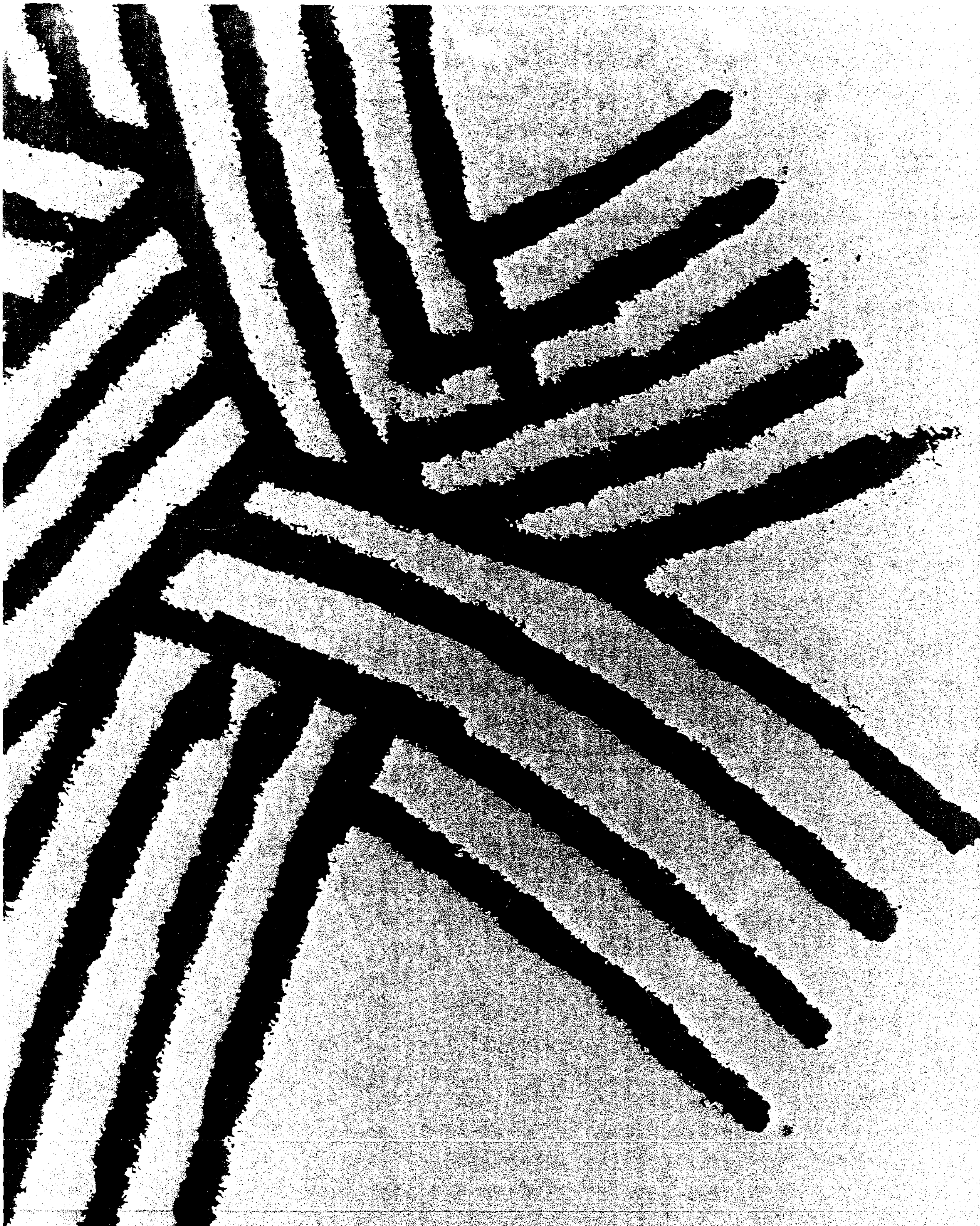

Environment and Colorado
A Handbook

Edited by Phillip O. Foss

A Publication of the Environmental Resources Center,
Colorado State University, Fort Collins

The Symbol:

Wavy lines converge and move outward again, symbolizing energy, air currents, water, earth, *environment*. The interweaving of the lines suggest the interaction and interdependency of all the elements in an environmental system.

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Foreword

As the environmental issues begin to emerge and proliferate, it is apparent that one or more of the current issues will touch, if not dramatically affect, each person's life. These emerging concerns will require man to ponder his life style and re-evaluate his philosophy toward his environment. Not only will the re-evaluation process cause struggles between various factions of the public but will tax the scientific community to remain true to their traditional commitments. Even the educated and well informed may succumb to the temptation to allow fear and emotion to predominate, or to limit man's horizons. Others, on the other hand, view the problems of today as the threshold of a new and exciting frontier — a challenge to be met by the limitless resources of man's intellect. In this process of re-evaluation and examination of alternatives in the quest to attain the appropriate balance, major policy decisions must be struck which will affect all of us. These major decisions undoubtedly will require redirections which are not properly left to special interest groups or vocal minorities, but must find their foundation in an understanding and acceptance of the people as a whole. This understanding and acceptance can only be achieved through knowledge. Considering the origin, tradition and historical mission of Colorado State University, no institution, and the individuals who constitute the institution, are better able to provide a helping hand in the conveyance of the knowledge necessary to accomplish the desired decisional process. This book was conceived and is dedicated to that purpose.

John E. Bush
Deputy Attorney General
State of Colorado

Editor's Note

Problems of the environment cut across all aspects of human life. Their long-range solutions draw upon the knowledge and innovative skills of all disciplines. Equally important, implementing those solutions depends upon citizen awareness and an understanding of the nature and complexity of the problems.

Because Colorado State University combines in one institution most of the social, physical, and biological disciplines directly involved with environmental quality control and improvement, the Environmental Resources Center felt it could render a significant public service by assembling a handbook of reference information prepared by members of the CSU faculty. With the encouragement of Mr. John Bush, then Vice-President for Student and University Relations, a steering committee was organized to design such a handbook. Full credit goes to the members of that committee for initial conception and final organization of this publication. They are: John R. Bagby, James R. Bennett, Wendell H. Bragonier, John E. Bush, Myron L. Corrin, Norman A. Evans, Edward C. Knop, Sumner M. Morrison, Kenneth Oakleaf, Everett V. Richardson, Richard T. Ward, and Ross M. Whaley.

The steering committee and authors sought to produce a reference work of value to the widest possible range of readers, including high school students, college and university students, professionals, businessmen, and other interested citizens. The authors, therefore, have avoided as much technical language as possible, although it is difficult to write about technical matters without using technical terms. We believe that the reader with a genuine interest in the environment will find the articles both interesting and useful in understanding the most pressing environmental problems currently confronting Colorado.

The views expressed in this handbook are those of the individual authors and do not necessarily reflect the views or policies of Colorado State University or of any other agency of the State of Colorado.

Phillip O. Foss
Editor

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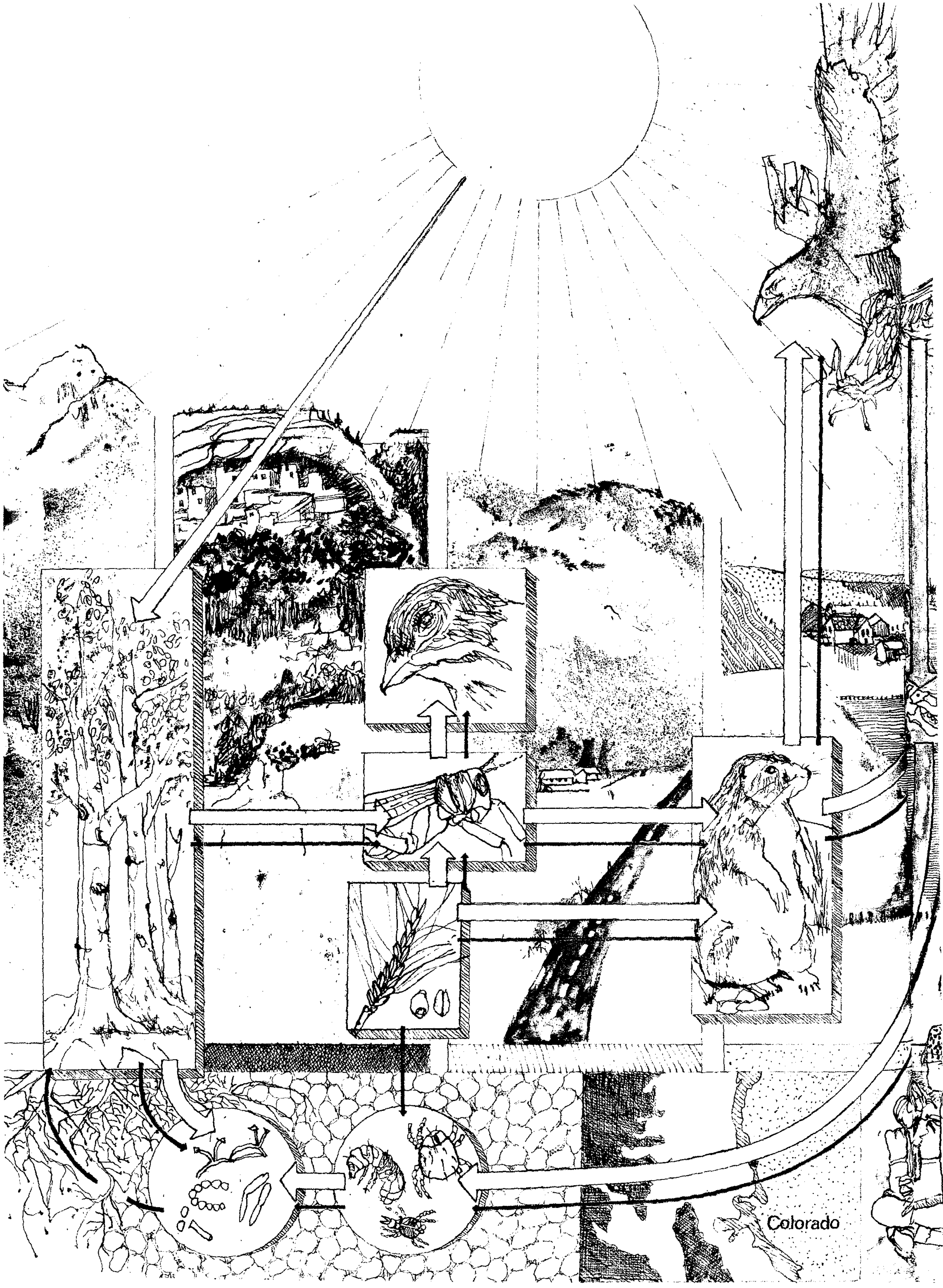
Colorado

Environment and Ecology

As energy from the sun flows through the ecosystem, so the influence of the hand of man moves through the Colorado environment. Man's influence is seen most in the urban areas, and decreasingly in the plains, which he farms, and the alpine regions, upon which he rarely treads. An understanding of man's interaction with the environment, and the interaction of the various elements in the ecosystem, are vital to anyone wishing to improve or protect environmental quality.

General Nature of Ecological Systems

Norman R. French
Professor of Biology, Colorado State University

Symbolic of modern man's awareness of his surroundings and his evolutionary ties to nature is the now common usage of the term *ecology*. This term has been around for several decades, but only in recent years has it come to mean so many things to so many different people. We find it is used by teachers and housewives, by politicians and student activists, by magazine writers and manufacturers of detergents. Unfortunately, it often means quite different things to different people, depending on their points of reference. Points of reference are quite variable in our society, because they depend upon our training and experience, our socio-economic status, and a variety of personal experiences and desires. It is the purpose of this chapter to explain the general nature of ecological systems, in an attempt to provide a basis for understanding the problems that are discussed in detail in the later chapters.

Ecology is the study of the interactions that determine the distribution and abundance of living organisms. These interactions occur between plants and animals and their nonliving environment. It should be emphasized that even among the experts who have some understanding of ecology, there is often disagreement as to the implications of human endeavors in terms of practical and long-term ecological problems. There are scientists who speak with authority in the field of ecology who maintain that if man continues on his present course of technological development and affluent living, he will in the course of time make his planet uninhabitable for his kind. Man is depicted as being in conflict with nature. Other scientists, who speak with equal authority, maintain that natural systems have evolved and developed under a series of insults and threats of various natural kinds, and that those which survived to the present day are those which are able to withstand such abuses. That is not to say that individuals or particular species will not suffer, but the community or ecosystem of which they are a part is resilient and will eventually return to some stable condition. We know that whole civilizations have developed, flourished, and foundered in the past. The Garden of Eden and the great cities of the Babylonian Empire all stand now in the midst of desert. We know little about the agents that brought about these situations. It would be well for us to examine critically the contributions of biotic and of sociological events to the demise of past civilizations.

General Nature of Ecological Systems

The original direction of the discipline of ecology, as implied by the origin of the term (it comes from the Greek word *oikos*, meaning household), was the study of plant or animal organisms in their natural setting. In other words, this was a science devoted to the understanding of how organisms live and function in the environments to which they are adapted. This was intended to be distinct from studies of anatomy and physiology, which were not necessarily related to an organism's activities in nature. This is not to imply that valuable ecological information has not been derived from laboratory studies, because important hypotheses have been formulated and clarified by investigations of organisms under the controlled conditions of the laboratory, where stresses or modifications of the environment to which the organism was exposed could be modified at the will of the investigator. Such scientific endeavor has come to be known as *physiological ecology*.

More recently, the science of ecology has turned attention toward the *interactions* among different organisms occupying the same environment. Investigations address questions about what the organism does in its natural setting — how it affects and in turn is affected by other organisms. This movement produced some of the classic studies of ecology, those involving the interactions between predators and their prey. It was observed that organisms interacting in such a direct manner might vary considerably in numbers, but nonetheless, over the long-term they functioned in a sort of dynamic equalibrium. This means that, although the numbers of both species were constantly changing, over a long period of time a pattern could be recognized which kept repeating itself. In this way the quality of the relationship between the two organisms was maintained, in spite of the seemingly great quantitative variability brought about by this relationship.

The next logical extension of these concepts was to consider the interactions of more than one group of organisms. The concept of *food* *webs* became established. In its simplest form, this means that one organism consumes another, and is in turn consumed itself by a third organism. If such a chain is multiplied and extended in two dimensions, it becomes apparent that the term *web* is an appropriate description.

It is a fundamental purpose of science to seek generalizations. This also applies to the science of ecology. It was soon recognized that the food web concept applied to a wide variety of natural communities, including both land dwelling and water dwelling organisms. Therefore, ecologists sought to arrange the patterns of consumer and consumed into levels or layers, much as our governmental, military, or other institutional organizations are structured in terms of rank, with the lowest at the bottom and the highest at the top. These ranks in ecological terms became known as *trophic levels*.

Just as the predator-prey relationships fluctuate and develop a pattern over a period of time, so the components of more complex food webs increase and decrease according to the way food resources are available to each level or as each level provides resources for another level. This is the *trophic dynamic* view of ecology. Introduction of this concept laid the foundations for the approach to understanding whole communities. A *community* is composed of a variety of plant and animal organisms, large and small, occurring together and therefore affected by the same physical environmental factors and sharing the same resources. Resources include all of those items which are essential to life, such as space, nutrients in the soil, or water from the atmosphere.

When a community of biological organisms exists together, sharing or competing for resources and in other ways each influencing the existence of the other either by utilization

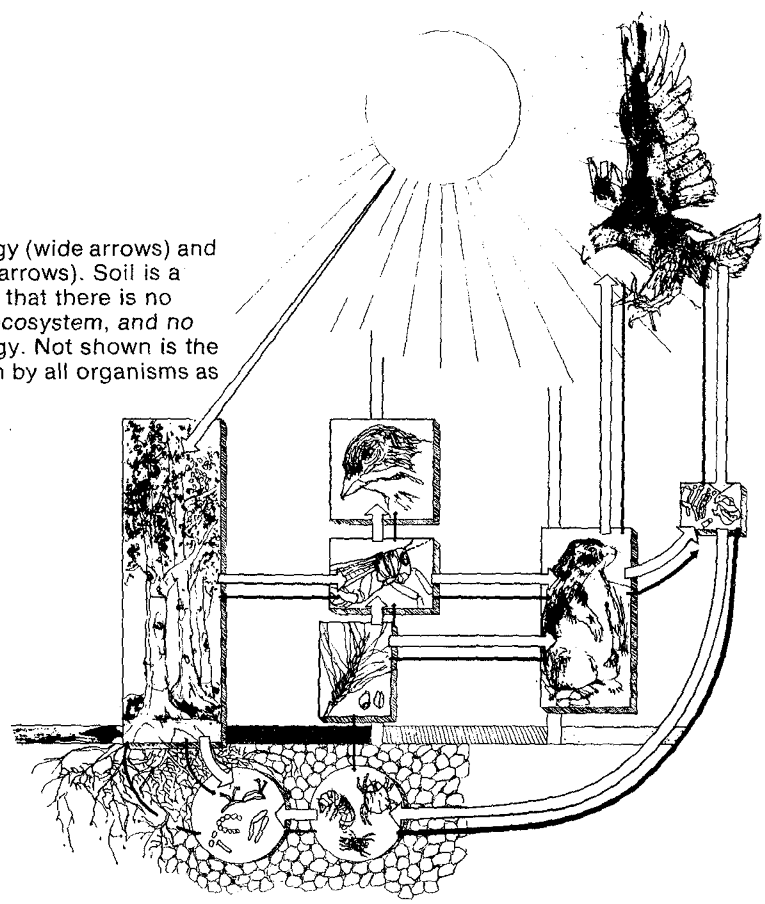

Diagram of the flow of energy (wide arrows) and cycling of nutrients (small arrows). Soil is a reservoir of nutrients. Note that there is no reservoir of energy in the ecosystem, and no cycling (only flow) of energy. Not shown is the energy lost from the system by all organisms as respiration or heat.

of materials or modification of the physical environment, we have a situation which fits the definition of a *system*. A system is a collection of objects ordered together in such a way that they function as a unit. Consideration of biological organisms in this sense led to the formulation of the term *ecosystem*, which appeared nearly 40 years ago. Considered in this light, a community of biological organisms is actually a series of elements connected together by various biochemical or biophysical interactions. It is the interactions which form the common thread to this union and link the elements into a single whole or totality, the ecosystem. *Systems ecology*, then, focuses attention on the interaction rather than on the organisms, populations, or the community. Thus, a pond or a forest or a grassland may form a natural ecosystem. Each has a characteristic physical environment, and the organisms existing therein form an ordered association of interacting units which act together in the cycling of nutrients through the system and the capture and transfer of energy from unit to unit throughout the system. It is the purpose of systems ecology to quantitatively describe and trace the flux of these materials through the elements of the system. The diagram shows a qualitative representation of the movement of energy and nutrients through a grassland ecosystem.

Major Ecosystems of Eastern Colorado

In this region the broad plains of the middle of the North American continent abruptly meet the mountains. This meeting forms a sort of hinge where the vegetation formations of the plains briefly intermingle, but quickly form a transition to the forested slopes of the foothills and the upper mountains. This sudden change provides a striking contrast between the flora and fauna of different zones, and contrasts are always instructive because they emphasize the differences in two adjacent regions.

The plains region has a continental climate, characterized by great temperature extremes throughout the year, a relatively small amount of precipitation, and a large proportion of bright sunny days. The cold winters permit accumulation of moisture in the form of snow, most of which comes with storms moving in from the west or northwest portion of the continent. In June there is a shift of the major storm tracks, and summer precipitation comes primarily in the form of thunderstorms which develop as the moist air masses penetrate northward from the Gulf of Mexico. Vegetation of this zone is low and comparatively sparse, being dominated by those types which can tolerate the uncertain moisture supply. Low growing grasses and drought resistant shrubs and forbs dominate. Cactus and yucca are common. Many of these, such as the grasses and the cactus, can take advantage of the infrequent summer storms. These plants are essentially quiescent during dry periods but can spring into life and produce new growth with each passing storm.

The important process of decomposition, which breaks down and releases the minerals bound in dead organic material thereby making them again available for assimilation and growth, is also limited by moisture. This process starts rapidly in the spring months, as soon as temperature is no longer limiting, but then pauses as the soil dries, accelerating again when summer thunderstorms temporarily provide optimum environment for this activity.

Production of organic material in the form of leaves, fruits, and seeds is comparatively limited, and this, in conjunction with the simplified structure of the vegetation, limits the variety of habitats available to consumer organisms. Therefore, birds and small mammals are also limited in number, and important insects are very cyclic in their abundance.

There is now only one large native grazing animal of importance on the plains — the pronghorn. Preying upon small consumers is a limited set of secondary consumers: Swainson hawks, golden eagles, and coyotes. For utilization by man this region is best suited to grazing his domestic animals. The vagaries of the climate and the marginal moisture preclude all but a very limited amount of cultivation.

The foothills and lower slopes of the mountains are similarly characterized by comparatively low moisture availability; most of the moisture comes in the spring and summer, while the fall and winter are relatively dry. Of course, with increasing elevation more of this falls as snow. Total annual precipitation increases about 2 inches per thousand feet of increase in elevation. Although temperatures in general decrease with increasing elevation, the minimum temperatures are not as extreme as might be expected in the foothills region. The reason for this is the lack of air stratification on the slopes of the mountains, a characteristic feature of the plains which results in some periods of intense cold. Ordinarily a diurnal temperature decrease of from 3 to 6 degrees per thousand feet elevation may be expected.

High winds are not an uncommon feature of this region. The westerly winds pushing over the top of the mountains lose their moisture, thereby preventing normal cooling because of the contribution of the latent heat of condensation. When these winds descend the eastern slope of the mountains, however, they gain in temperature as well as velocity as they move downward. Winds of 70 miles per hour are not uncommon. They have been known to reach velocities in excess of 100 miles an hour.

In the foothills zone there is a transition from open woodland of ponderosa pine with grass and forb understory to conifer forest dominated by Douglas fir and Englemann spruce as one moves toward higher elevations. Stands of aspen or lodgepole pine occur in disturbed areas. The fauna of this region is more diverse, following the increased diversity of vegetation forms. There are thrushes, warblers, and various finches occupying suitable habitats. Less frequent are pine grosbeaks and occasional flocks of crossbills. Small mammals such as chipmunks, golden mantle ground squirrels, and tree squirrels find suitable habitat here. A tuft-eared squirrel, endemic but not common, may be found in the mountain forests. Large mammals include the mule deer and the elk or wapiti. Much of the foothills region remains relatively open even during the winter months, being only periodically covered by snow. Therefore it is suitable for grazing by domestic animals all year around.

The high mountain regions are notable for their strong winds and short growing season. They form important watersheds which provide the necessary supply for the region with longer growing season but shorter supply of moisture on the plains below. Forests of spruce and subalpine fir give way in higher elevations to limber pine and finally to tundra. Characteristic birds of these upper regions are kinglets and Audubon warblers in the forested region, and pipits and rosy finches in the alpine country. Characteristic mammals are the marmot and pika. The only large herbivore is the bighorn sheep. Meadows and alpine tundra are utilized during the short summer season for grazing domestic sheep.

Human Ecological Systems

Is man an integral part of such ecosystems? In a pioneering society, man was clearly very close to the producers (plants), the consumers (animals), and the cycling systems of his environment. As his ability to cultivate and store cereal grains and to domesticate and keep animals improved, he was able to store certain foodstuffs and thereby gain a degree of independence from the vagaries of environmental conditions. Further, this ability to produce and store granted a degree of leisure never before known by an organism in the world. With leisure came the opportunities for specialization and cultural development, promoted to a high degree in modern society.

A family living in an urban setting will consume three tons of food in a year. Generally only a very small portion of this food comes from the farms surrounding the city in which they dwell. They have grain grown in the midwest, vegetables produced in the far south, fruits from tropical regions, and various consumables from all parts of the world. The danger of this comfortable way of life has only been recognized in recent years. We have reached the stage that Aldo Leopold had feared, namely the belief that food comes from the grocery and heat comes from the furnace.

The entire development of our agricultural technology has been aimed toward the production and distribution of food. This is a worthy endeavor and has been highly successful, but it ignores the fact that ecosystems are developed for *cycling* of nutrients and minerals. In the evolution of human societies we have attempted to substitute cycling of currency for cycling of nutrients. This has for the most part been successful, in spite of periodic crises involving the dollar or the pound. It has been a convenience for society but has not fulfilled the needs of the biological systems. The great amounts of waste produced by the concentrations of people in urban settings are either buried or burned, or treated and poured into other ecological systems different from those in which they originated.

Most of us are far removed from the basic activity of production of consumable energy for the good of our group. We have become so efficient that this is accomplished by only about 5 percent of our population. The rest of us sell our labor and receive for consumption an amount of money or some other convertible standard of value. This gives rise to another set of interactions, also with characteristics of a system, an economic system. In fact, we have given much more critical concern to the functioning and well-being of our economic system than we have to our role in the natural system. The following chapters will provide greater insight into some specific problems, and suggest alternatives that hopefully may lead to solutions.

Acknowledgment

This paper reports on work supported in part by National Science Foundation Grant GB-31862X2 to the Grassland Biome, U. S. International Biological Program, for "Analysis of Structure, Function, and Utilization of Grassland Ecosystems."

Regional Ecological Systems of Colorado

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Colorado is not only a Rocky Mountain state covered by a mantle of rich evergreen forest and alpine tundra, but it also includes within its borders extensive areas of plains grassland, savanna woodland, shrubland, and even desert. Each of these areas makes its own unique contribution to the harmony and counterpoint so characteristic of the mix of Colorado landscapes. The legendary beauty of these landscapes results from the great diversity and complexity of the environmental and biotic factors which control them. It is the purpose of this chapter to describe and interpret these landscapes so as to offer basic information which may assist in decisions relating to the current environmental crisis within the state. First, a generalized overview of each of several important environmental factors is presented, and later the state is divided into four more or less natural regions for further treatment of their unique characteristics.

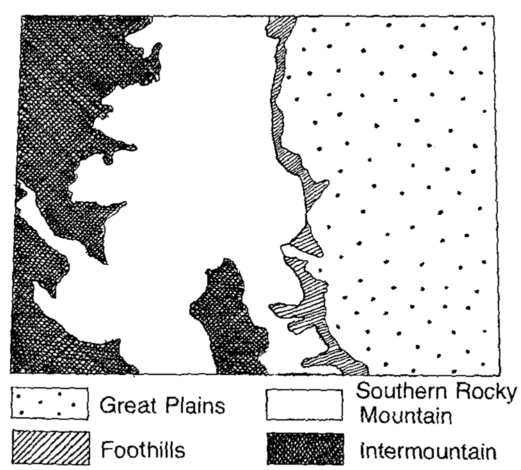
An Overview

For hundreds of millions of years the area now called Colorado underwent a series of mountain building and erosional cycles which eventually led to the formation of extensive beds of stratified sedimentary rock. About 90 million years ago, these horizontal beds were pushed upward from below by new mountain building processes and some of the sedimentary rocks were lifted to very high elevations. At that time, a cross section of the state would have resembled a sidewalk, pushed upward and badly broken by some irresistible pressure from below.

As the new mountains arose, new streams swept away the comparatively soft sedimentary rock and deposited the debris around the flanks of the mountains to form broad plains. In Colorado and adjacent states, these new mountains are the Southern Rockies, and they form a high central core running from north to south through the state. The depositional areas to the east of these mountains are the Great Plains, while depositional areas to the west became the basins and the plateaus of the Intermountain area.

Thus, Colorado is naturally divided into three topographic regions: the Great Plains, the Southern Rocky Mountains, and the Intermountain Basin and Plateau Region. To these natural units may be added a convenient, and hopefully useful, fourth: the Foothills Region of the eastern slopes. The foothills are a group of low tilted hogbacks running parallel to the eastern base of the mountains. They were formed by the uneven weathering of alternating bands of comparatively soft and hard sedimentary rock tipped upward on the west by the rise of the Rocky Mountains. This region is in reality transitional between the plains and mountains, but its recognition is justified by the very large human population that has settled within and near this thin strip, and by the unique problems which this population has created. Many of the major cities of Colorado — Fort Collins, Denver, Colorado Springs, Pueblo, and Trinidad — are located along this narrow corridor.

One minor and three major air masses dominate the climate in Colorado. A polar continental air mass (cold and dry) originates in northwestern Canada and flows southward and southeastward into the Great Plains, while a tropical gulf air mass (warm and wet) originates in the Gulf of Mexico and flows northward into the plains. When these air masses meet, the warm, wet air from the Gulf is forced to override the colder, drier, and denser air from Canada. As it rises, the warm air mass loses pressure and heat, and precipitation ensues. The third major air mass originates in the north Pacific (cool and wet) and flows eastward across Oregon and California and eventually into western Colorado. As this air mass continues across Colorado, it is forced to rise over the Southern Rocky Mountains and its moisture is deposited on the western slopes of these mountains.



