonchemical means of disease control is breeding for resistance, as is evidenced by the large number of disease-resistant crop plants under production. The result of additional research in this area would be certain to result not only in reduced danger of pesticide pollution, but in substantial savings to the producer and ultimately to the consuming public.

Nematocides

Nematocides are widely used for control of nematode pests of crops, particularly crops of a high per acre value. The leading nematocides do produce residues that may be a potential hazard on more and more agricultural land. It is therefore essential to develop other methods of nematode control.

As with insects, breeding for resistance to nematodes can go far toward eliminating present and potential residues from use of nematocides. Here again it is the most economical form of nematode control. Nematode-resistant varieties of important field and truck crops have been developed, including stem nematode-resistant alfalfa, and nematode-resistant soybeans and sugar beets. Additional research is needed on breeding and development of methods of breeding for nematode resistance in all crops and in ornamentals. Additional research to assess the impact of nematodes, particularly on certain crops, also is needed to properly assess the magnitude of the problem.

Herbicides

Use of herbicides has increased rapidly over the past two decades because of their effective counteraction to the waste in resources and effort caused by weeds and brush. Weeds cause waste in productivity and efficiency of land use, losses in product quality, and reduced efficiency of water management. Weeds and brush can impair the health and efficiency of people and of livestock. They harbor insects and disease organisms that attack crops. Weeds and brush in water sources, and on ditch banks, highway, railroad, and utility rights-of-way, in fence rows, and on other areas serve as reservoirs for invasion of fields through movement of seeds and vegetative parts by wind, water, soils, and man and animals.

Weeds waste water, fertilizer, light, space, equipment, and labor. The waste and losses caused by weeds in crops ranged from 2 to 20 percent of the crop value for the period 1951–60. Farmers spend about $2½ billion annually to control weeds. Yet, during the period 1951–60, the estimated annual loss owing to reduced crop yields and quality caused by weeds ranged from 3 to 25 percent, depending on the crop.

The economic and social significance of efforts to reduce the losses and waste caused by weeds can be illustrated by the enormous scope of weed-control operations in this country each year. Cultural, mechanical, ecological, and other bio-environmental methods of weed control are used on about 365 million acres of intertilled and drill-seeded crops each year. In addition, nonchemical methods of weed control are used on most of the more than 1 billion acres of forage and grazing land.

Farmers supplement nonchemical methods of control with chemical methods. In 1966, herbicides were used on about 120 million acres of land. Each year herbicides are being applied to about 35 percent of the national cultivated crop acreage.

Herbicides have been used under soil and climatic conditions not previously explored, which resulted in most of the problems associated with the use of herbicides.

Far better information is urgently needed on the fate of herbicides in soils, plants, water, and air, including the cultural practices and climatic conditions that incur a modifying influence. The residual toxicity of herbicides on succeeding crops is in many instances unpredictable.

Effort to develop superior herbicides with better specificity and fewer adverse residual or side effects must go on apace. There is an urgent need for better herbicides to control water weeds without adverse effects on fish life, domestic use, or recreation potential of the water.

Many of the serious problems from use of herbicides stem from drift to nontarget areas. Concentrated effort is needed on engineering, chemical, and biological principles to develop better techniques to minimize drift. The physical nature of herbicide materials may be improved to abate drift.

Better information is needed to guide disposal of herbicide containers and unused herbicides.

There is a real need to develop more feasible weed control techniques that involve nonconventional chemicals. For example, a chemical that was specific in inhibiting pollen production only on ragweed or only on cheatgrass would be a tremendous boon. Selective, specific, nonpersistent, low-toxicity chemicals that stimulate or inhibit weed seed germination would have a revolutionary effect on the development of safe, effective methods of weed control.

Economic Intelligence and Research

There is an immediate need for periodic national, regional, and State surveys of waste problems. These economic surveys should include general and special surveys. The general surveys should be designated to yield comprehensive information on the kind, location, and seriousness of a broad range of waste problems. Special surveys should be designed to provide information on specific pollutants as radionuclides, chemical air pollutants, airborne materials, sediments, plant nutrients, inorganic salts and minerals, organic wastes, infectious agents and allergens, exotic organic chemicals, and thermal pollutants. These special surveys should be designed to provide information on economic effects, abatement costs, existing institutional control arrangements, etc.

Economic surveys would highlight critical problems requiring studies of greater depth. Case studies are needed to determine the socioeconomic relationships in selected problem areas. These studies would serve to trace the economic implications for selected problems, to specify feasible alternatives for solution, and to provide information for the determination of rational compromises between production efficiencies and quality of the environment.

There is a continuing need for research to facilitate changes in our institutional structures. There are serious problems of economic adjustments to meet changing standards in the entire area of environmental quality. Local ordinances and court actions have caused abrupt cessation of agricultural operations in some areas. The establishment of water and air control standards may influence the method of waste disposal. Substantial financial burdens could be imposed on agriculture.

Thus, there is an imperative need to generate information on the economic implications of decisions made, the alternative means of regulation, and the alternative adjustment possibilities for affected firms and industries. The research must be based on expanded knowledge of the control programs in existence and those that are emerging under Federal, State, and local regulatory authorities and financial arrangements. This information should be supplemented by information on the organization of firms and the structure of relevant industries and markets. It is probable that some types of regulation may influence patterns of interregional competition and the size of efficient firms within particular industries.

There is also an obvious need to improve analytical techniques to assess external economies and diseconomies, secondary economic effects, and the nonmonetary benefits and costs of waste disposal systems and pollution control programs. Procedures are needed for benefit-cost analysis in support of programs with multiple objectives and multilevel decisionmaking framework.

Analytical capabilities need to be improved for tracing the economic implications of waste disposal regulations in a systematic manner. One possibility is the development and testing of simulation models for use in analyzing a variety of waste problems.

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