Once across the mountains, the descending air tends to have a drying effect upon the plains. A minor air mass originates in the deserts of Arizona and New Mexico and, as it is forced to rise over the San Juan Mountains, delivers precipitation to the southwestern part of the state. The jet stream, a very high and very fast moving river of air, flows from west to east and may significantly modify the weather patterns described above. The jet stream tends to produce a storm in its northern wake and clear weather to its south. The weather patterns within the four regions are further discussed below.

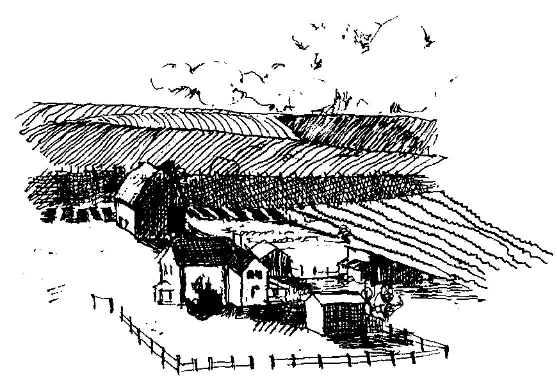
The natural vegetation on a site is the product of a particular set of environmental parameters and local history, and is thus a reliable indicator of the past and present events. The long life spans of most native perennial plants permit them to "average out" a long series of events; they are ever-present and sensitive to environmental conditions. Thus, any effort to interpret, manipulate, or manage the landscape must give special consideration to natural vegetation.

While the four regions considered in this chapter are differentiated primarily on geologic and topographic considerations, natural vegetation correlates well with them. The Great Plains Region is characterized by low precipitation and frequent droughts and is dominated by short grassland; the Foothills Region is dominated by alternating bands of thin and deep soils and supports alternating bands of shrubland and grassland, respectively; the Southern Rocky Mountain Region, with its comparatively abundant and reliable precipitation and cool temperatures, supports evergreen forests, with shrublands at the mountain bases and alpine tundra at the summits; the Intermountain Region has severe and prolonged droughts and is dominated by a variety of desert shrublands and woodlands.

The Great Plains Region

The Great Plains occupies the eastern two-fifths of Colorado at elevations from 3,500 to 6,000 ft. Most of the land is relatively level, but some is gently undulating with slopes up to 20 percent. The soils have been derived from outwash materials carried eastward from the mountains. These materials have often been reworked by wind in such a manner that the fine materials have been blown away to form loess deposits while sands have remained behind as "lag." Thus, soils of the plains may be separated into "hardlands" and "sandylands." This distinction is important since, in arid climates, coarse textured soils tend to permit more vegetative growth than expected for the region because these soils infiltrate more water from high intensity storms, and also lose less water to surface evaporation, than do fine textured soils.

The Colorado Great Plains has significant climatic differences between its various subregions. Precipitation is about 5 inches per year greater in the east than in the west (ca 13-18 in.) and 2 to 3 inches greater in the north than in the south. Summer temperatures are about 5 degrees warmer in the south than in the north, and this same pattern is followed in length of the growing season, which is about 150 days in the north and 170 days in the south. Well over one-half of the annual precipitation falls during May, June, and early July. Some moisture is received in convectional thunderstorms in midsummer. However, relative humidities are almost always very low in the plains and plants are usually under water stress.



The vegetation of the hardlands may be characterized as shortgrass plains. The dominant species are blue grama, buffalo grass, western wheatgrass, and two species of dryland sedge. The northern hardlands, i.e., north of the Platte-Arkansas divide, have needle-and-thread on soils with a significant sand fraction. Buffalo grass loses its importance near the foothills and is replaced by western wheatgrass and green needle grass. The southern hardlands, i.e., south of the Platte-Arkansas divide, are dominated by blue grama, galleta, buffalo grass, and cane cactus. Galleta and cane cactus are species from the desert plains to the south and give the area a distinctly arid aspect. Soils with a moderate sand fraction support grasslands dominated by a mixture of short and tall grasses: blue grama, sand bluestem, little bluestem, buffalo grass, and sand dropseed.

Sandylands throughout the region support low shrublands of sandsage which share dominance with many grass species: sand bluestem, sand dropseed, and little bluestem. The northern sandylands have among their dominance needle-and-thread and sand reedgrass, but these species are unimportant in the southern sandylands. This important difference in species composition may be due to the relative stability of the sandylands in the south as compared to those in the north.

Large areas of mesas and rough broken land occur south of the Arkansas River. These landscapes consist of steeply rolling to rough broken land, flat-topped mesas, steep escarpments, and deep canyons. The soils are largely residual from basalt, sandstones, and shales. They are shallow and rock outcrops are common. The vegetation consists of open pinyon-juniper woodlands and savannas, juniper shrublands, and oak thickets. All of the above have understories of blue grama and galleta grass.

Swales within the region tend, because they are usually alkaline or saline, to support western wheatgrass, salt grass, and alkali sacaton. Arroyos and streams which have a permanent underground water supply support sandbar willow, box elder, and plains cottonwood. Cottonwood trees are dependent upon stream action for their establishment, and their distributional pattern within a bottom land offers a record of its recent flood history.

Land use within the Great Plains is highly dependent upon the landscape types described above. Relatively flat areas with medium textured soils are almost always farmed. Heavy clays, sandy soils, and rough lands are usually relegated to grazing. Cultivated areas within the Great Plains are subject to severe wind erosion, especially during winter months and periods of extended drought. Grazing lands may suffer water erosion if abused, but wind damage is usually slight.

The sedimentary beds of geological material underlying the Great Plains contain important ore bodies of coal, oil, natural gas, and limestone. The drastic disturbance of the Great Plains landscape by mining is usually costly and difficult to repair. Severe summer drought, alkaline and saline soils, and high winds are major problems. The low stature of the vegetation renders almost any disturbance highly conspicuous.

The Foothills Region

As the Rocky Mountains arose through ancient sedimentary beds they carried some of these materials to high elevations. Along the eastern edge of the uplift however, the beds were merely bent upward. Subsequent erosion has largely freed the mountains of their sedimentary burden but along their eastern border the upturned beds are now exposed; the oldest beds are to the west and the youngest to the east. All run parallel to the mountain front. These stratified beds are of unequal hardness and differential erosion has caused the harder rock to form sharp ridges, while the softer rocks have been eroded into valleys. This set of parallel hogbacks and valleys forms a narrow corridor some 10 to 15 miles wide which runs directly south from Fort Collins to Trinidad. This corridor, which has a general elevation of 5,500 to 7,700 feet, is the Foothills Region.

This region consists of three unequal parts: a northern unit, from Douglas County northward; the Black Forest unit, along the Platte-Arkansas divide; and a southern unit, from north of Colorado Springs to the New Mexico border. In the northern unit, the back slopes of the hogbacks are east-facing, are tilted 15

to 40 degrees, have very thin soils, and support shrubland. The undisputed dominant north of Denver is mountain mahogany, but to the south oakbrush assumes dominance. Mixed with these dominant shrubs are skunkbush, chokecherry, serviceberry, rose, and bitterbush. Occasionally ponderosa pine forms open and poorly developed stands on rocky hogbacks. When it does, the principal shrubs remain as understory. Of special interest is the occurrence of a unique and isolated but well developed pinyon-juniper woodland at Owl Canyon, 16 miles north of Fort Collins. This stand is far outside the normal range of these woodlands. The valleys in this unit are often sharply defined by their deep soils and grasslands. The principal species on these deep soils are western wheatgrass, blue grama, and needle-and-thread. Along the broken lower slopes of the hogbacks big bluestem, little bluestem, Indian grass, and blue grama share importance with the shrubs. The principal land use of this unit is grazing, but some of the broad valleys are farmed, both dry and under irrigation.

The Black Forest unit has the highest elevations (6,700 - 7,700 ft.), the highest annual precipitation (20 in.) and the shortest growing season in the Foothills Region. These characteristics permit the extension of well developed ponderosa pine forests and savannas along a high ridge which here forms the divide between the Platte and Arkansas Rivers. These pinelands, however, retain foothill shrub species as an understory. The pines are mostly restricted to elevations above 6,700 feet. A particularly interesting feature of this area is the occurrence of many stands of "true prairie," the vegetation type characteristic of the sub-humid grasslands of Illinois and Iowa. The presence of these plant communities in central Colorado suggests a relic of post-glacial time when great mammals roamed the Colorado plains. The principal use of this area is grazing and some forestry. Due to the steep slopes, both water and wind erosion are active in the unit, and gully and rill erosion may be severe when the cover is removed. This unit is currently being developed for low density housing.

The southern unit of the Foothills Region extends from north of Colorado Springs to the state line. It is an area of rough broken land with elevations of 5,500 to 6,500 feet and an annual precipitation of about 15 inches. The summers are warm and the growing season is long, so that the effective precipitation is very low. The soil is derived from a heterogeneous mixture of sedimentary rock, but in general it is medium textured and shallow. The vegetation on ridges is mostly open pinyon-juniper woodland, oakbrush, and mountain mahogany with blue grama and galleta grasses forming the ground cover. Cane cactus adds a distinct desert appearance to these woodlands. The flatlands are dominated by southern grassland, including galleta, blue grama, and ring muhley. Alkali and saline soils are common in poorly drained sites and support western wheatgrass, alkali sacaton, and greasewood.

The land is used mostly for grazing but some areas of favorable topography are used for dryland farming. Severe sheet and gully erosion may be active on overgrazed areas and wind erosion may cause damage to unprotected soils.

Many special problems are associated with the Foothills Region because of its proximity to very high human populations. In its natural state, and even under systems of low intensity use such as farming and recreation, the region has a high level of stability. But under the intensive use of the last decade signs of severe deterioration have become evident. The deterioration processes may be grouped in an increasing order of severity: recreation, construction, and mining. Recreation is usually only a problem in so far as roads are built to provide access to recreation sites. Construction (both housing and commercial) is a more serious problem because it usually involves an increase in population, increased roads to service the installations, and problems associated with the difficulties inherent in building in the rough, stony, and arid terrain. The most severe (though usually local) problem with this region is the mining of the high quality limestones available in several formations of the foothills. The past reclamation records of these mining operations have been discouraging.

The Southern Rocky Mountain Region

This region is formed by a high elevation mountain mass which occupies the central two-fifths of the state. There are 17 mountain ranges and groups within the mass and six great intermountain valleys whose origins and histories are closely linked to them. Fifty-three peaks in Colorado stand more than 14,000 feet, and over 300 peaks exceed 13,000 feet. The mountains are composed of many rock types, but their cores are all granites or metamorphized granites. Sedimentary rock of Paleozoic and Mesozoic age was uplifted in the mountain-building process, but it has been largely eroded away. However, isolated sedimentary rock is still widespread but local throughout the region. Tertiary intrusions, batholiths, sills, and dikes are very common and it is these that have provided the great mineralization which has supplied the base for Colorado's legendary mining industry. Lava flows and other volcanic activities are common on the western side of the mountains, especially in the southwest where the San Juan Mountains dominate the landscape.

Because of the previously discussed flow of the great air masses over Colorado, the western slopes of the mountains are comparatively moist, while the eastern slopes, mesas, valleys, and basins are comparatively dry. It is the high snowfall on the western slopes that permits development of the ski country. The amount and effectiveness of the precipitation is strongly influenced by elevation; high elevations usually receive more precipitation than low elevations, and lower temperatures at high elevations tend to make the available moisture more effective for plant growth. This general pattern is highly modified by aspect, slope, topographic position, and soil texture. Thus, the vegetation of the region can be visualized as responding to vertically oriented environmental gradients. For convenience of discussion, the following model is presented mostly in terms of discrete vegetational units, but in reality these units grade imperceptibly one into the other to form a continuously varying landscape.

Montane (6,000 - 8,500 ft.)

The lowest elevations of this unit are usually occupied by oakbrush and mountain mahogany. The general aspect of these communities is that of closed to open woodlands of deciduous shrubs and small trees. The dominant species are Gambel oak, chokecherry, mountain mahogany, and serviceberry. The oakbrush community is best developed in southern and southwestern Colorado, where it mixes freely with pinyon-juniper, sagebrush, and ponderosa pine. Oak is absent from the northern Front Range mountains.

Ponderosa pine is the characteristic tree of the Montane. At its lowest elevations, immediately above the shrub communities, ponderosa pine forms woodlands of scattered small trees which are usually intermixed with shrublands and woodlands of pinyon-juniper, oakbrush, mountain mahogany, and grasslands. With increasing elevations, ponderosa pine increases in size and achieves heights well over 75 feet. The aspect of the pine savannas is that of individual or small groups of large open grown ponderosa pine in a matrix of shrubland and grassland. At still higher elevations, the density of the trees increases and extensive ponderosa pine forests develop. Douglas fir, another large tree, may form a secondary component of the forest. Douglas fir is often the dominant species on north-facing slopes, a secondary species on east to west slopes, and is usually absent on southern exposures. Thus, an east-west valley in the Montane will usually support contrasting forests on its two sides; Douglas fir will dominate north-facing slopes while ponderosa pine will dominate south-facing slopes. At the highest elevations within the Montane, Engelmann spruce and even subalpine fir appear with ponderosa pine and Douglas fir. Within the Montane, forests and woodlands tend to be restricted to stony outcrops and areas of thin soil. Grassy parks dominated by mountain muhley, Idaho fescue, Arizona fescue, and little bluestem occupy the deeper soils.

Subalpine (8,500 - 12,000 ft.)

Englemann spruce, subalpine fir, aspen, lodgepole pine, bristlecone pine, and limber pine are the principal trees of this unit. They occur together in an array of combinations resulting from the responses of individual species to a number of important biotic and environmental gradients. First subalpine fir and then Engelmann spruce are most capable of forming stable stands, since they are the species most successful in establishing new generations of their own kind under the influence of their own shade. Thus, once spruce and fir stands are established, they tend to hold a site until destroyed by some external force such as fire or insects. Aspen and lodgepole pine are usually the first tree species to invade burned, lumbered, or insect damaged areas. These pioneer species, however, are usually unable to reproduce under their own canopies and therefore they are succeeded by other species, in this case, subalpine fir and Engelmann spruce. Thus, in the Subalpine, fir and spruce are considered climax species while aspen, lodgepole pine, bristlecone pine, and limber pine are successional species. On sites too dry to support spruce and fir, however, aspen and lodgepole pine are capable of forming stable stands. In general, aspen appears to be favored on deep, fine textured soils and in slight depressions, while lodgepole pine is favored on shallow, coarse textured, and stony soils.

The vertical and horizontal distributions of many species within the Subalpine are not uniform. Vertically, aspen, lodgepole pine, subalpine fir, and Engelmann spruce form a generalized relative importance series from low to high elevations. Horizontally, aspen stands are best developed in the central, and especially the southwestern mountains, while in the Front Range and Park Range systems, aspen usually forms small and often stunted stands but is still a major component of the forest. Lodgepole pine does not occur in the San Juan Mountains, is marginal in the central part of the state, and attains its best expressions in the Front Range and Park Range systems.

Throughout the Montane and Subalpine units, big sagebrush dominates alluvial valley fill and some hillsides that are composed of finely fragmented parent material. North Park is a conspicuous example of high altitude valley fill dominated by big sagebrush.

Grassy parks, dominated by Letterman needlegrass, spike trisetum, and Thurber's fescue occur on deep soils throughout the Subalpine. South Park may serve as an example.

Tall willow shrublands with an understory of grass-like plants, or "carrs," often develop in meadows where active alluvium is present and where the water table is near or above the soil surface for a part of the year. Carrs appear to depend on frequent flooding by fast moving mountain streams for their survival. Carrs are dominated by several (at least 8 to 10) species of shrubby willow which may attain heights of 8 to 12 feet, and have sedges and Canadian bluejoint as dominant understory species. This type dominates the drainage systems of mountain landscapes from 7,000 to 11,000 feet. Willow carrs are the capillaries of the mountain water transport system since they are the first to collect and channel melt water. It is essential that they remain as undisturbed as possible if we are to continue utilizing their services in watershed management.

At the highest elevations in this unit, Subalpine forests gradually give way to Alpine Tundra. Tree densities decrease and the trees themselves become dwarfed and distorted, forming a krummholz. Engelmann spruce is the principal tree species here but bristlecone pine and limber pine may form extensive stands on dry and windswept ridges.

Alpine Tundra (11,000 - 12,5000 ft.)

Alpine Tundra occurs above the upper limits of tree growth. The climate is cold, the growing season is short, and frost can be expected at any time of the year. The vegetation has a high percentage of grasses and sedges and looks similar to a short grassland. Woody plants, including several species of willow, are

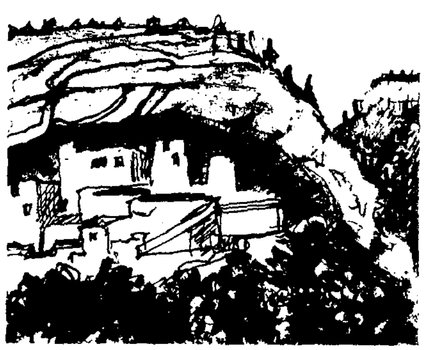
common although they grow as prostrate forms. Virtually all species are long lived perennials. Community patterns within the tundra appear to respond primarily to three interrelated environmental factors: snow duration in the spring, soil stability, and soil moisture. In areas where snow lies late into the summer, an alpine avens-sibbaldia-gravel community occupies intermediate sites and a hairgrass meadow holds the most stable sites. Where snow disappears early, or where it fails to accumulate during the winter months, the stability gradient, from least to most, is: a nailwort cushion community, a sedge-dwarf clover-turf community, and a kobresia-turf community. Sites of late snow duration usually have abundant moisture, except perhaps in late summer, but snow free or early snow melt sites are often subjected to early summer drought. Thus, the alpine avens-sibbaldia-gravel, mountain dryad-shrubmat, and hairgrass meadow communities form a mesic to wet mesic moisture series. Similarly, the nailwort cushion, sedge-dwarf clover-turf, and kobresia-turf communities form a dry to dry mesic series. Drainage ways within the tundra, usually occupied by small shrub (willow) meadows, direct water to the willow carrs below and are important to the watershed system.

The Southern Rocky Mountain Region is largely federal land, and its primary uses are summer grazing, timber, recreation, mineral extraction, and watershed. Some private lands are farmed, but this activity is restricted to a few mountain valleys. Because of the steep topography, geologic erosion, which often takes the forms of landslides, rock falls, mud slides, and rock flows, is common, and locally may be extremely hazardous to man and his property. Accelerated erosion is generally slight on well vegetated sites, but once the vegetation has been disturbed, sheet and gully erosion usually becomes severe. This is particularly true on coarse granite derived soils such as are found in the Pike's Peak area. The recent development of many mountain homes and their accompanying road systems have caused serious erosional problems. The reestablishment of vegetation in this region is severely hindered by the short growing season, low winter temperatures, soil heaving due to frost action in the fall and spring, and to the absence of plant varieties which are not only acceptable in reclamation work but can also tolerate the extreme mountain environment. Drastically disturbed land associated with the mining industry creates many severe special problems. Mine wastes, especially tailings piles, may provide substrates totally unsuited for plant growth. These areas are not only unsightly in the extreme, but may contribute air and water pollutants. While reclamation problems on these areas are difficult, they can be conquered by a diligent and sustained application of the proper technology.

The Intermountain Region

The western one-fifth of Colorado exists within this region, which is outlined on its east by a highly sinuous line running from Routt to La Plata Counties. The region draws its name from the large basin between the Sierra Nevada Mountains in California and the Rocky Mountains. This basin is composed of stratified Cretaceous and Tertiary rock through which numerous mountain peaks protrude. While it is a structural basin, it stands about 7,000 feet in Colorado and forms the eastern edge of the Colorado Plateau. Almost all of the Intermountain Region of Colorado is on the Colorado Plateau, although the extreme northwestern corner of the state, that drained by the Yampa River, is a part of the Wyoming Basin. The Colorado Plateau was formed from sediments deposited during the long period when Cretaceous seas and Tertiary fresh water lakes dominated the area. During the Pliocene, some 12 million years ago, a major uplift occurred which caused much of the Tertiary materials to be stripped from the area by streams superimposed within their former drainage channels. The continuously arid climate of the Intermountain Region has encouraged the development of highly angular topography as river valleys have been deeply cut by flash floods and widened by retreating wall escarpments. In Colorado, south of the Colorado River, virtually all of the Tertiary, and in places the Cretaceous, sediments have been stripped from the surface. North of the Colorado River, the Tertiary Wasatch, Green River, and Bridger formations remain. The deep canyons, high vertical escarpments of valley walls, broad river valleys, and stratified beds of colorful sedimentary rock so common and characteristic of this region present some of the most spectacular scenery to be found.

The San Luis Valley in south central Colorado is here considered a disjunct of the Intermountain Region. It is a structural valley between the Sangre De Cristo and San Juan Mountains. This flat basin is filled with alluvium from these mountains; the drainage in the northern section of the valley is internal, while the southern section is drained by the sluggish Rio Grande River. Sand dunes have formed along the eastern edge of this valley as rising particulate-laden air is forced to drop its heavier particles as it ascends over the Sangre De Cristo mountains.



The climate of the region is dominated by the flow of Pacific air over the high Sierra Nevada and Cascade Mountains, where it deposits its moisture on their western slopes. It later descends into the Intermountain areas as a warming and drying mass. The outstanding characteristic of the climate in the Intermountain Region is aridity. Many stations within the area have annual precipitation values lower than 10 inches; examples from Colorado are Grand Junction (8.8 in.) and Montrose (9.5 in.). As the Pacific air continues its journey eastward and lifts over the Southern Rocky Mountains, it again becomes a moisture producing body and deposits rain and snow on western slopes. Stations with relatively higher elevations within the Intermountain Region, such as Durango, Meeker, and Lay, have annual precipitation values in excess of 15 inches. As the air mass continues to rise on its eastern journey, it contributes the heavy snow fall associated with the subalpine and tundra areas of the Rocky Mountains. It is these snow-laden western slopes which provide the base for the important ski industry in Colorado. The San Luis Valley is caught between two high mountain ranges and is the driest portion of the state, with annual precipitation values of about 7 inches.

The minor air mass which originates in northern Arizona and flows northeastward over the San Juans creates the same general pattern as the Pacific air mass: the Four-Corners area at 5,000 feet has a precipitation of 8 inches; Mancos at 7,000 feet has 18 inches; while Wolf Creek Pass, at 10,850 feet, has 30 inches.

The vegetational patterns within the Intermountain Region are dependent upon the distribution of an array of separate but often closely interrelated environmental factors: effective precipitation, soil moisture, salinity, elevation, exposure, soil texture and stoniness, and soil stability. While is is not possible to describe all of the vegetational complexities found within the region, the scheme presented below will hopefully display the principal behavior patterns of the dominant and conspicuous woody plants against these environmental patterns. The scheme starts at the point where the Colorado River crosses the state line into Utah and proceeds upstream and upslope. Many of the desert species and communities characteristic of the Intermountain Region penetrate deep into the other three regions of the state, and some species and communities from the other regions are found here.

Drainageways with permanent water, either above or below ground, which are not saline, support riparian woodlands. These are deciduous wooded areas dominated by cottonwood and box elder in the tree layer, sand bar willow, chokecherry, rose, and clematis as the principal shrubs, and a great variety of weedy herbaceous species in the ground layer. In wide, permanent river bottoms, these species form broad bands that may cover most of the flood plains, but upstream they are often restricted to narrow bands of a few feet on each side of the stream. As the headwaters of streams approach uplands, these tree species disappear and the stream valley may vanish into shrubby breaks dominated by serviceberry, chokecherry, and rose. If the streams persist to Montane and Subalpine forest, narrow-leafed cottonwood becomes dominant. Here the flood plain may disappear into a narrow mountain valley or may broaden to support willow carr.

Shadscale usually dominates flood plains with somewhat saline soil. It tolerates saline soils better than the sagebrush but not nearly as well as does greasewood and, on a given site, mixes with these species in proportions depending upon soil salinity. The aspect of this type is that of a dull silvery gray, thorny, open shrubland, two to five feet in height with an understory of galleta grass and salt grass. The shrubs are usually about two to five feet apart but, as salinity increases, these distances may increase to 6 to 10 feet. This type is widespread in the flat, lower valleys of the western three-fifths of Colorado. It occurs on well-drained soils that are not at all or only slightly saline, and at elevations below 7,000 feet. The type is well represented in the San Luis Valley.

Greasewood shrublands occur throughout the state but particularly along flat lowlands and drainageways below 7,000 feet within the Intermountain Region. These shrublands require that the water table be near the surface, that the soils be clay, and that they have a high saline or alkaline content. Greasewood is a dull-green shrub with short succulent leaves which attains heights up to 8 feet, as in the San Luis Valley, but in the Intermountain Region it is usually less than 5 feet tall and forms open stands where the plants are 3 to 10 feet apart. It is usually the overwhelming dominant, although species of sagebrush, shadscale, rabbitbrush, and saltbush often occur as minor members of the community. Understory grasses are often salt grass, and alkali sacaton. This vegetation type dominates virtually all of the nearly level to gently rolling valley fill in the San Luis Valley where it forms tall, dense stands which are difficult to penetrate on foot.

Along the lower Colorado and Gunnison Rivers, at elevations of 4,500 to 6,500 feet, a clayland area has developed from the Mancos formation. The heavy clays of these parent materials are so impermeable to water that they are incapable of supporting more than very sparse, scattered individual plants of salt sage, saltbush, and shadscale. While these clay hills are the most conspicuous, whenever clay beds of the Mancos and a few other formations surface in areas where the precipitation is less than 10 inches, sterile claylands may develop.

Thousands of acres in western Colorado support big sagebrush. This type is best developed below 7,000 feet but extends up to 10,000 feet in warm mountain valleys and on plateaus far into the Southern Rocky Mountain and Foothills Regions. It is able to withstand a wide range of temperatures, but rainfall is usually between 7 and 15 inches. It is best formed on unconsolidated alluvium that is neither saline nor alkaline and is well drained. This type is particularly well adapted to alluvial fans. Its general aspect is that of an open, silvery-grayish shrubland where plants attain heights of 3 to 6 feet. While big sagebrush is clearly dominant, it mixes with shadscale and to a lesser extent with greasewood. Fringed sage and rabbitbrush are common associates and there is usually an understory of western wheatgrass, slender wheatgrass, and Indian ricegrass. Fire and grazing play important roles in the sagebrush types; fire favors grass over sagebrush, while the opposite is true for grazing.

Very steep hillsides with unstable soil often support communities with fringed sage and shadscale. On these steep slopes, the cover is usually less than 20 percent, and there are scattered individuals of many of the species found within the desert shrub communities.

North of the Colorado River, in soils derived from the comparatively soft Tertiary Bridger, Wasatch, and Green River formations, shrublands of serviceberry, snowberry, mountain mahogany, sumac, chokecherry, and rose occur in protected gullys at the headwaters of streams and on north-facing slopes. Serviceberry is often the clear dominant on northern slopes. These shrublands seldom attain heights greater than 6 feet and form dense to fairly open communities.

The small area in northwestern Colorado that is within the Wyoming Basin, parts of Moffat and Routt Counties, is comprised of, from west to east: rolling plains on poorly consolidated Tertiary materials dominated by big sagebrush and blacksage; and steep broken Cretaceous hills dominated, from 6,500 feet, by serviceberry, chokecherry, Gambel oak, aspen, and spruce.

Pinyon-juniper shrublands and woodlands dominate large areas of southern, south central, and especially southwestern Colorado. The type reaches its best development from 6,000 to 8,500 feet on the Mesa Verde Plateau, which is in the southern extreme of the Intermountain Region. There annual precipitation is about 18 inches and the growing season about 160 days. Soil cover on the Mesa Verde formation is thin, and most of the plants are rooted directly in crevices in the broken but intact rock.

Pinyon-juniper woodlands at Mesa Verde consist of evergreen trees about 20 feet in height and sufficiently far apart to permit easy walking space. The shrub understory is big sagebrush, bitterbrush, mountain mahogany, rabbitbrush, and serviceberry, while important herbaceous species are western wheatgrass, blue grama, june grass, and Indian ricegrass. Outlyers of this community are found on rock outcrops far out into the Great Plains south of the Arkansas River.. Juniper, in this case, one-seeded juniper, extends much farther into the Plains than does pinyon. Similarly, in the Intermountain Region, Utah juniper is far more important than pinyon north of the Colorado River, and, near the Wyoming border, pinyon becomes an uncommon associate of juniper.

At its lowest elevations, pinyon-juniper is immediately upslope from big sagebrush. The demarcation seems to be that big sagebrush favors alluvial materials while pinyon and juniper are usually rooted in fractured bedrock. At its highest elevations, pinyon-juniper intermingles with oakbrush woodlands and ponderosa pine.

Oakbrush woodlands occur throughout all but the northeastern part of the state, but they are best developed in the southwest between 7,000 and 8,000 feet where they mix freely with big sagebrush, serviceberry, pinyon-juniper, ponderosa pine, and even Douglas fir and aspen communities. Gambel oak, the only dominant in the oak community, grows in continuous thickets to widely spaced clumps. Thickets tend to form on steep slopes while clumps are usually associated with gentle to flat terrain. Mature oaks achieve heights of 10 feet and have stem diameters of about three inches. The most common associated shrubs of this type are: snowberry, big sagebrush, serviceberry, chokecherry, mountain mahogany, and rose, while elk sedge is the principal herb. At present, and probably for at least the last century, oak woodlands appear to be stable, neither spreading nor retreating; they are probably kept in balance between the tendency to spread by root sprouts and the retarding influence of frequent fire.

At elevations of 8,000 feet in the southwest, and 7,000 feet in the northwest, oakbrush begins to mix with ponderosa pine, Douglas fir, aspen, and Engelmann spruce. These Montane and Subalpine species first appear at lower elevations on north- and east-facing slopes, but with increasing elevation, Gambel oak is reduced to only a minor component of the vegetation on south-facing slopes and then is no longer present above 9,000 feet.

Ponderosa pine, Douglas fir, aspen, Engelmann spruce, and subalpine and white fir occur at appropriate elevations throughout the Intermountain Region, especially on north- and east-facing slopes. They are best thought of as disjunct members of the Southern Rocky Mountain Region, just as big sagebrush, which occupies the alluvial valley fills within the Southern Rocky Mountain Region, is best thought of as a disjunct of the Intermountain Region.

This region is a part of the "Desert Southwest" and possesses some of the most spectacular scenery available on the continent. Many archaeological sites related to the early Anasazi cultures (e.g., Mesa Verde National Park) add to the area's wealth of attractions. Its favorable climate, its proximity to the majestic San Juan Mountains, its early mining history, big game hunting, fishing, and winter sports make it outstanding as a vacation land. Surely, the relative economic importance of tourism can only increase as long as these attractions remain unspoiled. Some of the land use procedures which have been suggested, however, threaten these valuable resources.

The principal economic activities within the region, in addition to tourism, are mining, livestock, and irrigated agriculture. A large part of the region is federally and state owned.

The principal mineral resources are coal, natural gas, uranium, and vanadium. The reclamation of the drastically disturbed land due to mining activities is difficult in this region since, at low elevations, extended droughts are frequent. Rainfall often comes in torrential bursts and once the natural vegetation cover is broken, erosion tends to accelerate rapidly.

Overgrazing has tended to increase sagebrush at the expense of grassland and thus reduce productivity, but there is little evidence that the grazing has accelerated erosion. Irrigation agriculture in protected canyons and valleys is well developed.

The proposed development of oil shales will take place within this region. Proposed retort processes suggest that massive amounts of tailings will be generated in the extraction of the hydrocarbons. These tailings have many of the physical characteristics of black talcum powder and are likely to be subject to blowing. Chemically, the tailings are highly saline and very low in phosphorous and nitrogen. Present plans for the storage of these tailings in the landscape seem inadequate, and the revegetation of spoils from this development will also be difficult.

Analysis of Population Systems: Perspectives on the Colorado Case

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Central to the whole range of social, political, economic, and environmental issues facing the state of Colorado is the matter of population. The consequences of our changing population numbers, distribution, and composition are pervasive and omnipresent. Some of these consequences are: natural resource depletion, exodus from remote rural communities, subdivision of the high country, increasing urban domination of the state, construction of new schools and neighborhoods, and enhanced cultural opportunities of the Front Range, to mention but a few. It is simple to note that population characteristics play a critical role in the internal affairs of the state, but to understand how and why population characteristics affect Colorado's present and future is exceedingly complex. The purpose of this chapter is to examine and illustrate some of these complexities through a selective analysis of Colorado's population data.

Basic Social Demography Concerns

The task of population analysis is to determine, by theoretical and mathematical analysis of population data, what the social, political, economic, and cultural causes and consequences have been, are, or probably will be, of given features and trends of population units. A simple illustration suggests the nature of the questions with which social demography is concerned. If a major mining operation were planned for a sparsely settled and remote rural area, the analyst would attempt to determine how the characteristics of the population unit will change regarding size, age distribution, sex balance, racial and ethnic mixture, the proportions employed, the proportions of single persons, college graduates, persons from urban backgrounds, etc. Then, on the basis of previous studies, he estimates what the social consequences of these changes will be, such as new schools and recreation facilities required, altered land values with new residential development, increased demand for commercial and professional services, club and church memberships, changed leisure patterns, etc.

Two special activities associated with population analysis are considered most important by the general public: the prediction of the future size, structure, and composition of population units (given certain trends and what the analyst knows about the continuation of these trends) and the anticipation of social problems associated with population changes, along with the suggestion of ways to improve the problematic situation.

The analyst works with three main classes of variables: births, deaths, and migration. Using these he determines rates, causes, and consequences of (1) population numbers, (2) population structure, or age and sex distributions (e.g., what causes and results from such factors as increased proportion of elderly, or a surplus of young adult females, etc.), and (3) population composition, the proportional representation of various races and ethnic groups, the percentage of married, literate, etc.

The obvious purpose of assessing such categories is to determine the interrelationships and the changes they precipitate. For instance, new industry brings about a heavy in-migration of young married adults, increasing their proportion in a population. The birth rate normally increases resulting in an increased proportion of children and a greater need for schools, playgrounds, parks, and pediatric physicians. The increased proportion of young adults will also increase the average level of education, thus affecting the types of political and social participation. It will likely increase the racial or ethnic heterogeneity of the population, thereby requiring increased tolerance in potentially problematic conflict situations within the unit.

This sort of chain reaction effect is what population analysts call socio-demographic "systems," where certain changes in population numbers, structure, or composition have effects on other population characteristics and on the social, economic, political, and cultural life of the people in that population unit.

Before an analysis of a system can be made, some sort of boundary must be assigned that system. There may be some sort of natural limits or boundaries, such as communities, states, or nations. Before a community can be classified as urban or rural it must be determined how many people there must be in a community in order for it to be classified as "urban." This definition has changed over the years from the 1900 definition of urban communities as all incorporated towns of 2500 or more people to the unit of Standard Metropolitan Statistical Area (SMSA) introduced in the 1950 census, which includes a whole county or counties in which there is located a central city of 50,000 or more people.

When determining the limits of population units or systems, we must remember that such systems tend to overlap, with few sociodemographic systems being neatly self-contained. An increase in the population of a major metropolitan center, for example, usually means an increase in that state's population, with practical implications for both.

Just what constitutes a "population problem" is obviously a matter of judgment. Generally, we consider a "population problem" to be a consequence of a characteristic of a population unit's size, density, structure, or composition which jeopardizes the welfare or development of the unit. If such characteristics threaten to reduce the quality of people's lives, the stability of the society, or its possibilities for appreciable improvement, we have a "population problem." Since social population systems are so interrelated with natural ecology systems, the "problem" is typically insufficient resources (food, undeveloped land, jobs, political power, etc.), or insufficient technology (procedures for securing desired goals, both engineering and social techniques) to accommodate effects of changed population characteristics. Sometimes, however, there are too few people, perhaps of specific kinds, to enable efficient use of the available resources and technologies. Therefore, "population problems" may be overpopulation, underpopulation, or simply not having an appropriate balance of ages, sexes, and occupational skills required for the kind of collective living the people in a population unit desire.

Now, let us see how these demographic factors apply to the state of Colorado.

Selective Analysis of the Colorado Case

Population Numbers

In studying a population unit, the first concern must be with the numbers of people included in that unit. To understand Colorado's growth and size, for instance, it is helpful to know that while the world's population increased 23.3 percent between 1960 and 1970 and that of the United States increased 13.4 percent during the same period, Colorado's population increased 24.8 percent to a total of 2,207,259.

While the world and the U.S. populations grew primarily by "natural increase" (births in excess of deaths), Colorado's numbers increased more as a result of migration into the state, which means the state can anticipate a substantial future increase due to natural increase alone. Thus immigrants are increasingly making up a larger proportion of the state's population. Such mobile populations tend to be younger, with more children and lower death rates, than stable populations. Regarding density or dispersion data, the average number of people in the world per square mile of land surface in 1970 was 71.2, compared with 57.4 people per square mile in the United States, and only 21.3 persons per square mile in Colorado, illustrating Colorado's relatively low population density.

Comparisons within Colorado give an even better feeling for its nature as a population unit. For instance, 1,769,343 people (80 percent of the state's population) are located in the ten counties which make up the Front Range Urban Corridor, where the density is an average of 112.9 persons per square mile. And while the state's growth rate between 1960 and 1970 was 25.8 percent, the Front Range Urban counties experienced a 33.8 percent increase over the ten-year period. Thus, it is apparent that Colorado's growth is almost entirely a matter of population increase in the Front Range Urban Corridor. Comparing selected Colorado counties, they range in size and density from Denver County with 514,678 (density: 5,418 psm) to Hinsdale County with 202 persons (density: 0.2 psm). Comparisons of growth and decline data for county units is, logically, even more extreme when population subunits are compared. Pitkin County, in which Aspen is located, increased by 160 percent between 1960 and 1970, while San Miguel, in the southwest part of the state, *decreased* by 34 percent during the same period. Overall, the state pattern shows that the most rapid population loss was in the peripheral areas of the state, most dramatically along the eastern and southern border, while the most dramatic growth was in the Front Range and the high country within easy reach of the Front Range.

Population Structure

Population structure, it will be recalled, refers to the age and sex distributions of a population unit and is of importance as a demographic variable because it (1) reflects migration patterns and (2) determines the likelihood of births and deaths in a population. During its mining days Colorado's booming population was young and had a great surplus of males. As a result, both death and birth rates were low. Since young adults are the most mobile people, the state's average age will decrease as their proportions increase due to immigration; and within the state those areas losing population will become older (with a low rate of natural increase) while the rapid growth areas will become younger, with consequently higher birth rates and lower death rates. If we assume that both young males and females leave declining areas in equal proportions, those areas will eventually develop a higher proportion of females, because females tend to live longer than males. And if either young males or females tend to emigrate from such areas disproportionately, the birth rate will reflect the lesser of the two, since we tend to marry within narrow age ranges and frown on polygamy.

The 1970 Colorado data show these characteristics. The median age in the state is 26.2 years, with urban areas having a 25.9 average; small towns (2500 to 10,000), a 30.2 average; and rural areas, a 27.5 average. This is in spite of the fact that rural birth rates are typically higher than urban rates, with proportionately more children to pull down the rural average. When we compare the proportion of the urban population which is in young adulthood with the rural proportion, we see that 23.6 percent of the urban population is between 20 and 34, while only 18.4 percent of the state's rural population is in this age group. This is clear evidence of heavy adult emigration from rural areas, considering that the proportion of urban and rural youth of ages 15-19 is 9.9 and 9.7 percent, respectively.

The state's sex ratio (number males per 100 females) is similarly revealing. In 1970, Colorado had 97.5 males per 100 females, as compared with a U.S. sex ratio of 96.4. The ratio for Colorado in previous years was 1950 — 100.8, 1930 — 105.1, and 1910 — 116.9. Clearly, the excess of males characteristic of frontier population units has evened out through the years to resemble the national ratios. Comparisons between units within the state reveal that the urban areas have an excess of females (1970 sex ratio = 95.7), while rural areas evidence surplus males (all rural = 102.8; rural farm and hamlet = 104.1). This is primarily accounted for by a greater historic rural female deficit, widowed women moving from rural to more comfortable urban areas, and a higher young adult female outmigration rate from rural areas. The greatest surplus of females is to be found in urban central cities and in communities of 10,000 to 50,000 (1970 sex ratio, 92.0 for both), to which women are more likely to move (younger to central city, where widow rate is also higher, and the older to smaller urban centers). The effect of selective migration is dramatically illustrated by the sex ratio for Colorado Blacks, whose statewide sex ratio is 105.2, going as high as 239.1 (males per 100 females) in the urban fringe and 208.4 in urban areas of 2500 - 10,000 people, testifying to greater male migratory propensity within this population.

Population Composition

The composition of population units refers to distributions of all characteristics of demographic interest except age and sex — race and ethnicity, occupation, education and literacy levels, marital status, religion, retirement status, location of residence, etc. A number of these composition variables have been introduced above. They are ordinarily considered in relation to the population characteristics of total numbers, age, and sex. The special significance of composition characteristics is that (1) they tend to influence such demographic rates as births, deaths, and migration (e.g., persons who are more educated are more mobile, those with lower occupational and literacy levels have larger families, etc.), and (2) they usually have social consequences that people are highly sensitive to, as a proportionate increase in minority group persons or single and divorced persons alters the social climate and standards of a community or state in ways that are often controversial. A primary way in which composition of a population unit changes is through migration, which ordinarily increases the heterogeneity (diversity of characteristics) of the population. Several examples of Colorado composition changes follow.

The percentage of nonwhites in the state in 1900 and 1950 was 2.0 and 2.1 percent, respectively. By 1970, the nonwhite population had increased to 4.3 percent (of which 3.0 percent were Blacks, as compared with 1.5 percent Blacks in 1950. Since recent Colorado in-migration is mostly to the highly urbanized Front Range area, it is not surprising that nonwhites presently make up 5.8 percent of our metropolitan population and 8.5 percent of the state's metropolitan central city population. Expressed in another way, in the past decade the white population of Colorado increased by 24.2 percent, while the Black population jumped 66.1 percent (up 74.0 percent in urban areas). The consequence of this composition change, of course, is somewhat altered life styles and subcultural patterns within the population unit, especially the metropolitan areas. Consequently, the whole unit must make certain adjustments to facilitate social integration sufficient for viable and orderly community functioning.

Marital status and household data similarly reveal composition changes in the state. While in 1960 the percentages of males and females 14 and over who were married was 69.6 percent and 67.4 percent, respectively, both had dropped to 65.0 and 62.3, respectively, by 1970. A minor part of this difference is explainable by greater longevity (more widows and widowers) and somewhat increased divorce rates. But most of the difference is due to an increased proportion of unmarried young adults in urbanized areas. While the rural percent married data show little change between 1960 and 1970 in the state (1960 males = 67.8, females = 73.7; 1970 males = 67.8, females = 69.4), the urbanized areas show a decrease from 71.2 percent to 64.5 percent for males and from 66.0 percent to 61.2 percent for females during the period 1960 to 1970. Obviously, this reduction in the proportion of the married population will have a direct effect upon the birth rates. More importantly it reflects a general change in social values in the state that is having an even greater effect on demographic trends. With the rapid in-migration and increased urban domination of the state, a more urbane or cosmopolitan orientation emphasizing freedom, privacy, and consumptive responsibility is being felt. This is reflected in birth rate and household occupancy data. While the 1960 fertility ratio (number of children under 5 years of age per 1000 women 15 to 49 years old — or in the childbearing years) was 516 for the state and 500 for urban areas, this figure had dropped dramatically to 340 for the state and 334 for the urban areas by 1970. There is a substantially smaller rural-urban difference in 1970 (27) when compared with 1960 (64). Similarly, the average number of persons occupying a residential dwelling in 1960 was 3.21 for the state and 3.13 for urban areas, which decreased to 3.08 and 3.02 by 1970 with a similar rural-urban convergence.

Composition characteristics and changes could be presented on occupations, religions, ethnicity, education and so forth at length with essentially the same patterns being apparent. Colorado's population is becoming increasingly heterogeneous (diverse) in the wake of rapid in-migration and population growth, with the urbanized areas, principally in the Front Range Corridor, showing the signs of impact most clearly and directly. As the urbanized areas adjust socially, economically, and politically to changes in population composition, structure, and numbers, the rest of the state, perhaps after a slight lag, feels the impact too, with adjustment being reflected in a convergence of rural and urban population characteristics.

It is impossible to do justice to a topic so broad as Colorado's population characteristics and trends in so short a space as this. But it is hoped that this paper has provided a better understanding of the social demographer's methodological approach and perspective of the state's population case. When viewed in the context of complex interrelationships within population systems and between such systems and other natural, economic, cultural, and political systems, it becomes very apparent that population analysis is both a difficult and exceedingly important challenge.

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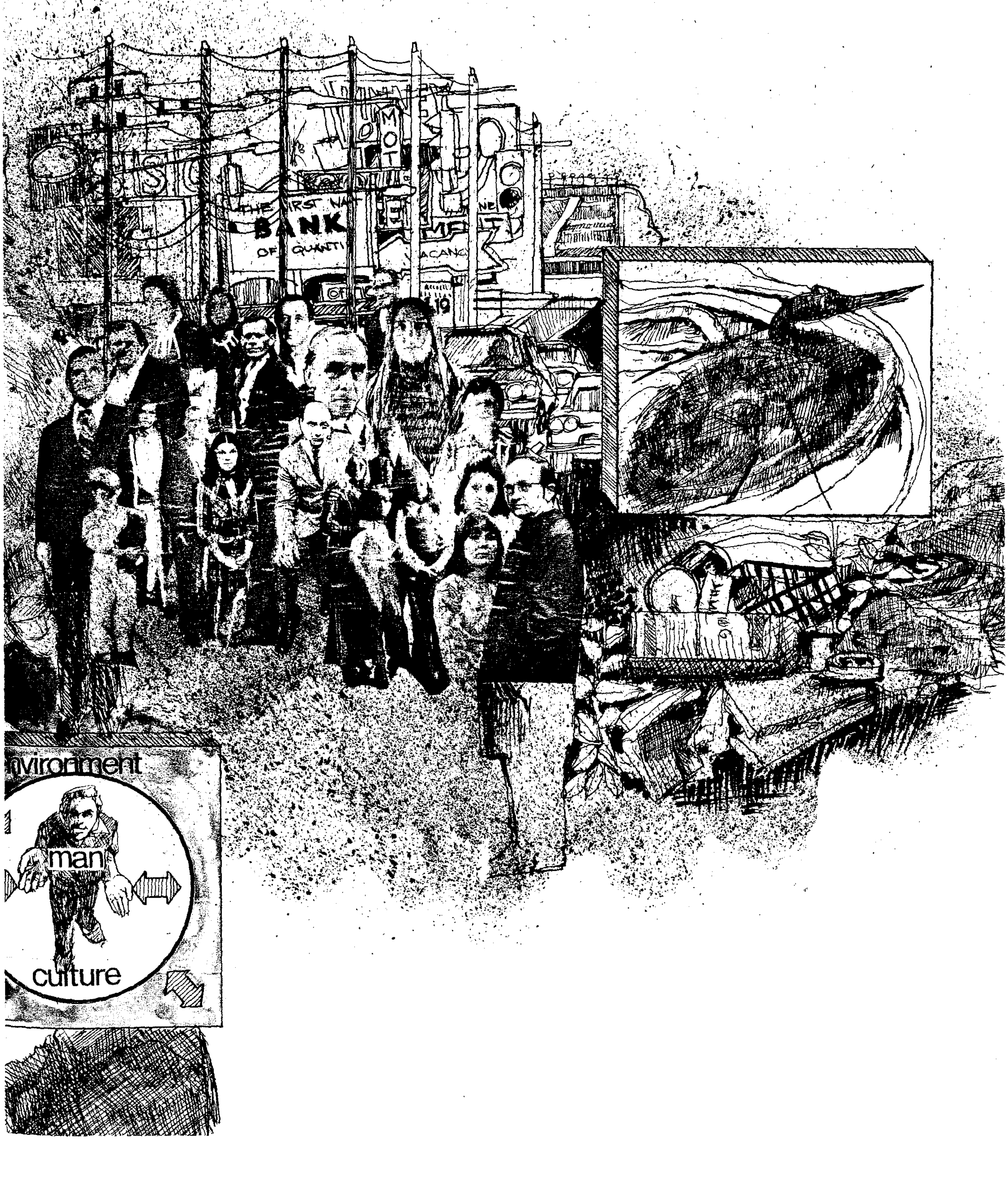
resource
recovery

Social and Economic Aspects of the Environment

Man exercises control over his environment through social, cultural, political, and economic systems. The philosophy man holds today will, to a large extent, determine the environment he lives in tomorrow. Which alternatives will he choose?



The Common Sense of Environmental Economics

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Abraham Lincoln, as usual, said it well: "The state should do for its people only what they cannot do for themselves."

In Lincoln's day it was easier for people to do for themselves than it is today. In spite of their comparative poverty, and with but few exceptions in the larger cities, people could, *by themselves*, move around, breathe clean air, fish, hunt, walk, acquire land, lumber and other resources to build homes, grow food, dispose of garbage, and even work themselves up from a log cabin to the presidency of the United States. Today that is past. Society has become interdependent in the strongest sense of the word: it is impossible to do anything by yourself. Impossible, that is, unless one is prepared to drop completely out — to become a virtual savage in life style and a pariah among men.

This transformation in society from a state of independence to one of interdependence has left the science of economics gasping and choking in the dust of the Twentieth Century. American economics has been above all a theory of individual choice and for individuals to choose, individually, they must not be overly dependent on other individuals' behavior.

There is much to be said for the economics of surplus and free enterprise which characterizes the "old" economics. Any sensible person must experience a deep fear of state control of the economy — or of anything else for that matter. But that philosophy, consisting as it does mainly in nostalgia for the last century — and a largely mythical interpretation of that century at that — is, perhaps, itself a great threat to freedom. It does not pose solutions to the contemporary problem of technologically necessary interdependence, rather it proposes simply to act as though interdependence does not exist in the hope that it will somehow die of neglect and miraculously go away. Thus, while we choke in pollution, while resources are being voraciously consumed, while millions struggle in squalor and poverty, the old economics insists, "No government intervention in the market system!"

Specifically, there are three forms of interdependence leading the unregulated market to fail in performing its functions and thereby creating contemporary environmental problems. They are (a) leaks, (b) lumps, and (c) inter-time. Each is discussed in order.[1]

(a) *Leaks* In order for a market system to perform correctly, everyone must pay for the costs he creates and be rewarded for the good. True, there are nobly philanthropic people who will not harm others even if they can get away with it and who will help others without reward, but philanthropists are notable for their scarcity. When costs are not paid for and benefits not rewarded, these effects leak from the mind of the decision maker — he does not count them in making his decision. Therefore, there is too much of the cost-creating activity and too little of the benefit-creating activity.

In order to illustrate the importance of these leakages (or external effects as they are technically known), two systems may be compared: the independency system of the frontiersman and the interdependency system of contemporary man.

The frontiersman and his family grow their own crops and livestock. Sewage and garbage are returned to the soil — or if the frontiersman chooses not to do so, he must at least live with his effluvia and suffer the consequences. In such an "open" environmental setting even smoke from the frontiersman's chimney rarely finds the nostril of a neighbor and, most often, when it does, it is a rather pleasant experience.

It is not difficult to contrast this independency model of the frontiersman with the confused state of contemporary man. First, the acts of production and consumption are separated — he works for IBM, but eats California grapes. Secondly, the waste effluvia both from his consumption and from those who produce for him are either taken care of by someone else or not taken care of at all. Consumption must be followed by waste disposal in one way or another, and in a modern, interdependent society someone must — or should — worry about what happens after that. Similarly with the producer: as the farmer treats his fields with pesticide, someone must — or should — worry about what happens to the pesticide after it has passed beyond the immediate attention of the farmer.

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[1] *For more detailed discussion see Paul W. Barkley and David W. Seckler,* Economic Growth and Environmental Decay: The Solution Becomes the Problem, *New York: Harcourt Brace Jovanovich, 1972.*

Even proponents of the economics of surplus and free enterprise admit that in such circumstances the leakages must be stopped by government intervention. They and most other economists recommend putting taxes on the source of the leakage equal to the cost of taking care of them (or to the damage they cause). Thus water used for flushing toilets should be taxed in an amount equal to cleaning up the water. Faced with these high costs, which the flushers themselves now would pay rather than someone else, two things will happen: (a) toilets will tend to be flushed less often and (b) new toilets which use less water will be developed and purchased. Similarly with pesticide and other chemicals — a tax will raise their cost, causing a cutback in the amount used and development of less harmful substitutes as well as changed farming practices.

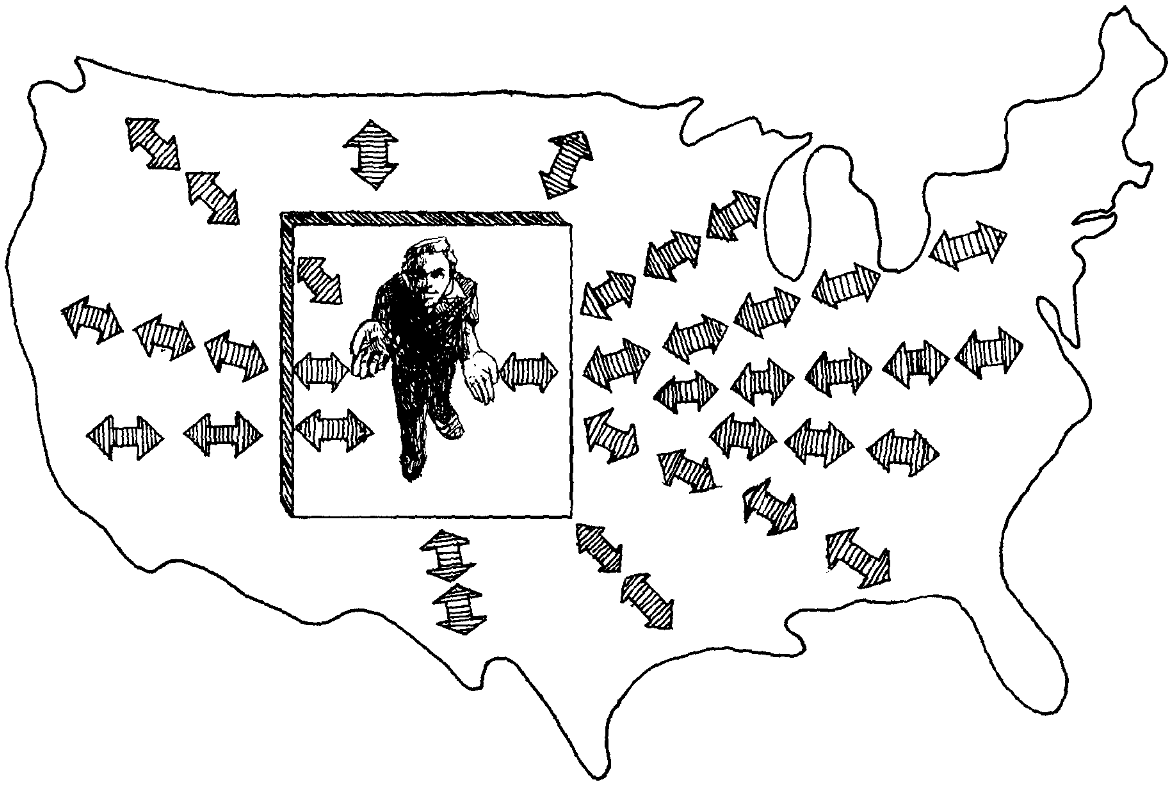
(b) *Lumps* The second source of market failure is the lump problem, as we have called it. A steak or bicycle can be purchased by someone for his own enjoyment. He buys it and uses it and that is that — except for possible leakage problems. But what if someone likes vast wilderness areas, or the blue whale swimming in the seas, or the Grand Canyon, or George Washington's house — how can he "buy" these kinds of goods? The answer is he cannot individually buy them. The reason is that they are too "lumpy" — they come in pieces too big for anyone, even the most wealthy, to buy. Yet these kinds of goods often have more than one use. Trees in wilderness areas can be cut for lumber and the land used for vacation home developers. Blue whales have valuable oil products and their meat is good dog food. The Grand Canyon is a "natural" reservoir for water developers, and George Washington's house could bring a high price either for some wealthy person to live in or to chop into souvenirs. How can the man who likes these things in their natural "lumpy" state bid against those who find it easy to make them into unlumpy, highly marketable commodities?

One answer would seem to be that we and other people who like these things would get together, pool our funds, and buy these lumpy things in a lump. It's a good idea, but it rarely works. The reason is natural human cunning and an opportunity to use it — an irresistible combination. You and your friends may form a political campaign to save the whale. You contribute time and money. You ask me to do the same since I, too, love the whale. But I slyly think to myself: "If these people are successful and I do not contribute, I will get the whale 'for free.' If they fail and I do contribute. I get nothing anyway, so why contribute?" And the others are thinking the same way or worse. They are thinking, all my time and money just to give it away to that xl$** xl? Never! So these cooperative things rarely work.

Again, government intervention is called for. We all vote for a tax on ourselves to provide all of us with these collective goods. It is not always completely fair because a minority may not want them, yet they must pay taxes anyway. But that's democracy — you help buy my collective goods, I'll help buy yours.

(c) *Inter-time.* The third and last major form of market failure is of a different nature. It concerns the position of a man or of an entire society over longer periods of time. There is an inevitable conflict in human affairs between the desires of the present and the needs of the future. The way in which we make decisions to minimize these inter-time conflicts is one of the more difficult and interesting problems of economics.

A good example of this kind of decision is that of going to school. Most students can think of many things they would rather be doing than studying. Yet they study and sacrifice other pleasures in the present for the opportunity of better jobs and a better informed life style in the future. It is almost as if there were two people involved: the present student and the future person, and the student is working and sacrificing to make a better life for the latter. It is indeed a kind of philanthropy.



In many social decisions, it becomes in fact a philanthropic matter, for present generations are sometimes required to sacrifice for other, sometimes far distant, generations. The most well-publicized problem of this nature is that of resource depletion associated with the Club of Rome Report, *The Limits to Growth.*[2] According to this study, known reserves of a great many of the most vital minerals — copper lead, gold, silver, etc. — will be exhausted within the next century and if that happens, the industrial order and civilization itself will come crashing down.

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[2]*Donella Meadows,* et al., The Limits to Growth, *New York: University Books, 1972.*

These dismal projections are good examples of the difficulties of the inter-time problems we have been discussing, for they are rife with unknowns. Particularly crucial to the question of resource depletion, for example, is the question of future technology. We do not, by definition, know what future knowledge (and hence technology) will be; if we did, it would not be future but present knowledge. Since we do not know future technology, we do not even know the true mineral reserves of the world. For if it were possible to capture, through highly advanced technology, the traces of minerals found in sea water or common rock, an almost limitless supply would be available. Minerals exist in abundance, but unfortunately the great bulk of the world's mineral supplies are highly dispersed as traces in low-grade ores.

To further complicate matters, possible technologies which could accomplish miracles are on the horizon. Fusion energy is the most spectacular. Based upon the principles of the hydrogen (rather than the atom) bomb, fusion reactors could create virtually limitless supplies of energy from the most abundant of all resources — sea water. With fusion energy, every cubic mile of sea water would create more energy than all the world's initial supplies of fossil fuels (coal and petroleum).

So there we are, without almost miraculous breakthroughs in technology, we will almost certainly condemn future generations to a catastrophe of resource exhaustion. With these breakthroughs, most reserves will become far more abundant in the future than now. What should we do? Sacrifice the present for the future by reducing our incomes and resource consumption? Or "go for broke" in the belief that science will provide the required miracle.

Of course, this puzzle cannot be resolved here. But a vitally important clue can be offered. In inter-time problems where we simply do not know enough to make rational decisions, the principle of reversibility becomes decisive. This principle may be illustrated by the education example with which we began. Say a young man in high school does not know whether he wants to become a lawyer or an auto mechanic. If the latter, he will not need future education, if the former, he will. Should he drop out of school or not? The answer is clear: he should stay in because that is the reversible course. If he stays in school and later decides to be a mechanic, he can easily become one. But if he drops out and later decides to become a lawyer, he is almost precluded by the irreversible act of dropping out. This example provides at least a partial approach to the question of resource depletion now confronting society. If we continue to squander resources as we have in the past, we embark on an irreversible course of action from which future generations can be saved only by such technological miracles as fusion energy. If on the other hand we now conserve resources, future generations will be better off if these miracles are not forthcoming, and if they are, the policy can easily be reversed and they can live it up.

In sum, the "old" economics emphasized independence of individual choice, the new the interdependence of choice. They differ only in terms of changing emphasis as the environment has moved from an open (or surplus) state to a closed (scarce) state. Interdependency creates problems between people in the form of leakages and collective goods and between generations in the form of inter-time allocations of resources. These interdependencies are, by definition, beyond the capacity of any individual to control. They must be controlled by the collection of interdependent people affected. The only way to do this in most cases is through government intervention of one form or another. Contrary to the belief of many, government intervention is often the only way to provide meaningful choices in such interdependent systems as the environment. Lincoln's dictum also means the government *should* do for its people what they cannot do for themselves.

Social Aspects of the Environment

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Man and His Environment

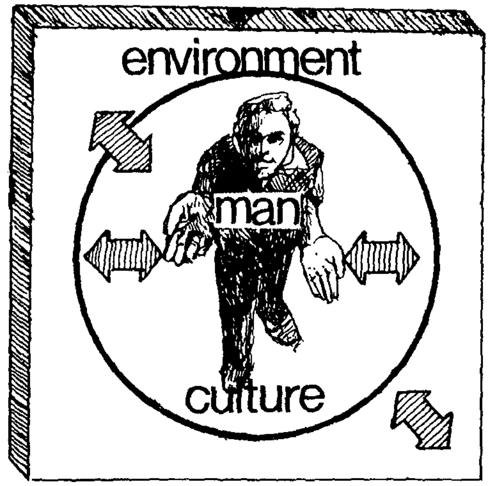
The word *environment* has become one of the favorite terms characterizing the 1960's and 1970's. Indeed a tremendous amount of writing has focused interest on the interrelationship of man with his surrounding world and has presented in stark terms the visible problems resulting from the spillovers of technological advancements. In the same context, therefore, and with emphasis on Colorado we need to understand and describe the man-centered system which is sensitive to the ideal of a harmonious coexistence of man-technology-environment. In other words, we want to see how present, as well as projected, conditions and trends in Colorado impinge upon the natural environment and ourselves, and consider how such trends and conditions can be translated into reasonable, nonhazardous, and beneficial aspects of a well-integrated system of collective life.

The terminology and explication of the various aspects of the environment, ecosystem, biosphere,etc., would be inordinately technical to describe here. Perhaps the best way to present the argument underlying the present exposition is to envision a harmonious relationship between three parts that compose our total environment, namely, *man, culture,* and *physical environment.* Men coming together create culture, which in turn affects man, but with both man and culture existing within the broader constraints of the surrounding natural environment. Volumes can be written about each of these seemingly simple parts. Here, our effort will be to explore the harmonious relationship between these three component parts and relate them to man's quest for an improved quality of life. In more abstract terms, we may say that QOL=f(M+C+E), an equation made out of the acronyms of the component parts introduced above. All the discussions about the environmental "crisis" and the major disruptions of the natural system center upon an understanding of these three key terms as they relate to some common goals whose expression may be articulated under the concept "Quality of Life."

Essentially, a total environmental concept should consider all conceivable systems affecting man as an individual and his community as a whole, as well as the interaction and interdependence of all such systems. Therefore, the term *environment* needs to be more broadly defined as the system of spatial, temporal, and social regularities which influence the biological and behavioral processes of a given population. This general definition implies that what is generally called the natural environment has meaning and utility only in the context of a social setting in which man (and his culture) interact with nature. The social scientist also increasingly uses the concept of system to describe the surrounding human community. Such a concept does not differ significantly from parallel ones used in physical and biological sciences, i.e., a configuration of parts that are in a relationship of interdependency. A social system is therefore composed of interrelated acts of people with a structure which is sought to some degree of regularity or recurrence and in any patterned social interaction which persists over time.

We have introduced these elementary notions in order to indicate that when we talk about *social aspects of the environment* we imply a systematic relationship between component parts many times as broad as the three concepts briefly mentioned above. At the same time, systemic relationships and interdependence are extremely important for us if we are to understand the underlying theme in any description of the depletion and spoliation of natural resources as accelerated by increasing populations, the advancement of modern technology, and excessive consumer behavior. Such an argument states that the production of many varieties of environmental pollution, ranging from air, water, and noise pollution to the more elusive esthetic or cultural pollution, seem to be the inevitable consequences of disturbances initiated by both the introduction of major technological facilities and by natural trends in life patterns of excessive affluence. At the end, a whole host of human or social disorders are created through the malfunctioning of the larger social system, becoming evident in what is popularly known as the environmental "crisis."

The following text tries to introduce very briefly some essential points concerning the social aspects of the environment in Colorado, particularly in the context of what one may describe as the fragile environment of the Rocky Moun-



tain States. What follows is a twofold presentation: first, a brief description of environmental challenges and the disruptions from the presence of large populations, uneven population distribution, distribution of resources, and incompatible styles of life for a rather arid environment; and second, an indication of the range of emerging environmental responses designed to meet the challenge of various problems associated with a generally fragile environment in Colorado. This last part involves also a brief presentation and discussion of some alternative strategies which may make possible a more successful meeting of future challenges in the state.

Environmental Challenges

Colorado, as part of the Rocky Mountain states, provides inspiring scenery with a combination of mountains and semi-arid or desert lands which surround the spine of the Continental Divide. In the eight mountain states the average annual precipitation is only 12 inches, a few points more than the mark of 10 inches used to describe a desert territory. Thus, in what essentially is a desert territory, man has chosen some of the worst places to live. In many of the areas of the Rocky Mountain West, flood plains have been selected, as well as aquifer recharge areas, fault zones, and unstable soils. More than anything else, limited water resources combined with a precarious physical environment are the constant constraints of a physical environment within which major social trends are taking place.

What used to be disadvantages for the mountain region, namely the relative desolation and dryness, are increasingly turning to be powerful magnets attracting large numbers of people and industry into the area. The salubrious physical environment, a hospitable climate, and the flight away from congested, polluted areas of other parts of the nation are providing Colorado and the arid west with some major social trends which are affecting the life of the region and which, increasingly in the future, will have dramatic consequences. In very broad terms, four regional and national trends are affecting the present and future life of Colorado:

1. Increasing population, especially the continuous movement of people to the west. While the population of the nation increased by about 14 percent between 1960 and 1970, Colorado increased in this period by 26.9 percent.

2. Increasing urbanization, metropolitanization, suburbanization, and rural decline. As the urban centers in the west continue to grow, the most pronounced feature in Colorado, as well as in the other mountain states, is the increased concentration of population around metropolitan cores. Major "urban giants" or "urban oases" are taking shape around well-irrigated areas, such as the Colorado Front Range, the Utah Wasatch Front, the Phoenix-Tucson Urban Corridor, and the Sante Fe-Albuquerque emerging conurbation. These emerging "megalopolitan" concentrations (still relatively small in comparison to similar urban agglomerations in the rest of the nation) are rapidly exhibiting the typical urban ills of traffic congestion, polluted air and water, urban decay, and crowding. Contrasted to this urban concentration, large parts of the state face relative rural depopulation and continuous movement of people from the smaller communities to the large metropolitan concentrations. In Colorado, close to 80 percent of the population is to be found in the urban chain between the cities of Fort Collins and Pueblo, a well-watered eastern front.

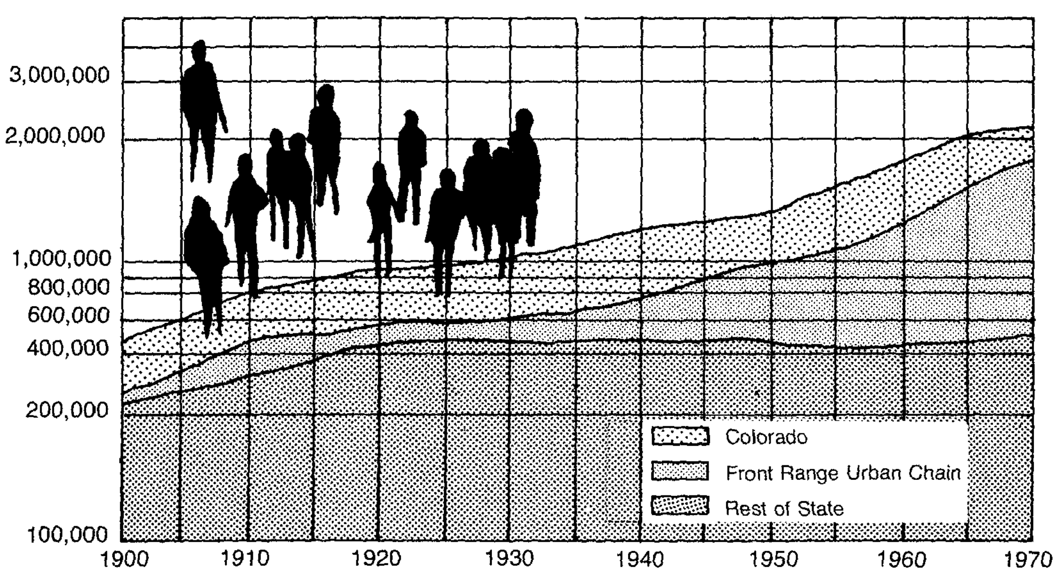
3. Increasing industrialization with the attendant changes resulting from the new and massive capital influx and new values and patterns of behavior. In recent years, an increasing number of industrial concerns have been established in rather traditional rural com-

munities of Colorado. This trend is expected to continue as a number of national corporations are trying to move into open spaces, not only for cheap labor, but also for inexpensive land, clean air, and a physical environment highly attractive for working conditions.

4. Finally, the increasing concern with ecological mismanagement is expected to dramatically affect policies of future growth, given the fragile ecological environment of the Rocky Mountain States which compounds typical problems of pollution. There is an increased awareness of a need for a new relationship between man, his culture, and the surrounding natural environment and a quest for definition of new cultural landscapes. By now it is recognized that we do not need to preoccupy ourselves only with quantitative growth, but also with the qualitative aspects of collective life, assessing and re-evaluating the consequences of continuous population growth and of accelerated urbanization.

Growth and unbalanced spatial distribution are key components of emerging problems. In Colorado, this unbalanced distribution of population along the eastern slope of the Rocky Mountains is a result of both physical factors and economic geography. Physical geography largely determines the western half of the state, while economic geography is a crucial factor for the eastern part and for the formation and vital role of the Front Range Urban Chain. This region, or the "urban corridor" or even the "Fort Pueblo Megalopolis" is of immense importance for the welfare of the state. By size alone, even the total population of the state in 1970 cannot qualify as peer among the large "strip cities" in the United States today. (In 1962, the metropolitan areas of Colorado accounted for only 1.1 percent of the total metropolitan population in the country.) What is most important, however, is the fact that due to physical factors and historical antecedents going back to the establishment of the state, the urban corridor of the eastern slope provides an unusual case of rapid growth and of potentially far-reaching consequences when examined in the context of the ecological limitations of the region.

Within the Front Range Urban Corridor, there are included 10 counties, nine of which have large urban centers. Also, within this axis lie 17 of the 21 Colorado cities with a population of 5,000 to 10,000. The 10 counties account for 1,755,341 persons or 80.5 percent of the total population of the state in 1970. As the following figure shows, this front range urban chain has been growing much more rapidly than the rest of the population in the state, which has remained more or less stable.



Population Trends in Colorado 1900-1970

This extremely large percentage of the front range urban population, contrasted to a corresponding percentage of 51.8 percent of the population in the same area in 1900, indicates not only the continuous urbanization in the state, but also the tremendous concentration of population within the strip area of the 10 counties of the front range. This growth is particularly pronounced in the suburban communities as contrasted to the larger central cities of Denver and Pueblo. This trend of suburbanization into the fringe spaces of the metropolitan areas is consistent with similar trends in the rest of the nation, giving rise to new forms of urban complexes, each made up of several component cities. These centrifugal patterns of growth which are observed throughout the region and the nation have important consequences in terms of land use and the emerging life style associated with "strip cities," "conurbations" or "megalopolises."

The continuous expansion of the front range urban complex is expected to continue in the coming years. In an estimate of the State Planning Commission, it was projected that by the year 2000 the front range counties will more than double their population to about 3,340,000 persons, representing 86 percent of the state's total population. A solid strip city is expected to cover an area of approximately 200 miles long. Thus, despite national recent trends toward controlled population, the Colorado Megalopolis, as well as other major urban concentrations in the mountain region, are expected to have very high rates of population growth from three sources: a) natural increase, b) internal shifts within the state from the rural areas and small towns to the urban concentrations, and c) intensified in-migration from the rest of the nation. All such rates of growth and projected urban expansion are bringing forward well-known problems of other major urban agglomerations in the nation, and increased concern about existing natural resources and limitations of the region. Urban encroachment, the constant demands of increasing numbers of people, and newly established or expanding industrial concerns will require careful planning of physical space, thoughtful allocation of resources, and constant preoccupation with both the natural and cultural landscapes of the area.

In view of such major sociodemographic trends in the area, we need to look a bit more carefully at the types of major environmental problems confronting Colorado.

There is general agreement among various writers and researchers that the major natural environmental problems have the following major sources.

1. Destruction of once productive environments by pollution of air, water, and soil because of irresponsible or uninformed land development, and by incompatible use of natural settings.

2. Destruction of natural species by pollution, spoliation of natural habitats, or by irresponsible hunting and farming practices.

3. Threat to life, health, and property from pollution of air, water and soil through the maintenance of unnatural environments and inadequate waste-treatment procedures, and by patterns of consumption encouraging irresponsible use of available resources.

Other parts of this book are attacking in more systematic fashion various aspects of environmental problems in the region. We need only briefly introduce some major types of environmental challenges and keep in mind, at the same time, that most of these problems can be traced to the patterns of life of the citizens in the state, the lack of provisions for systematic planning, and to the larger trends of growth which imperil the "fragile environment of the Rocky Mountain States."

The crucial point here is that rather than emphasizing the physical aspects and dynamics of the surrounding environment, our emphasis is on the institutions, behavior, and cultural values of the population as they relate to the all-encompassing natural world. Or, once again, the social practices and life styles affecting the use (and misuse) of natural resources is the important differentiation when discussing "social aspects of the environment."

To start with, among the major problematic situations is, of course, the rapid population growth described previously, not only in terms of its total size, but also in terms of an unbalanced spatial distribution within the eastern part of the state and in the urbanized front range corridor.

Equally important are problems associated with water resources. Water is the life blood of the west, and land without water is almost useless. Various commissions and various reports have already indicated that the region known as the mountain and western states is expected to have water shortages by the year 2020. In Colorado, water development on a grand scale is approaching an end. In particular, the urban water picture seems to be most challenging, since increasing demand will increase competition with agricultural consumptive use (which accounts for more than 90 percent of the total water use). For example, Denver presently serves 750,000 people with a per capita consumption of 209 gallons of water a day. Maximum daily total consumption has reached more than 394 million gallons of water. If population growth follows present forecasts, water must be reaching metropolitan Denver by the early 1980's from supply systems not yet in existence. Throughout many of the arid areas in the west, the choices are becoming rather narrow: either total use is brought into line with supply, or one type of water use might be sacrificed to maintain another. The high dominance of consumptive use by agriculture has brought forward very strong questions as to the policy of encouraging agriculture in rain-short regions while allowing land in moisture-rich areas of the country to lie idle. The constant hunt for water in the west is coming under increased criticism, especially for big projects designed to bring more of it to arid lands.

For the mountain states, as well as the west in general, one thing is becoming apparent — water needs exceed supply, since the total water demand for the west is put at 215.4 billion gallons per day by the year 2000, nearly 40 percent above the maximum dependable stream flow of 154.1 billion gallons per day. It should be noted, however, that in recent studies prepared for the National Water Commission, more optimistic projections concerning future water options have been made. It has been indicated that projected domestic demand and exports of food in the year 2000 could be met with some reduction in the use of water for irrigated farming. Scarcities of water can be met with the release of water from other uses, but all such efforts would require much more careful consideration and planning as to what the future of the state might be, as well as efficient management, and regulatory counter-incentives such as stricter enforcement and pricing policies. At the same time, it should not be forgotten that as a result of reduced water supply, insufficient stream flow may create problems for diluting waste and, therefore, may accentuate water pollution. Problems of consumptive use and stream flow requirements are also compounded by on-site water requirements, such as the preservation of wildlife, but are also important ingredients of the esthetic and recreational attraction of the region.

Essentially, if we are to understand the social context of the limitations of the environment in Colorado, especially with reference to problems of water use, the attitude of people in the state needs to be put into proper perspective. Many people in the area express the belief that water should be made freely available to everyone who "needs it." It is becoming apparent in view of national, regional, and local trends of population growth that a rational water allocation is not only a means of controlling growth, but an essential component of a policy of survival in a rather hostile environment.

Of equal importance to the trends and factors threatening the fragile environment of the region are problems that can be traced to the irresponsible use and distribution of land through misuse and single-interest community development. The major urban oases of the mountain states are experiencing the land boom associated with other megalopolitan spreads of the nation. The urban growth and the centrifugal urban sprawl are creating areas that are no longer cities or countrysides but amorphous urban masses of no distinct character and in many cases unrelated to the surrounding natural environment. Many cities of the state are growing like boundless, amoeba-like agglomerations creeping into the surrounding arid land. What is happening in this state should not be difficult to recognize from other areas in the country — there is unbridled land speculation and an effort of various developers to participate helter-skelter in a game of highly promising and profitable investment. This land boom is taking place with vast areas of grasslands being prepared for subdivision and with relatively barren acres of sage and scrub being sold at exorbitant prices. Quite a number of developers are busy destroying with their bulldozers the very quality of life that is being extolled as the major attraction of the region. There are at least 229 large-scale subdivisions being planned, platted, and sold in Colorado today. These subdivisions alone cover more than 800,000 acres of land. It is estimated that 400 to 500 subdivisions of less than 500 acres are also being platted and sold. The inclusion of these in the list would bring the total acreage of land documented as being subdivided in Colorado to over one million acres. In a recent progress report of the Colorado State Land Use Commission, it was reported that all land sales activity (recorded plats, expanion of existing subdivisions, and areas under option for development) is estimated to amount to a total of 1.5 to 2 million acres.

Such on onslaught on the environment has far-reaching consequences. For example, because the slope of most developments is steep, they hold little water and homes must compete for scarce underground pools. At the same time, the water supplies of various homes are polluted, since septic tanks do not work well in less than four feet of top soil and the slopes have much less. Problems of this haphazard growth exist also in terms of the access roads that need to be built and which, in turn, alter the natural flow of moisture.

Water and land are but a few of the conditions of the fragile environment in Colorado. There are also many other conditions of the area (and warning signs) which show that further growth and continuous trends of excessive consumption may lead to a geometric increase of problems associated with orderly planning and the harmonious man-environment relationship. To cite only a few of these problems:

The airshed is of critical importance since air pollution, particularly in the metropolitan Denver area, has become more than a simple nuisance. Problems of pollution from increased population and prevailing patterns of transportation will be accompanied also by controversies arising from the development in the late 70's and 80's of massive-scale strip coal mining to provide fuel to meet the country's increasing demands for electric power. In addition to present efforts in electric power generation, much more expansive plans are projected for the future, including strip mining for coal gasification and exploitation of the vast fields of oil shale in the mountain states. All in all, vast topographic and environmental upheavals are expected to occur in the region as exploitation of natural resources takes place.

Not only large power projects, but also day-to-day problems of waste disposal and sewage facilities are of crucial importance to the region, given the generally fragile ecological environment and the continuous municipal and industrial pressures. Pollution problems are also generated from the staggering amount of animal waste.

Similar problems of environmental disruption can be traced to the challenges imposed in the surrounding cultural environment from increased noise, problems of waste heat, and from the assault on the esthetic integration of the beautiful surrounding environment.

The list of problems affecting the quality of life in Colorado can be long, and so also can be the discussion of the many-faceted implications of environmental assaults. Perhaps we need at this point to summarize the broad trends impinging upon the environment of the state, thus providing clues as to the kinds of responses that need to be made if we are to maintain the attractiveness that characterizes life in this region. Among such trends we should include:

1. Rapid population growth.
2. Urbanization, especially metropolitanization.
3. Demands for recreation both from the citizens of the state and from increasing number of tourists.
4. Effluent problems as a result of air, water, and land pollution.
5. The role of Colorado as an energy supplier.
6. Transportation inbalances.
7. Decline in irrigated agriculture.
8. Increasing consumption and style of affluence.
9. General political and economic changes.

Environmental Responses

It has been repeatedly indicated that there is widespread recognition of the need to both reestablish and continuously maintain the harmonious relationship between man and his surrounding environment. For Colorado this quest is of utmost significance and of vital importance for the survival of the state.

Our responses can be shaped through an understanding of the requirements of social planning. In this process, the shape of physical structures and the organization of collective life largely determine the quality of life, as exemplified in two different but complementary goals — economic efficiency and social effectiveness. Colorado has the opportunity (although time is running out) to avoid many of the errors of haphazard growth and unplanned future which occurred in other states of the nation. The existing natural resources and the beauty of a most scenic environment need to be interrelated with community environments which will maximize social policy goals. The present "boom" mentality ignores a desired balance between overall population and a viable community environment. The disfunctional consequences of superimposed urban sprawl and speculative subdivisions must be averted by good design, utilization of open spaces and natural landscapes, and by a creation of smaller but functionally linked communities. The State of Colorado established in 1970 a seven-man Land Use Commission, a first step in an effort to develop a specific land use policy that would help the planned development of the state.

To generalize, we may indicate that the control of future growth of the population of the state can be achieved through three different, but interrelated alternatives, i.e., local land use alternatives, regional coordination, and finally statewide policies. Specific means for the accomplishment of cogent planning in all these alternatives include:

1. Growth moratoriums
2. Zoning
3. Open space preservation
4. Regional planning
5. Urban renewal and public housing programs
6. Environmental policy acts
7. Statewide land use plans
8. Coordination of the federal relationships of the region, especially in the context of a national growth policy
9. Environmental policies encouraging greater clustering of residential, commercial, and industrial areas
10. Strong legislative control over the allocation of water among competing demands.

At this point one should indicate, however, some basic principles of resource utilization around stated objectives combining public welfare, economic growth, and ecological preservation. There should be a recognition that *resources are part of the public domain*, to be invested and managed through development and multiple use in order to achieve both ecological preservation and larger ethical, esthetic, and cultural goals.

It is the last point which brings forward again the two interrelated dimensions of the environment. The objectives of a natural resources policy recognizing the social needs of the people of Colorado will be made by a balancing of three important dimensions:

1. *Efficiency* or the growth and material development of the state so that a solid base of economic sufficiency may be maintained.

2. *Equity* or fair access of resources and consumption to different elements in the population. However, it should be recognized that who gets what (equity) interacts with how much there is (efficiency) and that, therefore, certain trade-offs need to be made.

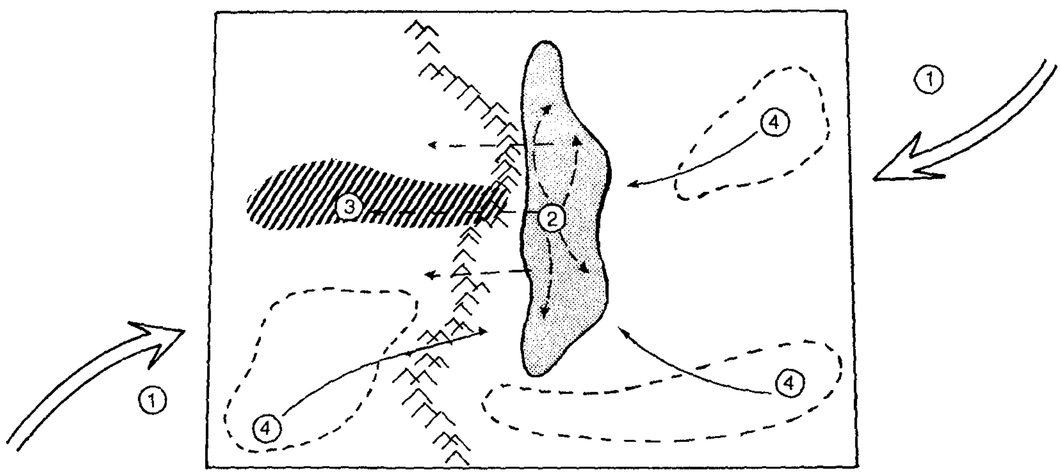
3. *Environmental management* which finally underlines the idea of what will be the rational trade-offs, given the limited resources of the region. Indeed, environmental management may in some respects clash with the quest for equity for all citizens of the state.

We have now come full circle to the key issues underlying the social aspects of the environment in Colorado. We may be able to summarize our line of attack by redrawing the map of Colorado in order to show the problematic areas. The following map is an impressionistic account of how a social scientist views Colorado through his own specialized eye. This map shows four major areas of concern where all the previously described trends and environmental disruptions are challenging the quality of life associated with the salubrious and majestic environment of the Rocky Mountain States.

We can also summarize the previous argument in a descriptive diagram that exemplifies the major trends, causes, responses, and consequences as a result of an interrelated number of conditions characterizing the social aspects of the environment in Colorado. What this very abbreviated chart indicates is that if we are to avert future disaster, certain policies need to be established early; otherwise, if present trends continue, not only will present problems be aggravated, but envisaged alternatives will be increasingly eliminated.

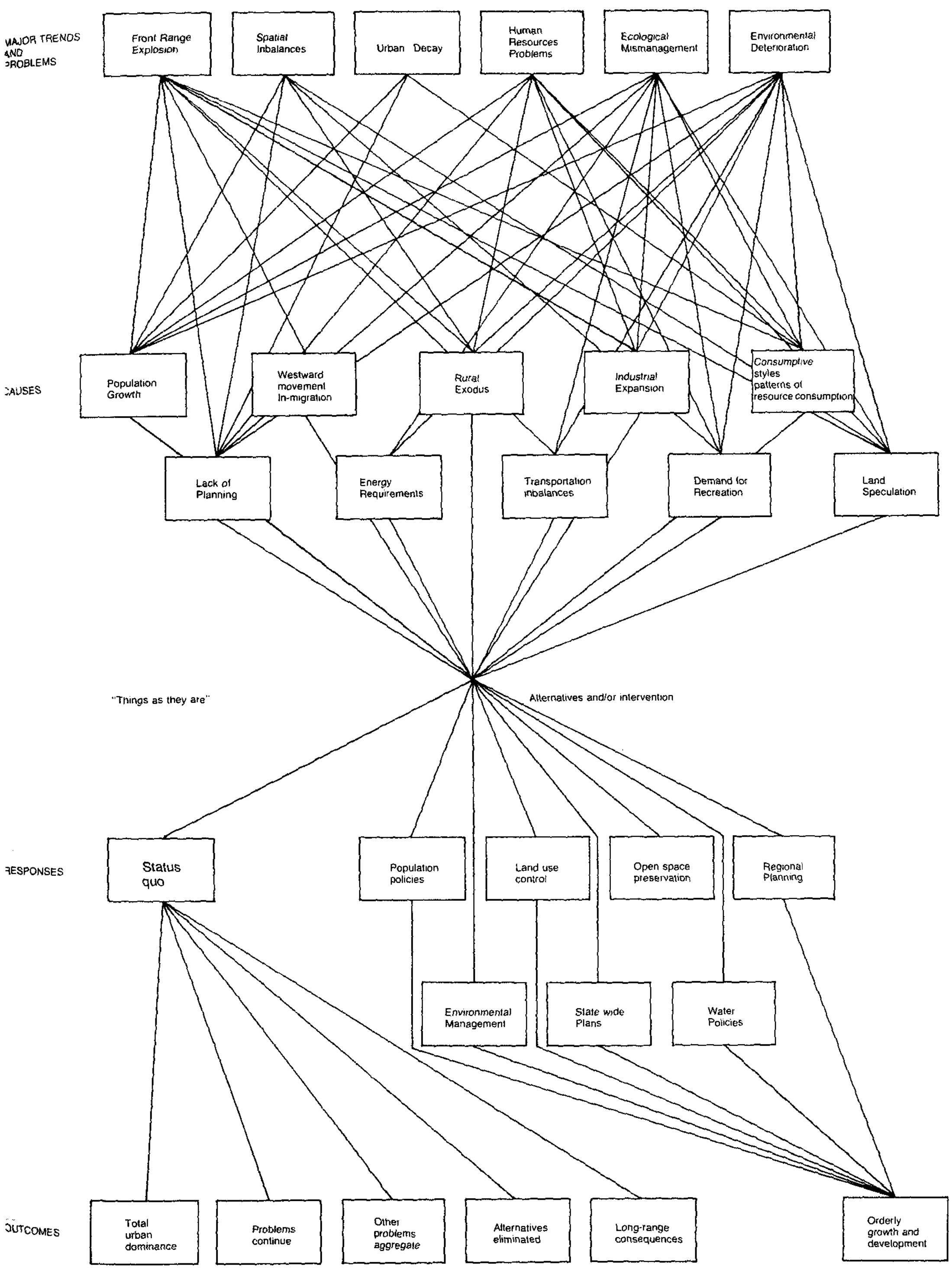
Despite many dire predictions, there is reason to be optimistic about the future of the state. The general awareness of the environmental plight, as well as the understanding of the fragility of the mountain region, is being translated into more specific recommendations and courses of action. There are strong indications that there is at least an implicit popular mandate for halting rampant and disastrous growth. The cry "think small" is spreading, and broad policies are emerging to avoid the haphazard growth of the region.

Formal and informal responses to the challenge of the area, as well as the need to maintain and enhance a region of particular beauty and of significant cultural satisfaction make it imperative that every means available and every innovative scheme of planning be used to guarantee both survival and fulfillment, or safety and quality of life for all people in Colorado.



An Impressionistic "Socio-map" of Colorado

(1) In-migration from the West and East
(2) Megalopolitalization and suburban sprawl
(3) Mountain "urban hinterland"
(4) Rural exodus, rural depressed areas



Major Trends, Their Causes, Alternative Responses, and Probable Outcomes in Colorado

Philosophical Aspects of the Environment

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"Philosophy bakes no bread," runs an old lament. Yet the hand is joined to the mind; action rises from belief. Ecology, when it becomes human ecology, thrusts man into a *logic* of his *oikos,* his home; ultimately it turns on a state of mind. The activist will soon become impatient with just "thinking." We concede that we often must act with unclear heads and, sometimes, understanding comes after action. But "Act now, think later" is a slogan the inadequacy of which has been amply demonstrated in environmental transactions. Granted that, untranslated into pragmatic proposals, even the soundest ego-logic is useless; ponder, on the other hand, the mischief done by a faulty one. *Environ mental* competence presupposes a mindset.

Nature is perhaps the most ancient philosophic category, yet the genius of many centuries has, ultimately, hardly left nature less enigmatic. We begin in one discipline, whether philosophy or physics, or biology or geology, only to find interfaces with many, whether geography, or economics, or politics, or art, or religion. We know, only to find the unknown vaster. We search, to find that the search returns upon ourselves, for the measure of nature requires the measure of man. Of late, this perennial quest has been thrown into fresh ferment. What is the temper of this ecological reevaluation?

Ecology,The Ultimate Science?

Ecosystem science is being often offered as an ultimate science that synthesizes even the arts and the humanities. "Although ecology may be treated as a science, its greater and overriding wisdom is universal," claims Paul Shepard, introducing an influential anthology, *The Subversive Science*.[1] Its first law and commandment is the dynamic steady requisite between organism and environment, homeostasis. Popularly, this yields needed recycling. Pragmatically, few will quarrel with insistence on a balanced budget. Philosophically, though, if proposed as an ultimate principle relating man to nature, there arise some crucial questions.

How far is man so continuous with nature that he must accept environmental limits? Is the steady state, for instance, compatible with unending progress? Does it compel a no-growth economy, or even a reduction of our standard of living? To answer, we need an inventory of potential resources in materials and energy, but also we employ axioms about an ever-advancing technology, limitless scientific development, what counts as betterment, and the wits of man in bypassing nature's limits. The presumptions of ecological spokesmen are strikingly reminiscent of the debate about geographical determinism — the belief that the physical environment significantly limits and fixes the character of a society. Man must submit to and operate within certain natural, ecological givens.

Doubtless he must. Yet much of the Western genius lies in its sense of man's discontinuity with nature, a vision awakened in us by the Hebrews and Greeks, and climaxing somewhat paradoxically in modern science as it uses man's knowledge of his natural connections to achieve an omnipotence through technology. This mindset regards as a tragic, oppressive mistake man's immersion in cyclic natural rhythms, his submission to the web of nature. Precisely this led to the stagnation of preliterate societies. A requisite of modern society is that man discover his uniqueness — his linear history, creativity, progress — by which increasingly he masters nature, turns it to his advantage, and remolds his environment to his liking. Against this, the ecological mood recalls us to a wisdom of relatedness, of man's necessary linkage to biological communities, to an affirmation of our organic essence. Can we reaffirm this without compromising man's enormous adaptive capacities in his relationships with nature?

Nature approximates but never long maintains a steady state; evolution is superimposed on equilibrium, rather as a melody develops against a rhythm. Disequilibrium generates the novelty of process. Evolution too has profoundly influenced our outlook, and musn't we blend the vector with the circle to get the spiral? In human history, might not homeostasis, however necessary, be but a half truth, true only when complemented by man's advancing environmental competence as he civilizes his

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[1] *Paul Shepard and Daniel McKinley, eds.,* The Subversive Science *(Boston: Houghton Mifflin, 1969) p. 4f.*

planet — a transformation that may well involve *continual disequilibriums, studied replacements*, and alterations of the natural ecosystems?

Ecology as an Ethical Science

He who would be a philosopher of nature must soon learn the naturalistic fallacy. The disciplined logic of modern philosophy has found itself unable to move from an *is* to an *ought*, from a *scientific description* to a *moral prescription*. Alternately stated, science is value-free; nature is amoral. In a classic inquiry, John Stuart Mill asks whether one ought "follow nature?" If nature means the sum of all phenomena including human agency, then man trivially follows nature; he cannot do otherwise. Natural laws are unexceptionable. If nature excludes human agency, then all human actions consist in altering nature and all useful ones in improving nature, and the advice to follow nature is by definition irrational; human agency is inevitably nonnatural. Moreover, much or perhaps most of what nature does, if regarded as morally prescriptive, is immoral. Mill recounts at length nature's ferocity, brutality, and indifference. Study nature though he may, and allowing all prudence, Mill can find nothing there which is right at all. "Conformity to nature has no connection whatever with right and wrong."[2]

But the ecologist has recalled another philosophical heritage. Western thought has been ambivalent; other sages, with different logic, have confronted nature to discover a larger wisdom. Lest we listen with short memories, let us recollect this other legacy, illustrated for instance in the Romantics, whose love of nature infected so many of the pioneers of the conservation movement. Emerson, for instance, in an equally classic appraisal, argues that nature yields commodity, beauty, wisdom, and discipline. When poetry and mysticism complement science, nature educates the character and serves as the touchstone of values. Though the vision proves complex and demanding, it is in environmental encounter that Emerson discerns the essence of morality. "Right is a conformity to the laws of nature so far as they are known to the human mind."[3]

Though the minority paradigm in recent philosophy, how remarkably has this claim been reappearing with the ecological turn! Ian L. McHarg, for instance, insists: "We must learn that nature includes an intrinsic value system."[4] In an article significantly entitled "The Steady State: Physical Law and Moral Choice," Paul B. Sears writes, "But morality today involves a responsible relationship toward the laws of the natural world of which we are inescapably a part."[5] Roger Revelle and Hans H. Landsberg introduce a prestigous study: "Science has another, deeper significance for our environmental concerns . . . This is the building of the structure of concepts and natural laws that will enable man to understand his place in nature. Such understanding must be one basis of the moral values that should guide each human generation in exercising its stewardship over the earth. For this purpose, ecology . . . is central."[6] In deservedly a seminal essay, Aldo Leopold's "Land Ethic," we are urged, "A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise."[7] Exceeding prudence and pragmatism, man's alignment with ecological law has become the great commandment. Ecology is an ethical science.

Ecology and Evolution

However prophetic these insights, correcting as they do the contemporary devaluation of nature, their confidence and exhuberance do

[2]*John Stuart Mill,* "Nature" in Collected Works *(University of Toronto Press, 1969), vol. 10, pp. 372-402, cf. p. 400.*

[3]*Ralph Waldon Emerson,* Nature, *facsimile of the first edition (San Francisco: Chandler Publishing Co., 68);* Journals *(Cambridge: Riverside Press, 1910), vol. 3, p. 208.*

[4]*Ian L. McHarg, "Values, Process, and Form," in Robert Disch,* The Ecological Conscience *(Englewood Cliffs, N.J.: Prentice-Hall, 1970), p. 21.*

[5]*Paul B. Sears in* The Subversive Science, *p. 396.*

[6]*Roger Revelle and Hans H. Landsberg, eds.,* American's Changing Environment *(Boston: Beacon Press, 1970), p. xxii.*

[7]*Aldo Leopold,* A Sand County Almanac *(New York: Oxford University Press, 1968), p. 224f.*

well to be chastened by the fires of a related query. After Darwin, it first seemed to the tough-minded that the new science endorsed a kind of ruthless egoism, a gladiatorial "tooth and claw" ethic; then, oppositely, repulsion from this prompted others to search for an ethic which abated evolutionary evils. Still others selected ethically significant trends. Evolution promotes life — survival and increase, or harmony, or integration, interdependence, and so on. But the selection was problematic, for did not evolution equally extinguish life, destroy and decrease species, disintegrate countless communities? Ethicists invariably supressed premises that guided their selection. A century of search for naturalistic ethics has been inconclusive.

The search for an ecological ethics must resurvey this ground, and that remapping has largely yet to be done. Whether or not it succeeds will rest largely on its reappraisal of nature.

The post-Darwinian world was, for all its law, yet an odious chaos and jungle. Though it partially anticipated it, the previous debate did not yet know the interdependent ecosystem. Only in recent decades have we been able adequately to set these conflicts within a dynamic web of life. Even predation, we now see, is beneficial to a species. Nature's savagery is much less wanton and clumsy than formerly supposed, and many are inclined to see in the ecosystem a certain wisdom not merely of awe but more nearly of reverence. So conceived, following nature is not merely a prudential means to independent moral ends, but is an end in itself, or, more accurately, it is within man's environmental relatedness that all his values are constructed. Man doubtless exceeds any environmental prescription, but this is not antagonistic to, but rather complementary to his world.

The ecological vision invites philosophical critique. But the problems are, hopefully, and alternately put, opportunities for deeper understanding. Take Leopold's intuition of the right as the preservation of the biotic community in which man is at once a citizen and a gentle king. How starkly this gainsays the alienation that characterizes modern literature, if not science, seeing nature as basically rudderless, antipathetical, in need of monitoring and repair! More typically modern man, for all his technological prowess, has found himself distanced from nature, increasingly competent and decreasingly confident, at once distinguished and aggrandized, yet afloat on and adrift in an indifferent if not hostile universe. His world is at best a huge filling station, at worst a prison, or "nothingness." Not so for ecological man; he is "at home" in his world, he confronts it with deference to a community in which he shares; his planetary home is seen as a thing of beauty to be cherished. The new mood is epitomized, somewhat surprisingly, in reaction to space exploration prompted by vivid photography of earth and the astronauts' nostalgia generating both a new love for spaceship earth and a resolution next to focus on reconciliation to it.

As we reengage our landscape, we must develop a calculus for an ecosystemic utilitarianism — the greatest good for the greatest number in a planetary community — a program that is likely to occupy ethicists for a generation but which is already urgently needed. How do we balance the need for electric power against the worth, for us and for our children, of wild rivers? How do we set the right to life of endangered species against the right to life of men who wish living and leisure space or resources? How in a hungry world do we justify a preservationist mentality with its dislike of pesticides and herbicides? In the most pressing and unanswered of the specific issues, how do we calculate the expense of environmental protection against its social costs, especially to the underprivileged? We do not know, and we flounder.

Man unexceptionally obeys natural laws, whether of gravity, of health, or of ecosystemic homeostasis. But because, virtually alone among the creatures, he can deliberate and foresee, there are options in his necessary obedience. Given the premise of the survival, if not the excellence and beauty, of the ecosystem and the worth of human life within it, natural law provides us with a norm which man flaunts to his detriment. Man chooses his route of submission, or should we say nature permits and frees him to be prudent — or moral? Like the laws of personal health, the laws of ecosystemic health may be obeyed or broken, only to be reckoned with at length. Is this ecological circumscription irrelevant, even alien, to our value systems, neatly articulated from it? Or do we prefer to say that man, construct values though he may, must set them in ecosystemic obedience? Some will swiftly reduce this to prudence, a matter of intelligent but not of moral action. But to the ecologically tutored, the current reappraisal suggests more.

God, Man, Nature

How thin the line between virtue and vice! Consider Western man's virile conquest of nature and its ecological transvaluation. His religion urged him with Genesis injunctions to subdue his earth. Reversing the faiths around them, the Hebrews put man over nature, not under it; they forbade astrology and the placatory fertility sacrifices to the baals of earth, sun, moon, and stars. Nor did they suppose nature to be evil, but rather God's good creation, neither to be hated, feared, nor worshipped, but rather "kept" and used as a bounteous gift. Man is the dominant creature, at once in nature and yet, under God, over it. The hierarchy is *God – man – nature*. This vision blended with and transformed the Greek rationalistic bent to sustain the medieval centuries.

In the secularizing of the modern age, though the monotheism lapsed, the axioms about man's dominion persisted. Comte's scientific positivism taught that "Civilization consists, strictly speaking, on the one hand, in the development of the human mind, on the other, in the result of this, namely, the increasing power of Man over Nature."[8] Emmanuel Mesthene, among the most persuasive of the apologists for technology, can ably rejoice that in our era man has broken his bondage to "the bruteness and recalcitrance of nature," no longer submissive to its hostility and indifference. "Nature is coming increasingly under control as a result of restored human confidence and power. We are therefore the first age which can aspire to be free of the tyranny of physical nature that has plagued man since his beginnings."[9]

But there is an inverse account which worries that this long entrenched legacy is obsolete, if not pernicious. In a celebrated address to scientists, Lynn White charged: "Modern science is an extrapolation of natural theology and . . . modern technology is at least partly to be explained as an Occidental, voluntarist realization of the Christian dogma of man's transcendence of, and rightful mastery over, nature . . . Over a century ago science and technology joined to give mankind powers which, to judge by many of the ecologic effects, are out of control. If so, Christianity bears a huge burden of guilt."[10] Or, take C. J. Glacken's forceful claim that our posture is aberrant. "The concept of man against nature as a philosophy has lost whatever creative force it had in the past . . . Man's technological innovative, conservative, conserving, humane role can be understood much better in an ecological setting than in one of contrast and antithesis."[11]

The ambivalence has long been there. Nature is wilderness yet paradise, demonic yet divine, asset yet enemy, jungle yet garden, harsh yet healing, means for man yet end in itself, commodity yet community, the land provoking man's virility yet evoking his sentimentality. The American's commonwealth violates yet rests on his continent, all his arts improve yet incorporate his surroundings, and in ultimate irony the pioneer slays what most he loves. There is oscillation: aggressivenesss/submission, exploitation/respect, struggle/harmony, insular man/man grafted to his landscape, independence/relatedness, man the conquering engineer/man the biotic citizen. What is new in the current debate is that the ecosciences are underscoring the continuities so as to humble the pride of the muscular West.

Can we sort out the truth? It is axiomatic in ecological models that there is not only mutuality but opposition in counterpoint. The system resists the very life it supports; indeed it is by resistance not less than environmental conductivity that life is stimulated. The integrity of the species and the individual is a function of a field where fullness lies in interlocking predation and symbiosis, construction and destruction, aggradation and degradation. Man's inclusion generates a philosophy, an *ought*, an intentionality, a transcendence. Yet for all his options, man remains an insider. He is not spared environmental pressures; for him they precipitate his uniqueness and define his integrity. But if we do not inhibit this truth with its complement, we fall into an anthropocentrism. Man is most optimistically the sole locus of values in a world merely tributary to him, or most pessimistically, orphaned, autonomous, lost in a hostile cosmos.

A Creative Struggle

Kept in its environmental context, man's humanity is not absolutely "in" him, but is rather "in" his world dialogue. His integrity rises from transaction with his opponent-partner and

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[8] *Auguste Comte,* Early Essays on Social Philosophy *(London: Routledge, 1911), p. 144.*

[9] *Emmanuel G. Mesthene, "Technology and Religion," in* Theology Today *23 (1967): 481-495.*

[10] *Lynn White, Jr., "The Historical Roots of Our Ecologic Crisis,"* Science *155 (1967): 1203-1207.*

[11] *C. H. Glacken, "Man Against Nature: An Outmoded Concept," in Harold W. Helfrich, Jr., ed.,* The Environmental Crisis *(New Haven: Yale University Press, 1970). 127-142.*

therefore requires a corresponding integrity. If we cannot derive values even from ecological facts, neither ought we to so locate values in man as to deny them to the nature which encompasses him. Thus the technological antagonism of man and nature is an ecological half-truth and when taken for the whole, inverts the true constitution of experience, which is that human nature is deeply rooted in, indebted to, and conditioned by nature, and that man's valuation of nature, like his perceptions, is drawn from environmental intercourse, not merely brought to it. Can we achieve a synthesis which preserves the dichotomy as a creative struggle exhibiting the excellence both of man and of the world within which he is set?

Could it be that the human presence is most noble when reciprocal to planetary community, when man's mastery over nature interpenetrates his submission?He may and must moderate or mind his world, yet the more competently and effectively he manipulates, the more urgently he must respect the worth of his empire. If he profanes nature, he profanes himself. Surely it is cardinal that his dominion be a commonwealth that provides for the integrity of all its component members, and that he govern in love.

Political Aspects of the Environment

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The current concern for environmental quality and control is focused upon a multitude of physical and social conditions that are perceived to be threats to the quality of life and perhaps even to the maintenance of life itself. Various individuals and groups concerned with the problem of environmental quality define the problem quite differently. They disagree as to the seriousness of the problem, the elements of the problem that are the most important, and the appropriate priorities for intended remedial actions. There are other individuals and groups that see the environmental movement as a negative force in the society which is diverting attention from the "real" problems such as economic development, racial progress, individual freedom, and social justice. The development of public policy designed to preserve the environment is further complicated by disagreements over the extent to which the institutions of government should intervene in the private sector and the relative roles that should be played by governments at the national, state, and local levels. These conflicting perceptions have made the environment into one of the most significant political issues of our time. There is general recognition that the political process is the primary instrument through which effective societal goals for environmental preservation and renovation must be established and through which the costs and benefits associated with such programs must be allocated. Any plan for environmental quality which ignores the political components of the problem is bound to fail.

Dimensions of the Problem

The environmental issue is marked by a large number of related interests and concerns. A common dimension of these conditions is that they all involve undesirable consequences of the intrusion of the activities of man into the natural ecological system. Some of the more frequently articulated dimensions of the problem which illustrate its diversity are (1) the dissipation and waste of nonrenewable resources such as basic minerals, fossil fuels, and wilderness area; (2) the over-consumption and destruction of renewable resources such as timber and wildlife; (3) the destruction of natural beauty and other aesthetic values by haphazard development and reckless disposal of solid wastes; (4) the threats to human health and the ecological system that result from the fouling of the air and water through indiscriminate techniques of waste disposal and the use of pesticides and herbicides; (5) population growth which leads to the overcrowding of urban areas, stress upon available supplies of natural resources, the destruction of privacy, and a general decline in the quality of life; and (6) the destruction of the oceans and the atmosphere to the extent that the survival of animal life on the planet is threatened. These conditions are representative of the infinite variety of the components of the current environmental crisis and the competing perceptions of the nature and seriousness of the problem.

The conditions that have activated the environmental issue are the additive effects of man's search for economic growth, personal freedom, and an improved life. They represent either unanticipated negative consequences or what have been considered tolerable costs of purposeful choices of man in the pursuit of highly valued goals. These goals have traditionally been pursued with little attention being given to the impact of the activities upon the quality of the environment. Air and water, for example, have been treated as free goods that are available in ample supply to dilute and carry away unlimited amounts of the wastes of industrial production, automobile exhausts, sanitation systems, and other assorted debris thrown off by a modern affluent industrial society. The costs of these activities are absorbed by the environmental system and they generally do not enter into the cost calculations of the persons responsible for pollution. The bulk of environmental destruction is the cumulative effect of many private activities, any one of which has only a negligible impact upon the quality of the environment. The internalization of the costs now borne by the environmental system by any single individual or firm may substantially increase the burden upon the individual without the achievement of any significant benefit to anyone. There is very little incentive for the individual to increase his personal costs unless he can expect that all other persons similarly situated will assume similar costs and that there will be substantial progress toward the goal of a clean and healthy environment.

The major sources of environmental degradation are activities of man designed to improve his life by increasing productivity, achieving competitive advantage in industry, and expanding the range of choice that is available to the individual. These intensely held values are most frequently achieved at the cost of environmental destruction, which until recently has been disregarded in the decisionmaking process. Decisions have been guided by the demands of the market system and the whims of individual preferences. The interest of a quality environment has gone unrepresented in the process. A significant change in this state of affairs requires that environmental concerns be interjected into the decisional process so that the costs to the quality of the environment become a part of the calculus of all relevant decisionmakers. There must be an internalization and reallocation of the costs that have traditionally been imposed upon the environment. Coordinated activity is required to assure that there are adequate incentives to shift the behavior of significant numbers of persons into patterns required to reverse the current trend toward environmental decay. Unless we can expect a sudden all-embracing conversion experience that establishes environmental concern as a core value in all members of the society, some external changes will be required in the norm system of the society. The agencies of the government must serve as the primary source of rules which restrain behavior destructive to the environment — at least in the short-run. Government, the effective voice of the collectivity, is the only society-wide institution that can represent and respond to such a diffuse and abstract interest as the "environment." Formal government is the only institution with sufficient power and control to effectively demand the internalization of the costs of environmental protection and to require the cooperation of all members of the society.

Why Governmental Intervention?

The necessity of governmental action for significant change in the environmental area suggests that those who are concerned with environmental improvement must become fully aware of those elements of politics which shape the nature and effectiveness of governmental policies. There are a number of basic factors operative in the American political system that may facilitate and/or retard the development and effectuation of viable public policy that is designed to bring about environmental protection and control. Only a brief survey of the most significant dimensions of these factors can be provided.

The use of government as an instrument to achieve environmental quality involves a great deal more than a judgment by avid environmentalists that there should be a law protecting their preferred interests. Even the determination that environmental control is in the "public interest" by significant numbers of persons in the society is at best a useful first step toward successful governmental intervention and effective public policy. The development of an awareness of the importance of environmental concerns must be followed by the careful design of means to achieve specific kinds of environmental improvement, the building of sufficient amounts of political support for the specific policies that are designed, the adoption of these policies by relevant political and governmental structures, the execution and administration of these policies with sufficient vigor to guarantee that the goals of the policies are achieved, and the constant monitoring of the programs to evaluate the extent to which they are contributing to goal achievement. The long range achievement of a generalized goal like environmental quality requires that long term, continuous, and intensive attention be given to each of the steps in the process. There are a number of core features of the American political system which contribute to this requirement and which militate against significant progress. Those interested in using government to improve the environment must be aware of those factors which lead toward this inertia in the system and carefully design tactics and strategy to overcome the resistance to change.

The two most general factors are the general organization of governmental bodies along democratic lines and the very broad division and fragmentation of political power in the society. The democratic premises upon which the system is based require that the agencies of government be responsive, responsible, and accountable to the people. A complex set of groups, organizations, and processes have developed to provide the linkage between political officials and the people. This structure is of such a nature that it gives differential power and influence to certain individuals and groups. Attempts to interject environmental elements into public policy must take into account the present structure of power and develop ways and means to reorder these established relationships. Environmentalists must so order their activities to assure that governmental officials are responsive to their interests and give a higher priority to environmental interests in official decision making.

Formal political power is divided in two different ways in the American political system. On the one hand, authority to act is divided among governmental agencies at the national, state, and local levels. A basic determination of which level of government should act in a given problem area must be made. The two criteria used in making this determination are: (1) which level of government has the legal jurisdiction and the resources to bring about the goals that are desired, and (2) which level of government is most likely to be responsive to the demands that are to be made. Many relevant policies involve cooperative efforts by two or more levels of government which requires that influence be applied at all levels for successful goal achievement. On the other hand, the power to govern at each level is divided among a large number of persons and structures, all of which may be important in bringing about the desired state of affairs. Legislatures, courts, executive agencies, and independent boards and commissions share in the power to govern. Most successful policies require the coordinated or at least supportive activities of a number of these structures. Innovations in policymaking can generally be blocked by negative actions of any *one* of them, while those seeking changes in the status quo must bring their influence to bear upon all of them. The structure of power in the American political system provides a large number of points of access to individuals seeking governmental support for their interests, and this state of affairs tends to favor those who wish to maintain public policy in an established pattern.

Effective Public Policy

The recent discussions of the environmental crisis have been quite successfull in developing an awareness that serious environmental problems are present in the society. However, a willingness to pay substantial costs for preservation and improvement has not kept pace with this growing awareness. Individuals are generally not willing to give up the convenience of the automobile, the desire for economic development and jobs, and excessive uses of energy that are required to bring about rapid improvement in air quality. Continued support for remedial activities depends on the development of means of environmental control that least threaten these core values. Alternatives must be selected not only on the basis of technological feasibility and the most effective means of control; they must also take into account the political and social acceptability of the proposals and the degree to which the alternative imposes unacceptable costs upon relevant groups in the society. A purist approach to the problem will probably result in a rapid dissipation of support and alienation from the ideal of environmental quality. Policies must involve compromises between the goal of environmental quality and other core values of the society which provide for incremental advance at an acceptable level of social and economic cost. The development of policy along these lines, supplemented by continued education and propaganda relative to the importance of environmental values, can be expected to have a reasonable chance of achieving progress toward the reduction of environmental decay and movement toward the improvement of environmental conditions of the society.

The adoption of remedial public policy is dependent upon the maintenance of a high level of intensity by those who are leaders in the environmental movement and a continued broad base of support for environmental improvement. Governmental agents will be responsive to demands flowing from such a base and will support well-worked-out proposals for program development. The interest of environmental quality can achieve a powerful position which will lead to the placement of environmental policy in a high priority position on the agenda of government. The adoption of policies that are designed to bring about the desired goals involves substantial danger for the environmental movement. There is a clear tendency to believe that the adoption of policies and the development of programs represent successful goal achievement and to diminish interest and intensity of involvement in the area. Persons who have been necessary participants in the demand for public policy frequently turn their attention to other public or private interests when appropriate policies have been adopted. However, the most critical factor is not the adoption of public policy but the consistent application of that policy to actual situations which alone bring about real change in alleviating the problem. Those interests that oppose the changes may be able to defeat the effect of public policy by gaining control or influence over the application and administration of the policy through time.

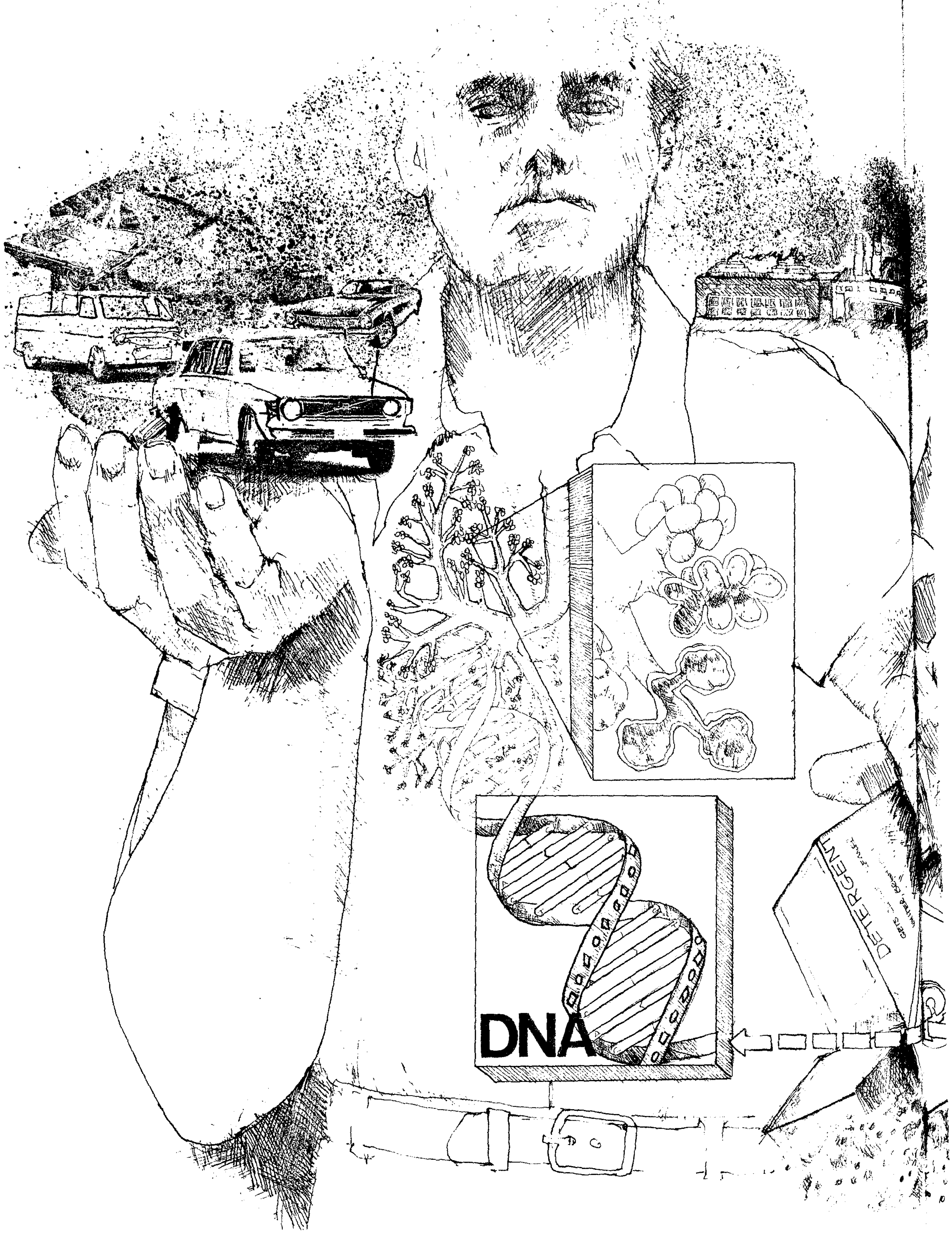
The most significant limitation faced by groups in the American political system, who are organized around the goal of developing support for broad public interest values such as environmental quality, is the ability to maintain the necessary interest, involvement, and pressure for the time required for long range goal achievement. Long term surveillance and systematic overseeing of the application and administration of public policies are necessary requisities of effective goal achievement in an open, diversified, and decentralized political system. Those who have a personal or economic interest in the subversion of public policy to protect the environment are much more able to develop stability of preferences and continuous interest than those who pursue a generalized goal in addition to their private interests. It will remain the economic interest of substantial elements of the society to restrict the application of certain policies designed to protect the environment as they apply to their businesses or private preferences. Slippage from governmental support for the goal of environmental quality can be controlled by the development of an ongoing, well organized, intense public that is able to maintain a permanent commitment to the goal of environmental quality. Environmentalists find themselves in the position of all reform groups. They flow from a perception of crisis; the goals that they pursue cannot generally be defined to be directly related to the private interests of their supporters; they are more successful in the area of shortrun policy adoption than they are in the arena of long term policy application. The environmental movement must evade the life cycle of reform movements if it is going to lead to effective permanent commitments to environmental improvement.

Summary and Conclusions

The environmental crisis involves a large number of individual problems related to the ecological system. Most of these are the consequence of purposeful behavior of man in the pursuit of highly valued social goals. Remedial action must rest upon changes in the value systems of substantial numbers of persons in the society or the design of alternative means of achieving presently held values without the current level of environmental destruction. The environmental consequences of action must be articulated as a specific cost and there must be self-conscious efforts made to calculate the nature of these costs and the ways in which they will be calculated. The fact that environmental destruction is primarily the result of the additive effects of many small private activities means that cooperative action on the part of the entire community is required to reverse present trends. The governmental system is the broadest institution available to channel collective efforts of members of the society into well defined programs for goal achievement. Therefore, the environmental crisis has become a very significant political issue and government has been selected as a prime instrument to guide and direct efforts toward environmental preservation and control.

The selection of government as an instrument of the environmental movement requires an understanding of the political factors which must be taken into account if effective change is to occur. The democratic nature of the system requires that substantial elements of the society be *persuaded* that environmental considerations should be given a high priority in policy development. As the interests in the society are very diverse, remedial policies must be designed that minimize the cost to other core values in the society. The rejection of such values as insignificant in comparison to environmental concerns will guarantee the selection of alternatives that are not politically viable. Compromise is required. The major achievement can be expected to be incremental advance toward the goal of environmental quality. The frustration caused by such slow change must not be allowed to diminish interest and activity or progress will not occur.

The fragmented nature of the political system requires not only that appropriate policies be of many governmental agents and agencies at a number of levels. The success of programs requires not only that appropriate policies be enacted into law but that they be administered in a manner that maximizes the basic goals of the policies. The overseeing of this aspect of the political system is the most difficult and critical aspect of the political process for effective goal achievement. Continuous attention to the entire process is required if substantial change is to be brought about. The political system can be an effective instrument of environmental improvement to the extent that substantial numbers of persons can develop and maintain long range consistent pressure for such a policy. The decline of interest in the value of environmental quality will lead to governmental activity which is either not relevant to the environment or designed to pursue other human goals even if they are destructive to the environment.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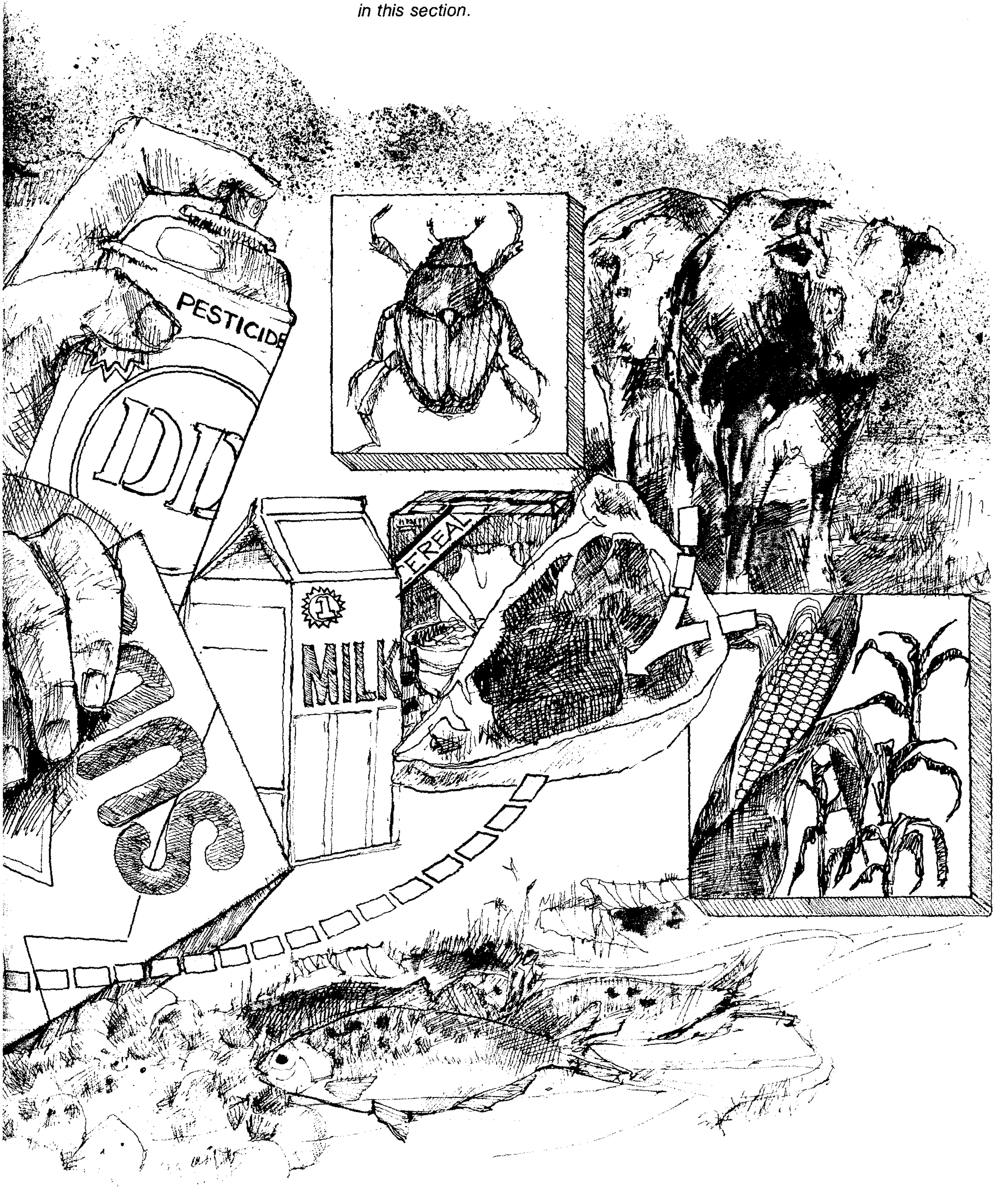
Current and Future Environmental Threats

What prices does man pay for polluting the environment? Genetic mutations due to exposure to chemicals or radiation, emphysema and lung damage, and the death of plants, fish, and animals are just a few of the possible consequences. What these pollutants are and how they affect living organisms will be explored in this section.



Human Physiological Concerns

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Man constantly strives to improve the quality of his life on earth. For example, to overcome pests which compete with us for food and spread diseases, man has developed a tremendous variety of biocidal chemicals of varying effectiveness, toxicity, and economic potential. Likewise, at home, at work, or on the road, man uses thousands of other toxic chemicals that help support and maintain our modern industrialized and technological society. Our concern is that the toxicity of some of these compounds is so great that they produce more problems and greater hazards than the problem they were created to solve. In addition, an even greater problem is that man has little or no knowledge of the long-term effects these compounds will have on human health and development or on the ecological balance of the earth. One can hardly contemplate the complexity of this problem because very little is really known about the balance and interdependence of life on earth. Many of the environmental pollutants most likely produce complex synergistic effects on living systems which are difficult if not nearly impossible to define. (6)

Common Environmental Pollutants and their Effects on Man

In this section the major effects of a few environmental pollutants on human physiological processes will be discussed to give the reader a broader feeling for the scope of the problem.

Chlorinated Hydrocarbons such as DDT, Dieldrin and BHC

We will begin our discussion of the effects of biocides on human physiology with DDT because it has been the target of much study, controversy, and legislation. (3) As a result of the notoriety it has gained and the potentially harmful effects it produces on man as well as other living systems, its use in the United States has been banned by an act of Congress.

Physical properties — DDT is a chlorinated hydrocarbon described as 1,1,1trichloro -2,2 bis (parachlorophenyl) ethane. The actual compound used as a pesticide is about 75% DDT and 25% various isomers (compounds having the same constituent elements but differing in molecular structure) such as DDE, DDD as well as other derivatives. DDT is very stable with an environmental persistence of about ten years or longer, exhibits great mobility in the environment, is relatively insoluble in water but very soluble in lipids (fatty tissue), and has broad biological activity as an insecticide.

Primary Effect of Toxicity — DDT, like most other chlorinated hydrocarbons, exerts its primary effect on all parts of the central nervous system. The effect is primarily on nerve impulse conduction and results in a state of hyperexcitability. In humans the first clinical signs of toxicity are a sensation of burning or itching of the tongue, lips, and face, and a tingling of fingers and toes. With large doses tremor appears, and there is a sensation of alarm, fear, marked uneasiness, and convulsions.

Secondary Effect of Toxicity — When DDT first came into popular use after World War II, its effects on humans were unclear and there was a variety of conflicting claims and counter claims about its effects. In one of the earliest studies on DDT in humans one researcher stated he felt tired, irritable, dull, mentally incompetent, heavy, and had severe joint pains. Later these observations were substantiated and a correlation between high DDT intake and liver damage was observed. Now there is substantial evidence to show that when people are exposed to DDT in reasonably high quantities it can affect a wide variety of body functions. (2) In small doses it can induce nonspecific changes in the drug detoxifying system in the liver which alters dramatically an individual's sensitivity to a wide variety of drugs. In large doses it can cause serious liver damage and even cirrhosis and hepatic failure. DDT's propensity for tissues with high lipid content results in a preferential uptake, storage, and gradual accumulation in the brain, gonads, adrenals, and fat cells of the body. One of the many notable consequences of this characteristic is a change in the pattern of sex hormone production and secretion. In addition, DDT can mimic the action of estrogen and induce growth in the uterus, vagina, and pituitary. Other investigators have cited pathological effects of DDT on the EEG patterns and structure of the brain, the neuroendocrine regulation of the body, the function of

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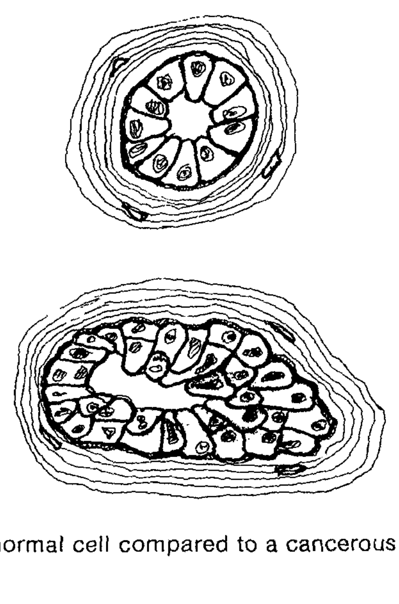
the kidney and the body's defense system. One should not become immediately alarmed after considering this list because these data were derived from cases where humans were exposed either accidentally or experimentally to high levels of DDT, while most people are exposed only to low levels. Such low levels probably produce at best only minor subclinical effects. It is not known whether these minor effects really materially affect the health and vigor of the general population.

One should be wary of continued exposure to moderately heavy doses of chlorinated hydrocarbons because there is a strong correlation between the accumulation of large amounts of these chemicals and the appearance of cancer in tissues such as the lungs, stomach, rectum, pancreas, prostate, and bladder. This correlation is particularly strong for people who use large amounts of pesticides in their homes. Such data, which increases daily, indicate that DDT and several other chlorinated hydrocarbons might also be carcinogenic and teratogenic agents. A carcinogen is a compound which induces cancer, while a teratogen induces harmful aberrations in fetal development. Teratogenic effects of DDT on fetal development are not yet well documented, but since DDT accumulates in fetal tissues at a more rapid rate than in adults, one should be wary of exposure to heavy doses of chlorinated hydrocarbons during pregnancy.



A normal cell compared to a cancerous cell.

Other chlorinated hydrocarbons — Other common and widely used chlorinated hydrocarbons are heptochlor, endrin, dieldrin and aldrin. Like DDT, they act on the central nervous system primarily in excitation. After heavy exposure the first signs and symptoms are nervous excitation, diarrhea, vomiting, atoxia and tremors. Later effects are cardiac and respiratory depression and finally in extreme cases, failure. A mild exposure is followed by dizziness, fever, loss of appetite, headache, muscular weakness, nausea and tremors. Most of the immediate effects result from intolerable interruptions of central nervous system functions within the body. Like DDT, most other chlorinated hydrocarbons slowly accumulate within the body, are chronically toxic, and produce liver and kidney damage even in small doses. They also alter the body's defense mechanisms and are carcinogenic as well as teratogenic. Finally, some of the clorinated hydrocarbons are converted into epoxides (potent mutagenic agents) by the liver. A mutagenic agent is able to alter the structure of genes; in extreme cases, this could affect the gene pool passed on to other generations.

Some of the chlorinated hydrocarbons like chlordane and lindane are extremely toxic. Both cause depression of the bone marrow and produce serious blood disorders. Fortunately, the use of these compounds is limited.

Organophosphates

These are phosphorothioate insecticides such as diazinon, malathion, parathion and TEPP. All organophosphates are nerve gases which produce a wide range of effects,from relatively harmless malathion to absolutely deadly TEPP. All exert their primary effect by inhibiting acetylcholinesterase, an enzyme responsible for breaking down the neurotransmittor acetylcholine into two inactive molecules, acetate and choline. Acetylcholine is required for the transmission of an impulse from one nerve to another or from a nerve to many other body tissues such as skeletal muscle, salivary glands, the gut, and the pancreas. When acetycholinesterase is blocked, the transfer of nerve signals is altered and a faulty response results. The first clinical symptoms of organophosphate poisoning in man are a runny nose and blurred vision. With time nausea sets in, followed by vomiting, excessive sweating, uncontrolled salivation and urinary incontinence. In cases of extreme poisoning, the heart beat is rapid at first, then gradually slows and finally stops. Terminal stages of poisoning are also characterized by heavy convulsions, coma, muscular paralysis and respiratory blockage. One might think that such potentially dangerous compounds would be used sparingly, but in 1968 sixty million pounds of parathion were manufactured in the United States, and this amount has increased markedly since the ban on DDT.

However, there are several advantages to the use of organophosphates in place of chlorinated hydrocarbons: a) there is no accumulation in the various tissues of the body; therefore, the danger of long-term chronic effects is dramatically reduced, and b) residues do not build up in the environment since the half life of most organophosphates in the environment and in the body is quite short. Recent evidence indicates that the persistence of most organophosphates is not as short as the manufacturers might have us believe. For example, organophosphate pesticide contamination has been detected in vegetables stored for periods of over seven months prior to retail distribution.

Many people have been seriously affected by persistent exposure to organophosphates. Most cases occur in the employees of manufacturers, ground sprayers, or crop dusters and in farmers who work around these materials full time. There are, however, numerous additional cases where migrant farm workers, suburban homeowners and even the total populace of small towns have exhibited overt symptoms of organophosphate poisoning and marked reductions in cholinesterase activity. In addition, there is good evidence that continued subclinical exposure to organophosphates can produce overt behavioral changes in individuals. Several different studies involving reasonably large groups of people exposed to organophosphates over long periods of time showed that some people exhibited marked schizophrenia with marked delusions, while others were severely depressed and had severe impairment of memory and concentration. When exposure to the pesticides was withdrawn, all individuals recovered (2,5).

Finally, some scientists believe that organophosphates are also teratogenic and carcinogenic to humans. This is questionable, however, since organophosphates are readily metabolized by the liver. First they are activated to phosphate analogs by oxidative microsomal enzymes; then they are rapidly degraded by cleavage at the aryl phosphate. It usually takes only about 20 minutes to degrade ~ 85% of the organophosphate accumulated from an acute exposure into innocuous water-soluble metabolites.

Carbamates

These are water-soluble insecticides or fungicides which are either anhydrides of ammonium carbamate or hydralysates of cyanamide. The fungicides are dithiocarbamates which are generally harmless to man but can cause bronchitis, conjunctivitis, dermatitis and pharygitis when one is exposed to large doses. The pesticides are dimethyl carbamates which, like organophosphates, are effective, rapidly reversible inhibitors of acetylcholinesterase. Since there are many similarities between the effects produced by carbamate pesticides and organophosphates on man, further discussion of this group is not needed.

Dinitrophenols

These are commonly used herbicides which increase the rate of oxidation metabolism and simulate hyperthyroidism in humans. In addition, their effects are cumulative, are not readily metabolized by the body, and are excreted very slowly. Patients suffering from mild dinitrophenol poisoning exhibit excessive sweating, thirst, and fatigue, and they usually have severe headaches. Unfortunately, the lethal dose of these compounds is small and there is no antidote. In severe cases of poisoning, the patient exhibits collapse, coma, cyanosis, fever, flushed skin, gastric distress, rapid deep respiration, warmth, sweating and tachycardia. Death results from hyperthermia.

The primary effect of dinitrophenols appears to be on a subcellular organelle, the mitochondria. Mitochondria are able to take the energy derived from the oxidation of foodstuffs and use it to drive ATP synthesis. ATP is a high energy compound which is used in most energy-requiring reactions of a cell. Dinitrophenols uncouple the reaction leading to ATP synthesis and the unused energy is given off as heat.

Pentachlorophenol, a chlorinated hydrocarbon, also uncouples oxidative phosphorylation in mitrochondria and produces symptoms similar to the dinitrophenols.

Polychlorinated Biphenyl

Polychlorinated biphenyls are widely used industrial chemicals that are synthesized by the direct chlorination cf biphenyls. In the past few years they have become an environmental pollutant of widespread occurrence. They produce, among other things, a skin disease characterized by severe acne. The most common initial symptoms are excessive eye discharge, swelling of upper eyelids followed by severe acne-like eruptions and hair follicle accentuation of the skin. In addition, recovery from polychlorinated biphenyl poisoning is extremely slow and difficult. In one case where extensive polychlorinated biphenyl poisoning was reported in Japan, many patients still had severe symptoms six years after initial exposure(4).

Mercury and other Heavy Metals

Organic mercury — organic mercury, such as ethyl mercury phosphate or methyl mercury, is commonly used as a fungicide in dusts and sprays and for synthesizing a wide variety of industrial compounds such as plastics. As a result of its widespread use, the amount of mercury in the environment has increased dramatically in the last several decades. It is not easily metabolized by the body, but accumulates gradually and has a predilection for brain, red blood cells, the liver and kidney. Organic mercury is a potent protoplasmic poison, having a particularly devasting effect on the brain and nervous system. The first signs and symptoms of mercury poisoning are headache, parathesias of fingers, toes, lips, and tongue, loss of coordination, a loss of lateral vision, and tremors. The severity of the poisoning increases for weeks and is characterized by emotional instability, speech defects, and in extreme cases coma and mental retardation. Recovery is slow.

The dramatic rise in the concentration in mercury in the environment has had some dire consequences for man. In Minamota, Japan, for example, 110 persons were killed or severly disabled and a number of babies were born with congenital defects as a result of eating seafood contaminated with methyl mercury discharged by a local plastics plant. Large amounts of salmon and other sea food have been confiscated by the FDA and destroyed because of high mercury content.

Although several countries have banned the widespread use of mercury, this country has taken no such action. In fact, mercury compounds are still used to coat a variety of seeds prior to planting(2).

Lead — Lead is an environmental pollutant of global distribution. When present in high enough concentrations, it has the ability to inhibit a variety of enzymes essential to homeokinesis within the body. In addition, it is cumulative and appears to be teratogenic and mutagenic. The primary source of lead in the environment is thought to be emissions from internal combustion engines.

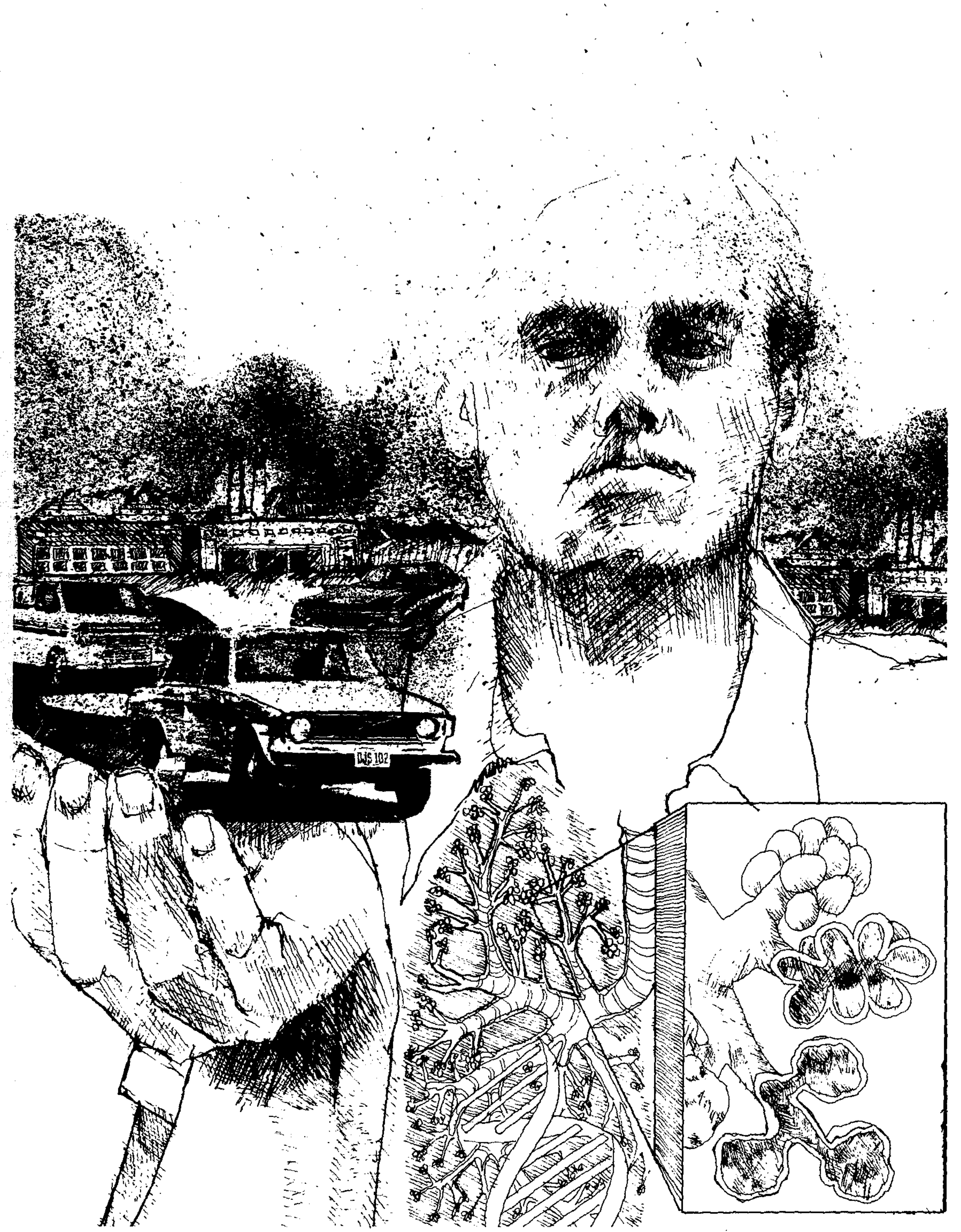
Other Heavy Metals — Heavy metal poisoning in man is produced by overexposure to copper, mercury, lead, molybdenum, nickel, thallium, tin, zinc, and others. The concentration of many such metals is increasing in the drinking waters of man as a result of poor mining practices, the unmonitored release of industrial wastes, and the excessive use and runoff of biocides in our landscape. It is difficult to estimate in any one area when the critical concentration toxic to man will be reached.

Other Pollutants

There are a wide variety of other noxious agents that are being poured daily into our environment, such as the fluorides. The total number is quite large, however, so the list above must be considered representative.

Future Environmental Threats

There is, as yet, little concrete evidence that the level of environmental pollution existing today is seriously affecting the health of the general populace. The primary goal of this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chapter is to point out that pollutants have the potential to do so, and therefore must be monitored with extreme care. In addition, even though it is dangerous one should not condemn the current-day practice of using biocides to control the spread of harmful organisms which serve as vectors of disease or which destroy our food crops. For the time being their use, hopefully on a more limited basis, is probably an absolute necessity. Attempts must be made, however, to develop new, less potentially harmful means of pesticide control and to find ways of applying biocides so that they affect only problem areas and do not spread through the biosphere. Even local gardeners should take care not to contaminate themselves, their families, and their neighbors. They should be completely familiar with the compounds they are using and the potential hazards they pose (1).

Some of the most serious long-term threats of environmental pollutants on human health come from the following areas.

1) Accumulation. Many pollutants are not easily metabolized by the body, have a propensity for specific tissues, and gradually accumulate at these sites. As a result, the concentration of these agents can slowly reach a potentially hazardous level even though the individual was never exposed to a single large toxic dose.

2) Synergisms. Many toxic chemicals interact with one another in such a way that their combined effects are far greater than either one used alone. This is an area of great concern considering the multiplicity of pollutants man is currently exposed to.

3) Mobility. Many chemicals exhibit great mobility via a variety of mechanisms and often wind up becoming concentrated, producing dire effects long distances from the initial point of application. In other words, people are constantly exposed to pollutants from sources and places they were not aware existed.

4) Long-term chronic effects. Many agents, although not immediately toxic, cause slow, gradual deterioration of a tissue or organ. Many pollutants, for example, are potential carcinogens and may produce cancer in a wide variety of tissues.

5) Development. An organism is usually far more sensitive during growth and development than it is as a mature adult. Many pollutants are teratogenic and induce birth defects in developing fetuses. Although not very much is yet know about this aspect of environmental pollution, it is an area of potential danger which must be monitored very closely.

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Psychological Consequences of Increased Population Density

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It becomes increasingly clear that we cannot sit back and wait for the future to happen without trying to shape it in some positive ways. But what ways are the best? The direction our plans for the future take must reflect serious thought and extensive research. It is not enough to conjecture that certain sorts of environments are better or worse for the survival of human civilization — the tools of science are appropriate and sufficient to help us make these most difficult decisions. One of the most profound questions which faces us concerning the structure of the future concerns the optimal and tolerable level of population density on the earth. There have been a number of theoretical speculations concerning density, a few survey-type collections of data to determine the consequences of current high density situations, and a very few controlled experiments to discover the actual psychological consequences of different degrees of crowding on human beings. I would like very briefly to consider a few of these and to indicate what directions future research must take if it is to provide us with the sorts of answers we will need for our population planning.

It is interesting to discover in the literature a split between groups of social scientists who have very different outlooks on the consequences of increased population density.[1] As they say, first the good news! There is one group of social scientists who emphasize the positive consequences of increased population. They point to the tremendous diversity of aptitude, achievement and life-style which can be provided for only in a milieu sufficiently populated to allow for high levels of division of labor.[2] They point to the modern urban center, with its stimulating culture, intellectual and economic life as an example of the rewards of increased density. Who can argue, on a walk around New York City, through scores of museums, colleges, and stores, walking up Broadway from Times Square to Lincoln Center, tasting the cuisine of hundreds of subcultures, that concentrating masses of people together has enriched the life and imagination of the human species beyond measure.

But, inevitably, then comes the bad news. Along with the attractive aspects of increased density come the unappetizing aspects. The second major group of social scientists points to the negative social consequences of increased population density as the foremost consequence — the poverty of many, the crime and pollution, the increased mortality despite apparent increase in services, the shattering noise, the anonymity and inhumanity of it all. These theorists emphasize man's evolution in a small group framework and wonder whether a system evolved for one setting can adapt to such a radically different setting. Some authors, like the biologist Rene Dubos, claim that man's unique survivial mechanism is his ability to adapt to every new potentially dangerous situation,[3] but others see that as unwisely optimistic.

A considerable number of surveys have been conducted in an attempt to discover whether in fact high density locations seem to contain people with more than their share of psychological problems. A great deal of this human survey research derives from discoveries which John Calhoun made on overcrowded groups of rats he observed in several experiments in the 1950s.[4] In a continuing series of studies, Calhoun placed a small number of rats in an enclosed area, provided them with sufficient food and water, and allowed them to reproduce with no restrictions. Under these benign conditions, the population of the colonies increased rapidly and eventually reached a point of density much greater than that which would occur in a natural environment. Dramatic negative effects were associated with these high densities. Social behavior broke down. Some males became uncontrollably aggressive while others became totally passive. Individual nests were invaded by marauding males, and

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[1] *Winsborough, H.H. The Social Consequences of High Population Density.* Law and Contemporary Problems, *1965, 30: 120-126.*

[2] *Cook, Donald A. Cultural Innovation and Disaster in the American City. In Duhl, L. J. (ed.)* The Urban Condition, *1963. Basic Books.*

[3] *Dubos, R. The social environment. In Proshansky, H. Ittelson, W. and Rivlin, L. (eds)* Environmental Psychology, *1970, Holt.*

[4] *Calhoun, J. B. Population density and social pathology.* Scientific American, *1962, 206: 139-148.*

females often did not even bother to build sufficient nests. Infant mortality rose sharply as did the rate of unsuccessful pregnancies. These severe effects applied to the great majority of animals in the colonies. Similar although less dramatic effects were observed by John Christian and his colleagues in a population of deer which has grown unchecked for over 40 years on an isolated Maryland island.[5]

The human survey researchers who have conducted surveys in crowded areas have taken the animal work as a starting point and a source of ideas concerning what variables to look at, but we cannot and must not conclude that because certain events occur in crowded animal populations the same sorts of events will occur in crowded human populations. Researchers in Honolulu[6] and Chicago[7] took some of Calhoun's measures and attempted to find the same sorts of correlations. They looked at rates of crime, mortality, welfare support, and mental illness in their areas and attempted to correlate these psychological breakdown symptoms with various measures of population (number of people per acre, number of dwelling units with more than five apartments, number of apartments with more than 1½ people per room on the average, etc.). The researchers found in both Hawaii and Chicago that the higher the population density measures, the more severe the symptoms of social and psychological breakdown. But interpretations made from these data are not free from ambiguity.[8] Population density is correlated with many social factors which might account for the various psychological consequences. The most obvious of these are income and educational level. The authors of various studies attempted, by statistical means, to eliminate these other factors from the computations, but their statistics have been called into question on a variety of counts. The upshot of these surveys, therefore, is that we can find, in a variety of urban settings, a positive correlation between psychological deterioration and high population density, but that we cannot at this point say that the population levels were the cause of the other symptoms. It might well be the case, for all we can surely say, that if better educated individuals with better jobs and a more hopeful attitude towards life lived close together, the pernicious consequences would not follow.

Well, are there any studies which have selected better-off individuals and subjected them to overcrowded conditions for any length of time? Judge the appropriateness of the following sorts of "natural experiments" for yourselves. We have a lot of data on individuals in submarines,[9] in arctic and antarctic stations, in prisons, POW camps and concentration camps,[10] in space capsules, and in civil defense shelters. Much of the data suggest that most people adapt remarkably well to the conditions, which often include privations other than mere crowding. But these are a long way from being either approximations of the long-term living conditions of people whose whole lives are spent in high-density areas, or they deal with special populations in special kinds of settings.

The epitome of scientific research is the controlled experiment. It is only when experimentally treated and nonexperimentally treated groups of individuals can be compared that we can draw conclusions and inferences regarding explanations with any degree of confidence. The number of reputable controlled experiments dealing with the psychological effects of crowding can practically be counted on the fingers of one hand. One study observed children at free play in either large or small groups and found that these normal children exhibited more aggression and less cooperation in the

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[5] *Christian, J. J., Flyger, V. and Davis, D. Factors in the mass mortality of a herd of sika deer.* Chesapeake Science, *1960,* 1: *79-95.*

[6] *Schmitt, R. C. Density, delinquency and crime in Honolulu.* Sociology and Social Research, *1957,* 41: *274-276.*

[7] *Galle, O. R., Gove, W. R., and McPherson, J. M. Population density and pathology: what are the relations for man?* Science, *1972,* 176: *23-30.*

[8] *Freedman, J. L., Klevansky, S. and Ehrlich, P. R. The effect of crowding on human task performance.* Journal of Applied Social Psychology, *1971,* 1: *7-25.*

[9] *Weybrew, B. B. Psychological problems of prolonged marine submergence. In Burns, Chambers and Handler (Eds),* Unusual Environments and Human Behavior. *Free Press, 1963.*

[10] *Carstairs, G. M. Overcrowding and human aggression. In Graham, et al. (Eds)* Violence in America, *Bantam Books, 1969.*

larger groups.[11] However, the number of play objects in the setting seems to have been kept constant, perhaps explaining why there would be increased competition and aggression. This is not to argue that increased population does not result in higher levels of aggression, but rather to say that if the level of resources can be kept high, perhaps the aggression can be avoided.

Another study attempted to assess the effect of size of rooms in psychiatric hospitals on amount of social and nonsocial behavior. The observation was that a higher percentage of nonsocial behavior was seen in the larger and more crowded rooms.[12] However, it seems not unlikely that the patients were assigned to smaller or larger rooms in the first place on the basis of differences in severity of their symptoms, or perhaps on the basis of differences in their economic status. These two studies, though experimental in nature, were not particularly well done. A better study looked at students' comfortableness in a particular classroom as a function of the number of students in the class. The subject matter was unimportant, it was found. Rather, there was a direct relationship between the number of students in the room and discomfort experienced.[13] Other researchers have also reported that one's personal feeling of being hot in a room is more a function of the number of people in the room than it is a function of the actual temperature of the room.[14]

Current research focuses on the effects of increased density on performance of learned behaviors. Results seem to suggest that whether the task is boring or engrossing, hard or easy, the density of individuals in the room does *not* seem to matter.[15] Again, as was stated earlier, the human animal seems to be able to adapt to a wide variety of unusual conditions without outward signs of difficulty; however, there has recently been a most revealing group of studies done by psychologists studying the effects of loud noise on human learning and performance.[16] These researchers found that people could work and learn in rooms with constant or intermittent sounds as loud as riveting machines. The people adapted to the noise. They could concentrate. BUT the interesting results came from studies of the aftereffects of working under these conditions. It was found that individuals who had managed to perform adequately during the stress showed high irritability and inability to concentrate on other tasks after the test session. It was like the situation of the bomber pilot who falls apart after he returns to the base or the nurse in an earthquake who works for 48 hours straight and then collapses completely. These results suggest that the human organism can adapt to conditions of extreme stress, but that a reactive buildup occurs which prevents functioning indefinitely at an optimal level and leads to ultimate collapse of severe proportions.

The major point to be made about studies of population density is that increased population may not *itself* lead to deleterious psychological consequences. We do not, after all, have a density receptor. But increased population density seems to create conditions of noise, competition, insecurity and loneliness which themselves *can* be shown to be directly related to psychological malfunctioning. It is not truly helpful to read, on the one hand, that population density is not related to psychological problems but that noise, migration and economic insecurity are. The research of the future must take into account the psychological meaning of crowding and the social consequences.[17]

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[11] *Hutt, C. and Vaizey, M. J. Differential effects of group density on social behavior.* Nature, *1966,* 209: *1371-2.*

[12] *Ittelson, W. H., Proshansky, H. M. and Rivlin L. G. The environmental psychology of the psychiatric ward. In Proshansky,* et al, op. cit.

[13] *Sommer, R. and Becker, R. D. Room density and user satisfaction.* Environment and Behavior, *1971,* 3: *412-417.*

[15] *Freeman, J. L., Klevansky, S. and Ehrlich, P. R. The effect of crowding on human task performance.* Journal of Applied Social Psychology, *1971,* 1: *7-25.*

[15] *Freeman, J. L., Klevansky, S. and Ehrlich, P. R. The effect of crowding on human task performance.* Journal of Applied Social Psychology, *1971,* 1: *7-25.*

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Human Genetic Concerns

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Each day brings new and more frequent uses of chemicals and radiation, and subsequent radioactive and chemical wastes are beginning to pollute our natural resources. Every human being is unavoidably exposed to these environmental hazards, and while the immediate threats to the individual are real and recognized, the potential harm to future unborn generations is subject to speculation.

Since 1927, we have known that genetic changes (mutations) can occur as the result of exposure to radiation. Studies in radiation mutagenesis have provided a background for the study of the potential genetic risks of an amazing variety of chemical mutagens also present in man's environment, but much is yet to be learned. Much of the basic work in chemical mutagenesis has involved the study of specific mutation systems in bacterial viruses and microorganisms, which, though valuable as basic studies, are of less value in the investigation of genetic risks to man.

Kinds of Mutations

Genetic changes occur in several ways: changes in the number of chromosomes (changes in ploidy), changes in structure (chromosome aberrations), and changes in the chemical structure of the genes (point mutations).

Changes in Chromosomes

Changes in number of chromosomes may affect whole sets of chromosomes (euploidy) or the gain or loss of one or more chromosomes (aneuploidy).

Point Mutations

Point mutations, or gene mutations, are of greatest concern from the viewpoint of genetic hazards. They vary widely in their effects from lethality to trivial changes in inherited traits with little or no effect on viability. They may vary from complete dominance to being completely recessive. In man, many point mutations are known which cause serious genetic diseases. McKusick[2] lists 415 such conditions caused by single dominant mutations, with an additional 528 which are less well established. Polydactyly, one type of dwarfism, one kind of muscular dystrophy, and several kinds of anemia are examples. The collective incidence of all such diseases caused by dominant mutations is about 1 percent of persons born. McKusick also lists 365 recessive diseases, for example, phenylketonuria (a form of mental deficiency), crystic fibrosis, and sickle cell anemia. These are unfortunately fairly common and well known, but most such recessive conditions are very rare. Recessive conditions caused by genes on the X-chromosome are expressed primarily in males. Eighty-six well established and 64 probable sex-linked mutations of this kind are known, including hemophilia, color blindness and a severe form of muscular dystrophy. X-rays were shown by Muller in 1927 to induce point mutations, and in the past 25 years an increasing number of chemicals has also been shown to be mutagenic. This is the basis of the increasing concern over the potential genetic hazards of environmental radiation and pollutants.

Molecular Basis of Point Mutations

Chromosomes, the carriers of the genes, are composed primarily of proteins and nucleic acids. The genetic information is contained in the deoxyribonucleic acid (DNA). The constituents of DNA are a sugar (deoxyribose), phosphate, two purine bases, adenine (A) and guanine (G), and two pyrimidine bases, cytosine (C) and thymine (T). The DNA molecule is a long double helix with pairs of bases along its length much like steps in a ladder.

The genetic information is contained in the sequence of base pairs in a triplet code in which each successive group of 3 base pairs codes for one of the 20 different amino acids which comprise the polypeptide chain of proteins. A point mutation results from a change in the sequence of base pairs. This may occur by base pair substitutions or by the addition or loss of a base pair. If a base pair is added,

[1] *Muller, H. J. 1927. Artificial transmutation of the gene.* Science 66:84-87.

[2] *McKusick, V. A. 1971. Mendelian inheritance in man: catalogs of autosomal dominant, autosomal recessive, and x-linked phenotypes. The John Hopkins Press, Baltimore. 738 pages.*

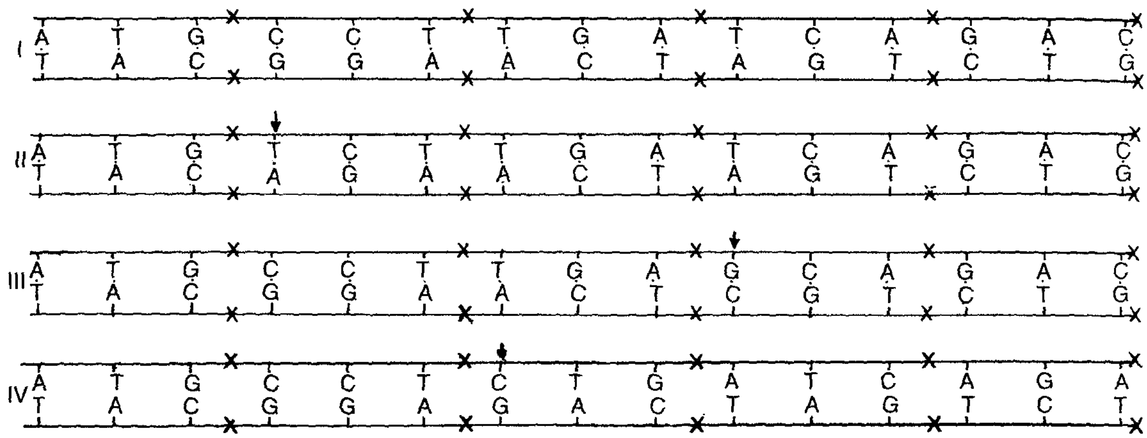

Figure 1. Schematic diagram of DNA structure and changes in structure causing mutations.

A = Adenine, G = Guanine, C = Cytosine, T = thymine
Each strand of the DNA molecule consists of the deoxyribose-phosphate backbone with the purine and pyrimidine bases attached laterally. The two strands are held together by hydrogen bonds, represented by dots, between A.T and G.C on opposite strands.
I - Normal structure assumed for a section of the DNA molecule. The successive groups of three base pairs (codons) are indicated on the strands by x.
II - Mutation caused by base pair transition; T.A substituted for C.G at the point indicated by large arrow. Second codon is altered.
III - Mutation caused by transversion at point indicated by large arrow; G.C substituted for T.A, altering the fourth codon.
IV - Frame shift mutation caused by insertion of C.G base pair at point indicated by large arrow. The third codon and all those to the right of it are altered.

for example, the successive groupings of 3 base pairs are all altered as the triplet code is read beyond the point of addition. The same is true if a base pair is lost. Such mutations are called frameshifts.

Each gene is thought to consist of about 1000 successive base pairs in the DNA molecule and it is estimated that man has from 10,000 to 40,000 genes.

Cause of Mutations

Spontaneous mutations.

Both chromosomal and point mutations occur spontaneously at low frequencies. The causes of spontaneous mutations are not known; an unknown proportion, not over 10 percent, of them may be due to natural radiation. Different genes vary widely in the frequency of spontaneous mutation, and in precise studies of induced mutation, the frequencies observed must be corrected for spontaneous mutation. Knowledge of this frequency of spontaneous or naturally occurring mutations in man is essential in order to estimate the genetic risks from radiation or any other environmental mutagen.

Radiation Induced Mutations

Changes in ploidy and aneuploidy, the gain or loss of a chromosome, can be induced by radiation. In general, the doses required to produce appreciable frequencies of euploidy and aneuploidy are quite large. As a result, there is relatively little genetic hazard to human populations at the low exposure and low dose rate from environmental radiations.

The greatest genetic hazard is the induction of point mutations. The frequency of induced point mutations in Drosophila (fruit flies) and mice, however, increases in direct proportion to the radiation dose and, hence, no matter how small the dose, there is a finite probability that some mutations may be produced. It is also now well established[3] that in spermatogonia and oogonia in mice (and hence presumably also in man), the number of mutations induced by a given dose of radiation is significantly lower (⅓ or less) when the dose is given at a low rate over a long period of time, as would be true for environmental radiation exposure. However, even though the frequency mutations per unit dose is lower at low dose rates, the number of mutations induced is still very probably linearly related to the total dose. Thus any increase in radiation exposure to human populations will increase the number of mutations and thereby cause some genetic risk.

It is necessary, therefore, to establish standards for radiation exposure to insure that serious genetic consequences do not ensue. Radiation is used for the benefit of man in many ways (in medical diagnosis, radiation therapy, industry, and the generation of electrical power) and the establishment of such radiation standards must always represent a compromise between the benefits to be gained and the increased risk of genetic mutations. The same is true for most environmental mutagens.

The most recent authoritative consideration of this complex problem of radiation hazards is the report of the National Academy of Sciences - National Research Council Advisory Committee on the Biological Effect of Ionizing Radiations (BEIR Committee) — published in November, 1972[4]. In their report, the BEIR Committee made assessments of the genetic risks in 4 ways: 1) the risk relative to the natural background radiation; 2) the risk for specific genetic conditions; 3) the risk for severe malformation and disease; and 4) the risk in terms of overall ill-health.

The average annual whole body exposure from natural background radiation was estimated to be 102 mrem (millirems, or 1/1000 of a roentgen-equivalent-man, a unit of radiation exposure), 44 from cosmic radiation, 40 from external terrestrial radiation, and 18 from internal radioactivity. By comparison, exposure from all man-made sources was estimated as 80 mrem per year, of which 73 mrem was from medical and dental uses of radiation. Global fallout from weapons testing contributed 4 mrem and nuclear power operations only 0.003 mrem. Even if the nuclear power industry expands from 6000 megawatts in 1970 to an estimated 800,000 megawatts in the year 2000, the exposure would be less than 1 mrem, or less than 1% of the natural background. From this viewpoint, the development of nuclear power would not seem to pose a problem.

The other three risks discussed by the Committee are largely based on estimates of the doubling dose of radiation, or that dose required to induce as many mutations as occur naturally. No data exist on the induction of mutations in man by radiation, so the doubling dose must be based on extensive data from mice. Even then, it is not precisely known, and a range of 20 to 200 rem per 30 years was employed.

Space does not permit a further more detailed consideration of the Committee's estimates of genetic risks of radiation or their recommendations. However, it is interesting that despite extensive investigation of radiation induced mutations for over 45 years, quantitative estimates must be based largely on data from mice and the basic factor, the doubling dose, is not known more accurately than within a 10-fold range. Related to natural background radiation, nuclear energy development seems entirely feasible without undue risk, but precise estimation of risk is not yet possible. Even greater uncertainties and more difficult problems will be encountered in estimation of genetic hazards from chemical environmental mutagens.

Chemically Induced Mutations

Modern man is exposed to an amazing array of potentially mutagenic chemicals in his environment. Barthelmess[5] has catalogued

[3]*BEIR Report, 1972.* The effects on populations of exposure to low levels of ionizing radiation. *National Academy of Sciences - National Research Council, Washington, D.C.*

[5]*Barthelmess, A. 1970.* Mutagenic substances in the human environment. *In Vogel and Rohrborn, pages 69-147.*

[4]*Ibid.*

several hundred. These include, among others, medicinal drugs and related compounds, antibiotics, stimulants including caffeine, foods and food additives, sweetening agents, industrial chemicals and solvents, pesticides, and carcinogenic components of coal tar. Many of these mutagenic compounds are also carcinogenic (cause cancer), and teratogenic (cause fetal malformations).

When one considers the effort expended in attempting to establish reliable radiation standards and the uncertainties which still exist, the enormity of the problem of assessing genetic risks due to environmental mutagens is staggering.

A number of systems for the quantitative study of mutagenesis are available. Much of the basic work in chemical mutagenesis[6] has utilized mutations in bacterial viruses, bacteria, Neurospora, and even purified DNA in bacterial transformation systems. Use of these systems can easily determine if a particular compound is capable of inducing mutations when applied more or less directly to DNA and hence can be used for screening purposes. However, use of such viral and microbial systems yield essentially no information on mutation induction by the same compound in man.

For a chemical to be mutagenic in a mammal, such as the mouse, it must be present in the germ cells, making the problem of chemical mutagenesis in mammals far more complex than that of radiation mutagenesis. Radiation can penetrate directly to the germ cell in the gonads, whereas chemical mutagens (which are inhaled, ingested, or injected) are subjected to the host's metabolism. Potential mutagens of different chemical nature may be metabolized quite differently, and some compounds which are potent mutagens in bacteria may be rendered non mutagenic by the host's metabolism. For example,[7] MNNH (N-methyl-N-nitro-N-nitrosoguanidine), highly mutagenic in microbial systems, has been reported to induce mutations in cultured mammalian cells, induces cancer in animals, and causes chromosome aberrations in onion root top cells, but has been completely inactive in tests of producing dominant lethal mutations in mice. Conversely, some compounds which are nonmutagenic may be metabolized into mutagenic compounds. Thus, cycasin, a carcinogenic glucoside extracted from certain tropical plants, is nonmutagenic in microbial systems; after oral administration into mice it is mutagenic to bacteria in host-mediated tests. Intravenous, intramuscular, or intraperitoneal injections of cycasin are not mutagenic in the host-mediated test. Again, the complexity of the total problem is apparent.

Because of the problems arising from metabolic processes of the host, it has been recommended[8] that mammalian test systems should be used along with microbial systems in testing potential mutagens, but the only such system available for directly testing for point mutations is the specific locus method, used so successfully in studies of radiation induced mutations. However, it requires observation of tens of thousands of mice, and is too expensive and time-consuming to be practicable for routine testing; only a few mutagens of particular interest can be tested in this manner. As an alternative, three other mammalian test systems may be used in conjunction: 1) the dominant lethal test, 2) direct cytogenetic observations of germ cells and/or bone marrow cells, and 3) the host-mediated microorganism assay. These tests involve relatively small numbers of animals, less time and cost, and are far more appropriate for routine testing. The dominant lethal test is based on the death of embryos in utero caused by chromosome aberrations produced in the reproductive cells of the parents. Direct cytogenetic examination also measures the induction of chromosome aberrations in reproductive cells (such as spermatocytes) or in somatic cells (such as bone marrow). The host mediated microorganism assay[9] is considerably less laborious than

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[6]*Drake, J. W. 1970.* The molecular basis of mutation. *Holden-Day, San Francisco, Calif. 273 pages.*

[7]*Legator, M.S. 1970. The host-mediated assay, a practical procedure for evaluating potential mutagenic agents. In Vogel and Rohrborn, pages 260-270.*

[8]*Mrak, E. Editor. 1969 Report of the Secretary's Commission on Pesticides, U.S. Dept. of Health, Education and Welfare.*

[9]*Malling, H. V., and G. E. Cosgrove. 1970. The internal level of mutagens in mammals. In Vogel and Rohrborn, pages 271-278.*

either of the other two. It consists of injecting appropriate strains of microorganisms in which mutations can be quantitatively assayed into the host, for example into the peritoneal cavity, administering the mutagen by another route, perhaps orally or by intramuscular injection, then later recovering some of the microorganisms and measuring frequency of mutations in comparison to appropriate controls.

Concomitant use of all these tests provides a powerful tool for the evaluation of environmental mutagens.

Summary

This brief consideration can do little more than outline a few of the difficulties and experimental approaches for the evaluation of genetic risks from environmental mutagens. The problem is far more difficult than evaluation of the genetic risks from radiation because of the distressingly large number of potential chemical mutagens and the complexities arising from the host's metabolism. However, encouraging progress is being made and valuable methods of assay are being developed. For the interested reader who wishes detailed information, some excellent books are suggested.

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Hollaender, A. 1971. *Chemical mutagens.* Plenum Press, New York. Vols. I & II, 610 pages.

Vogel, F., and G. Rohrborn. 1970. *Chemical mutagenesis in mammals and man.* Springer-Verlag, New York and Berlin. 519 pages.

Environmental Threats to Animals

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The problem of environmental quality is a complex one which involves man-made sources of pollution that are introduced into an existing naturally complex ecosystem. The natural ecosystem is characterized by various closed loops or feedback mechanisms. The end result is that effects which are caused in the system tend to aggravate themselves or to decrease with time depending on a variety of other contributing factors. The major problem in evaluating and controlling environmental quality is to identify these factors and to understand them in a quantitative way.

Polluting Materials

Polluting materials introduced into the environment do not flow through the medium in a uniform manner. A pollutant tends to be concentrated more in one small portion of the environment than in another. From one point of view, this is desirable because such concentration in limited volume makes it much easier to remove a given material in the treatment of water for health purposes. These local concentrations, on the other hand, can be harmful to aquatic organisms or terrestrial animals. A good example is the possible concentration of mercury in fish or the concentration of radioactive strontium in dairy products. Despite the fact that much work has been done on the biological accumulation of pollutants in the ecological chain, much more information is needed if man is to handle these pollutants, in the various concentrations in which they occur, in a meaningful way.

In discussing the problems of environmental quality and pollution of the environment, it is essential to understand that water, land, and air are not separate and distinct parts of the environment. Each, it is true, has special characteristics. However, they all interface one with another; they are all coupled together so that an insult imposed on the air or on the water or on the land by a pollutant inevitably exerts an effect on the other components.

"Sewage and feedlot pollution, especially in rural areas, readily enters the air, causing undesirable odors that,depending on wind conditions, can travel for several miles. The urban counterpart of this situation is the dust arising from construction activities as newly turned earth dries and is blown into the air. Coupling from land to water also results from construction activities when soil erosion results in silt entering the sewers and streams, often clogging them and preventing natural purification processes from working. Fuel oil that has leaked from supply pipes onto the surface of the ground also can enter sewers and streams, further hindering natural processes; acid mine drainage is an additional type of pollution occurring on land but entering into our streams." (Kerbek, 1972).

Air and land are also coupled together; for example, the electrical power generating plants burn coal, a fossil fuel obtained from land, and in the process inject into the atmosphere soot and dust and vapors. These materials eventually return to the soil where they are partially washed into receiving streams and partially picked up by plants growing in the contaminated soil. These plants, in turn, are eaten by animals who absorb the material in the plants.

Pollutants in the Air

As mentioned before, the use of fossil fuels to produce energy results in an enormous amount of various poisons being injected into the atmosphere each year. When all major sources of emissions are considered, one can estimate fairly accurately how much of various toxicants are emitted into the atmosphere. For example, from all sources during 1968, there were injected into the atmosphere over 100 million tons of carbon monoxide, over 28 million tons of particulate matter, over 33 million tons of sulfur oxides, about 32 million tons of hydrocarbons, and nearly 21 million tons of nitrogen oxides. The use of fossil fuel for transportation was the major source of carbon monoxide in the atmosphere, accounting for nearly 64 million tons per year. Particulates in the atmosphere seemed to originate primarily from the combustion of fuel in stationary sources such as electric power generating plants and from a variety of miscellaneous sources including agricultural burning, amounting to 8.9 million tons of particulates per year from fuel combustion in stationary sources. The major source of sulfur oxides is fuel combustion in such stationary sources as electric power generating plants; during 1968, over 24 million tons of sulfur oxides originated from this source. Transportation is by far the major source of hydrocarbons in the atmosphere. Nearly 17 million tons were introduced into our atmosphere during the year 1968 as a result of transportation needs. The nitrogen oxides are much like the sulfur oxides with respect to source, stationary fuel burning sources such as power plants accounting for 10 million tons of nitrogen oxides during the year 1968.

How do these materials affect our wild and domestic animals? Laboratory experiments indicate clearly that sulfur oxides are hazardous to a variety of animals. When the annual mean concentration of sulfur dioxide in air increases much above 0.04 ppm, animals begin to show signs of disability.

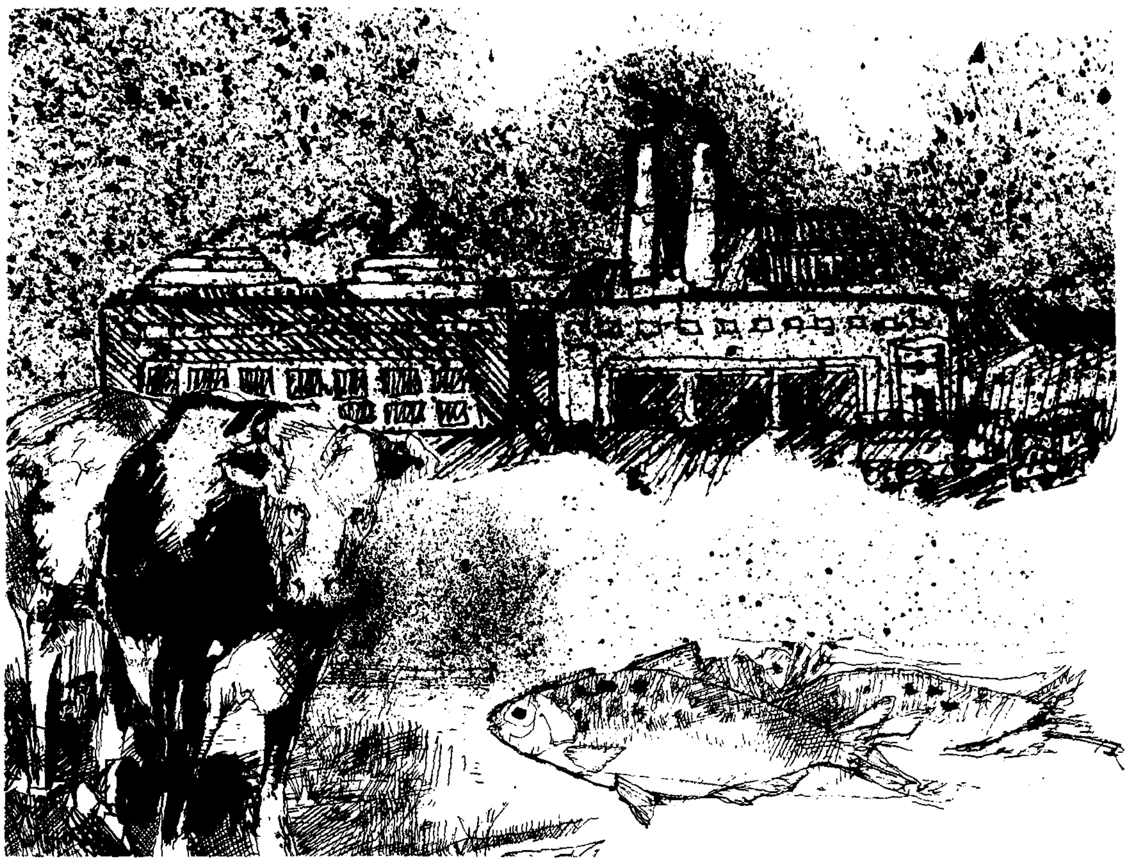
Particulate matter tends to exert an adverse effect on animals by two routes. First of all, the particles can cause physical damage to the lining of the respiratory tract. Sharp, although microscopic, particles can cut through the delicate lining of the lungs and breathing passages. When such effects occur, the animals then are susceptible to infection through the broken areas. On the other hand, some of these particulates, in addition to the purely physical or abrasive action, have definite poisoning actions of their own. We know, for example, that beryllium can cause severe lung damage and death in warm blooded animals. Lead is known to be absorbed and move into the bones. Asbestos has been implicated in the production of cancer. At the present time these materials do not occur in the atmosphere in amounts that are cause for concern. However, the fact that they are potentially hazardous suggests that careful monitoring and control is warranted.

Carbon monoxide, widely distributed in the atmosphere, is a well known poison. This substance occurs among the products of combustion when organic materials are burned to produce energy. One of the most potent sources of carbon monoxide is cigarette smoke. It is known that high concentrations of carbon monoxide cause death because the gas combines with the hemoglobin in the blood and prevents the blood from carrying oxygen. Carbon monoxide enters the body only through the lungs. From the lungs, it is absorbed into the blood where it occupies, on the hemoglobin molecule, the positions where oxygen normally should be. The affinity of hemoglobin for carbon monoxide is somewhere between 200 and 300 times greater than for oxygen. Consequently, when carbon monoxide is present in air breathed by animals, the hemoglobin preferentially accepts the carbon monoxide and excludes oxygen. The end result is that the animals so exposed cannot oxygenate the various organs and tissues in their bodies. Many experiments have demonstrated the harmful effects of carbon monoxide on animals. Dogs have been exposed for as long as six weeks to 50 ppm of carbon monoxide. At the end of the third week, the heart showed abnormalities. The same animals, when they were examined after death, showed changes in the brain.

Hydrocarbons originate from imperfectly burned organic fuel materials. Ordinarily, the hydrocarbons themselves are not toxic, at least in the amounts found in the atmosphere. They are of major concern because they serve to form, under the influence of sunlight, the dangerous thing called *smog*. This photochemical air pollution results in irritation to the eyes, and there are suggestions that skin irritations may occur; difficulty in breathing may occur and, with long term exposure, cancers can be produced.

Nitrogen dioxide is a lung irritant. In concentrations of more than 100 ppm, most animal species are killed. Most of the animals die because of pulmonary edema, a situation in which the lungs fill up with fluid and the individual virtually dies from drowning in his own body fluids. Rats that are exposed to half a part per million of nitrogen dioxide for four hours or one part per million for one hour show the beginnings of adverse reaction, including changes in lung proteins and other obvious pathological changes. A wide variety of animals, including some sub-human primates, after exposure to nitrogen dioxide show an increased susceptibility to pneumonia and to influenza infections.

It is obvious then that already in the atmosphere there are materials which under appropriate conditions of concentration and length of exposure can cause harm to useful animals. There are two corollaries we must keep in mind. First of all, if man is concerned for his domestic animals and for selected species of wild animals, he must insure that the atmospheric pollutants are kept at such a level as to pose no serious threat to the welfare of these animals.



Secondly, the human body is a warm blooded animal body. Environmental pollutants which pose a threat to animals can be predicted to be a real threat to man. Consequently, if a pollutant is known to be hazardous to animals, it should immediately be suspect as possibly harmful to the human body. The details of this kind of environmental threat are discussed elsewhere in this book.

Pollutants in the Hydrosphere

A water pollutant is any material, whether physical or chemical, that prevents a given body of water from being used for a specified purpose (Wilber, 1971a). Municipal sewage accounts for about 60 percent of all water pollution in the United States. Industrial sources make up most of the balance of water pollution. Pollution from agriculture, despite many claims, is a relatively minor source of water pollution in the United States.

There are many types of pollution. These include bacteria (Fjerdingstad, 1971); turbidity; lack of dissolved oxygen; a variety of inorganic materials such as iron, lead or mercury; phenols; a variety of organic materials; radioactivity; heat; various nutrient materials and assorted dissolved solids. People are most conscious of bacteria as sources of water pollution because bacteria adversely affect recreational use of water and the use of water as a municipal supply. However, in terms of aquatic life, bacterial contamination of water is of little concern. Turbidity, lack of dissolved oxygen, and most of the other sources of pollution are of grave concern to a healthy aquatic life. Turbid material which settles to the bottom of a stream or lake tends to blanket the bottom and kill larvae of fish and fish food organisms. In addition, sunlight cannot penetrate through these turbid waters and consequently green aquatic plants cannot produce oxygen through the action of photosynthesis.

If too much oxygen-using waste material is introduced into a lake or stream without adequate pretreatment, the oxygen present in the lake or stream will be used up in decomposing this material. Consequently, the oxygen will not be available for fish and other aquatic life and these will suffer adversely. The fish will die, fish food organisms will refuse to live, the ecological balance of the stream will be upset, and man will be denied certain uses of that stream or lake for purposes he may have in mind. (Wilber, 1972)

Inorganic materials tend to have an intrinsic toxicity which can result in the death of valuable aquatic organisms. Moreover, if concentrations of certain substances in water are too high, the water then becomes unfit for wildlife and for domestic animals. Indeed, an excessive amount of certain inorganic chemicals make it impossible to use the water for irrigation.

With the advent of an enormous synthetic organic chemical industry in the United States, a wide variety of strange synthetic chemicals (among which are detergents and pesticides) are introduced into receiving waters. Most of these substances are poisonous to fish and to aquatic life. Whether they are harmful, in the amounts now found in our waters, to domestic animals and wildlife is not clear. Moreover, whether they are all toxic to man is still obscure. Many do, however, cause a taste or an odor which is unacceptable to animals. Many of these materials when absorbed by fish cause the flesh of the fish to become tainted so that the fish cannot be used for food.

It has been estimated that the load of waste from municipal sewers can be predicted to increase nearly four times during the next fifty years. If this estimate is true, in the United States we are faced with a critical situation. Already we find that municipal sewage sources pose the major threat to our natural waters. If this threat is to increase four times over the next fifty years, vigorous action must be taken to insure that our natural waters are not further degraded so that they are no longer fit for wildlife or for domestic animals. Certainly, one approach to the problem is to demand more adequate water treatment so that waste material is not introduced into our streams. However, this demand could result in an even greater degradation of the environment. A number of estimates have indicated that if one is to demand 100 percent removal of waste material from a sewer system, the process may itself generate more polluting materials than are, in fact, removed from the sewage.

Of particular concern is the introduction through municipal sewage of excessive amounts of nitrogen and phosphorus into receiving waters. These materials in the proper proportions tend to overfertilize receiving waters. In the process, the acceptable or desirable balance of the aquatic system is upset and excessive algal blooms (overgrowth of pond scum) result. These blooms are particularly annoying in lakes and in streams where the rate of flow is relatively low.

The second largest source of water pollution in the United States is from industry. Industrial waste materials present an incredible variety of chemical materials going into our waters.

Because of the fact that so many substances being introduced into our natural waters are of unknown toxicity to fresh water organisms, it seems only proper that any foreign material should be considered harmful and not acceptable until actual biological testing demonstrates that a given material is not harmful to aquatic organisms. It seems appropriate that the source producing the foreign substance introduced into water should be responsible for demonstrating that, in fact, that material is harmless when it gets into the receiving waters. Mere chemical testing to estimate the amounts of a material in the water is not sufficient. Bioassays must be conducted with each individual component of an effluent to ascertain specifically the toxic nature of the substance.

Environmental Mercury

The hue and cry over mercury pollution of the environment is slowly calming down. The voices of sanity are now being listened to. The facts are being separated from fancy and fabrication. Hopefully this return to rational examination of an important matter of concern will lead to useful and constructive solutions. (Harris and Karcher, 1972).

In a paper at a special session on mercury in fish, in connection with the International Billfish Symposium at Kona, Hawaii, August 10, 1972, Dr. Albert C. Kilbye, Jr., Deputy Director, Bureau of Foods. U.S. Food and Drug Administration, Washington, D.C., attempted to put the matter in proper perspective. He said, in part (emphasis added):

> "In the normal course of events there is very little, if any, likelihood that people living the United States would receive exposures (to methylmercury) comparable to the Japanese villagers later described. However, it is necessary to describe what can occur in the extreme if we are to understand the present perspective on mercury as a potential health problem in the United States and why the FDA has set a guideline for mercury in fish (0.5 ppm total mercury).
>
> "There is no reason for public alarm or distortion of risk by magnification beyond the true perspective, because *no health crisis is imminent from mercury in fish.* We should understand, however, that there is reason to exercise prudence and caution, hence the existence of the FDA guideline . . . I would also like to emphasize that there has been no fully documented instance of a United States resident suffering clinically evident mercury poisoning from exposures to mercury in fish. However, the occasional presence of subclinical brain damage from *excessive* exposures to mercury in fish has not been excluded, particularly in relation to children or mothers who eat unusually high amounts of fish containing substantial amounts of mercury in the form of methylmercury. One reason for the guideline is to protect pregnant women from inadvertently damaging their unborn children."

Questioning of Dr. Kilbye from the audience confirmed: (1) that the FDA guideline for mercury in fish is expressed in terms of total mercury content, but (2) that it is assumed by the FDA that the total mercury content is made up entirely or almost entirely by the toxic methylmercury form. The questioners pointed out that there is, however, growing evidence, including some new evidence reported at the same session by another speaker representing the University of Hawaii, that the toxic methylmercury component is often substantially less than 100 percent of the total mercury present in fish. In recognition, they urged that the FDA should restate its guideline in the more realistic terms of methylmercury, thereby helping to reduce confusion and resolve many unnecessary controversies. For unexplained reasons, Dr. Kilbye disagreed, so that no apparent movement resulted from the mercury session.

Pollution Threats to Fish

About 23 million fish were reported killed by water pollution in 1970 in 634 separate incidents in 45 states. Of the five states not reporting fish kills, Nevada and New Mexico advised that no known fish kills were caused by pollution in 1970; and Maryland, Mississippi, and Ohio provided no information. The number of fish kill reports increased 36 percent in 1970 compared to 1969. This can be related to increased cooperation from state reporting officials, improved reporting practices, and increased public awareness of pollution-caused fish kills.

With the exception of 1969, the reported number of fish killed in 1970 was 40 percent greater than the number reported for any year

since the annual census of fish kills began in 1960. In 1969, one kill of 26.5 million in Lake Thonotosassa at Plant City, Florida, accounted for 64.6 percent of the total of 41 million fish killed. Since 1961, a total of 161 million fish have been reported killed by pollution in 4,548 separate incidents.

In 1970, there were 31 reported kills where the number of dead fish equaled or exceeded 100,000; five of these kills reached or exceeded the million mark. Industrial pollution continued to be the most frequent cause of fish kills with 213 reports for 1970 accounting for more than 9.8 million fish killed. Municipal pollution was the second most frequent cause of fish kills with 119 reports for 1970 accounting for 6.6 million fish killed.

One million or more fish were killed in: the Dog River, Alabama, with 3,240,000 killed by discharges from sewerage systems; the San Jacinto River, Texas, with 2,700,000 killed by a combination of industrial pollutants; the Delta Mendota Canal, California, with 2,500,000 killed by sewerage system wastes; Camille Creek - Lakes, Georgia, with 2,000,000 killed by sewerage system wastes; and Freeport Harbor, Texas, with 1,000,000 fish killed by unidentified pollutants.

Fish kills are dramatic indicators that water quality has deteriorated beyond acceptable levels. The adverse impact of industrial and of municipal sewage is clear. Vigorous efforts to control those two critical sources of pollution will be more productive of quality water than will diversionary efforts aimed at agriculture, beer cans, or individual septic tanks.

Fish kills must be looked on as signs of an ecosystem sick unto death. When kills occur, heroic methods of treatment for the ecosystem involved are warranted (Wilber, 1971b).

The Real Threat to Wildlife

The Interior Department's forthright and highly principled Assistant Secretary for Fish, Wildlife and Parks, Nathaniel P. Reed, gave a significant address — well worth reading in its entirety — before the early October, 1972, meeting of the American Humane Association, on the provocative subject of "Environmental Concern and Wildlife — A Humane Approach." It seemed to us that the Secretary, a man of impeccable integrity and conservation credentials, placed in proper context the whole question of wildlife conservation with these words (only a small portion of his excellent overall text):

> "In considering what is humane in treatment of animals, is it worse to cleanly kill a selected duck with a gun or to cover it with oil, drain its marshes so it can't reproduce or eat, or subtly poison it with pesticides or other chemicals over a period of years?
>
> The issue of antihunting is a false one because it sidetracks people from attacking the real threats to our native wildlife.
>
> It's not the hunter, but the heads of the water development agencies, the mineral extractors, the energy producers, the timber cutters, the stream straighteners, the stockmen's associations, and the real estate developers who are destroying America's wild heritage.
>
> What these people do will have far more effect on the future of wildlife than I, or any of my successors, or all the hunter groups put together.
>
> It's the beavers — the dammers, the ditchers and the drainers — those who cut and dig our lands sometimes beyond their capacity to recover or to sustain life, whom you need to face eye to eye if you desire humane treatment for wild animals. And those land speculators who are determined to sell every square inch of America to some sucker.
>
> Barnun was right. The real estate sucker has proved his point, multiplying at an astonishing rate. There are no slopes too steep, no soils so unstable, no ecosystem so fragile that those modern-day hucksters won't try to sell to some innocent sap.
>
> The danger is that while those interested in wildlife debate hunting, the 'developers' continue merrily on their path of sending wild land and wildlife into oblivion."

Unless controls for the common good are insured, and soon, over the above activities, the future of overall environmental quality in our land is dim.

Environmentalists who are concerned with the proper balance of nature must sooner or later address themselves to the changing social attitudes which are rapidly developing. There is growing sentiment (put to an almost hysterical level by groups known as Friends of Animals, Protectors of the Earth, etc.) to ban all hunting within the borders of the United States of America. If the social pattern continues in the direction it is going, there will be no hunting within the United States in about ten years.

Should this eventuality take place, we then will be faced with the serious problem of what to do with the numbers of surplus wild animals which now live and breed over large areas of the United States. Under a proper game management program where the device of hunting is used to harvest the surplus animals so that those remaining can live and thrive in a compatible surrounding, one can foresee mass starvation and mass degradation of the environment as a result of gross overgrazing.

When one puts this situation next to the problem of decreasing open lands across the nation plus the development by commercial interests of second and third homes for families, one then is faced with the inevitable decrease of compatible environments for wildlife at a time when the wildlife is increasing and thriving at a high level.

In the face of this dilemma, any moves which now are taken that will actually decrease the productivity of wild animal stock on public and private lands should be looked on as a beneficial environmental impact. In the absence of hunting as a device for removing surplus populations of wild animal species, some devices must be used to curtail what, in effect, would be a wild animal population explosion. Competent zoologists estimate that if all we wish to do with wildlife is look at it for esthetic purposes, or study it for biological purposes, no more than one-third the population of such animals as elk, mule deer, white tail deer, caribou, moose, and other large game animals would be needed to adequately satisfy the requirements. When one considers the smaller animals, it becomes imperative to look for ways of limiting their population. One hardly can welcome hundreds of jack rabbits per acre unless hunting pressure helps to reduce the numbers.

Summary

Environmental quality, as it refers to our domestic and wild animal populations, is dependent on many factors. Certainly the polluting materials which are carried in the air, or in the waters, or absorbed into the soil are a major concern. But social attitudes toward our animal population also play a part. Ecological systems operate in delicate balance, and we must be sure that the systems supporting our animal populations are not overtaxed by the even greater hazards of overpopulation. Control of numbers, as well as control of environmental quality, is therefore necessary.

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Animal Genetics: Current and Future Threats

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The genetic endowment of a population provides the thread of continuity from generation to generation. It determines the quality of the population and ultimately determines whether or not the population will survive. We stand on the threshold of the age of atomic power produced by nuclear fission, with all the attendant risk of release of radiation. And almost daily new chemicals are introduced into our lives and into our environment. It is fitting, then, that attention be paid to the risk that these pollutants pose to our animal populations in terms of genetic damage. To do this it is necessary first to discover the nature of the genetic change which can be caused, and then try to determine how great the risk of damage might be, drawing on the research results available to date.

Nature of Genetic Change

The genetic material is carried in long thread-like chromosomes in the nucleus of the cell. Chromosomes occur in pairs, and the number of pairs differs greatly in different species. For example, man has 23 pairs, cattle and dogs have 30 and the chicken has 39 pairs. The number of chromosomes apparently has little bearing on the degree of evolutionary advancement of the species, but the number for any species is remarkably constant and most species are, as we shall see, exceedingly intolerant of changes in the chromosome number.

The genetic material in the chromosome is known to be DNA (deoxyribose nucleic acid), and a certain length of DNA is called a "gene." The genes are essentially the units of heredity, and each gene has a specific role in the functioning of the animal, be it in terms of its digestive processes or its color pattern, its disease resistance or its behavior, its intelligence or its size. Everything an animal is or does is influenced to some degree by his genetic makeup, i.e., by the genes it carries. The number of genes is not precisely known but appears to be around 10,000.

Changes occur spontaneously in the genetic material. Such changes are called "mutations" (from the Latin verb *mutare* — to change). The most frequent kind of change is a relatively simple one in the chemical makeup of the DNA; this is known as a "point mutation" or a "gene mutation." More drastic changes are due to loss of larger pieces of chromosome, or alternatively to a duplication of a larger piece. Sometimes a chromosome will break in two places and the broken piece flip over, giving an "inversion." An even more common kind of break involves two chromosomes from different pairs; the two broken pieces exchange and reunite with the depleted part from the other pair.

These translocations cause difficulties when sperm or egg cells are formed at "meiosis" because the gamete frequently contains a large duplicated piece of chromosome. In general, animals are very sensitive to extra pieces of chromosome of this type, and any embryo produced by such a gamete has a high probability of early death; the larger the imbalance, the less the chance of survival. Finally, whole chromosomes are occasionally found surplus in a gamete, and a resulting embryo and even a whole set of extra chromosomes can be found in a gamete. The former occurrence can be found in man; for example, an extra chromosome gives rise to the condition known as Down's Syndrome or "Mongolism." However, the condition resulting from an extra set of chromosomes, known as "polyploidy," is found only in plants.

The principle types of genetic change in animals are, then, point mutations, deletions, duplications, inversions, translocations and extra chromosomes.

Environmental Threats to the Genetic Composition of Populations

The major sources of concern for the genetic well-being of populations seem to be radiation and chemicals. Considerable scientific evidence is already available on the genetic effects of radiation, but chemicals have been thus far less thoroughly studied.

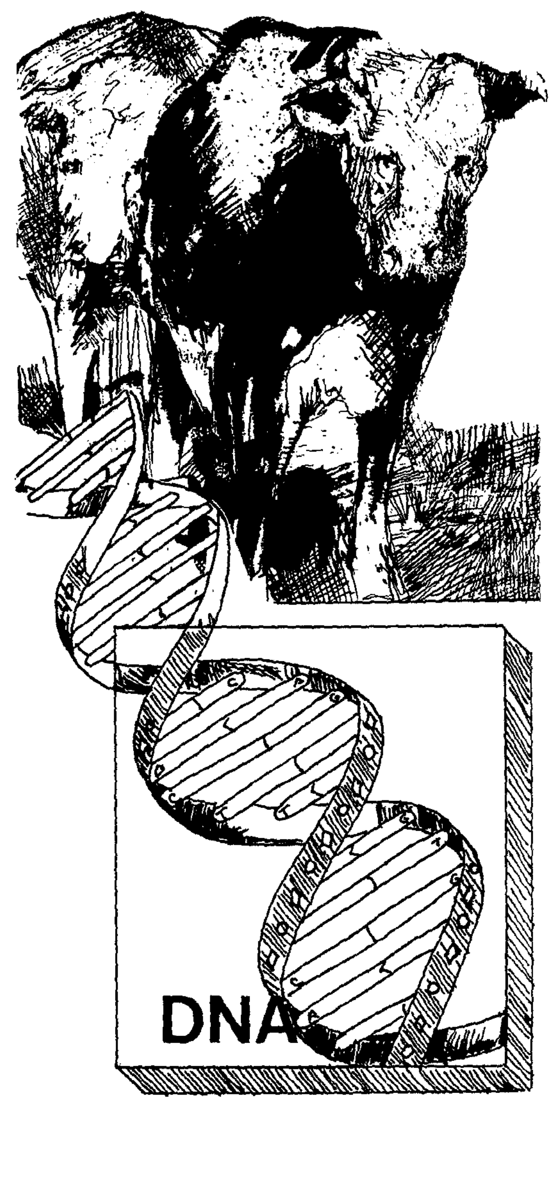
Genetic Effects of Radiation

Muller showed in 1927 that ionizing radiation would cause mutations in living material. Since then, thousands of reports have been published further clarifying and documenting the genetic damage resulting from radiation. Most of the evidence in animals has been obtained in two species — in Drosophila (fruit fly) and in the mouse. For the present purpose, the mouse results are presumably much more applicable than those on Drosophila. Most of the inferences drawn from the results have been extrapolated to man, rather than to any of the other animal species. On man himself very limited data are available, and most writers have been understandably very cautious about quantifying the extrapolations from mouse to man. On most of our species of domestic animal, very little experimentation has been carried out; on wild species, virtually no results are available. Based on available data, then, quantification of the exact risks to wild and even to domesticated populations become therefore extremely tenuous.

Many of the qualitative aspects of effects of radiation have been documented, however. Radiation appears to cause all of the kinds of genetic change referred to above which are known to occur spontaneously. The exact molecular basis for the radiation damage is even now not well understood, but the results very frequently appear as point mutations. Most of the point mutations are "recessive;" that is, in the heterozygous state, they are hidden by a normal gene, and the effect of a recessive is seen only when *both* chromosomes carry the recessive. A "dominant" gene is one which shows its effect even when present on only one chromosome of the pair, and is thus visible in the heterozygous condition. Dominant mutations occur much less frequently than recessives, both spontaneously and as a result of radiation damage. The frequency of both dominant and recessive point mutations appears to differ even from strain to strain in the mouse so that marked differences in frequency from species to species can confidently be predicted, and are evident in the limited data available. Males are much more susceptible than females, largely because of the continuous production of sperm cells in the testes; certain stages in the development of the sperm (for example, the spermatid) are more vulnerable to damage from radiation than are other stages. However, the spermatid stage is of very short duration so that the risk to the spermatogonia, or "sperm mother cells," emerges as perhaps the most suceptible to production of mutations.

Dose Rate Effect

Early evidence indicated a close linear relationship between radiation dose and frequency of point mutations; i.e., heavier dosages of radiation caused proportionally more mutations. In order to demonstrate clearly these relationships, virtually all experiments involved single acute doses of irradiation; the effects of smaller doses were inferred from extrapolation of the line from the acute doses. Recent evidence indicates, however, that mild doses of irradiation are much less harmful than was previously



projected. That is, the mutations per rem[1] from exposure of male mice at low dose rates of irradiation are considerably fewer than predicted from high dose rate effect studies. Further evidence comes from experiments in which mice were exposed to high doses of irradiation for as many as 40 generations; the offspring even then showed "no demonstrable effect on viability, fertility or growth, nor were there any detected abnormalities attributable to the radiation."[2]

These results, while in no way suggesting that caution in dealing with radioactivity of any kind is not warranted, are nevertheless reassuring for the welfare of our animal populations. Extensive calculations for man have shown that he is exposed, depending on the region in which he lives, to roughly 100 mrem of radiation from natural sources per year. By contrast, he receives only 4 mrem from fallout radiation (and even at the height of testing of atomic weapons, he received only about 40 mrem per year in localities experiencing the highest fallout rate), and a miniscule 0.9 mrem from "occupational hazards." This latter may, of course, increase as we penetrate further into the atomic age and rely more and more on nuclear fission for energy; "it appears to be technologically feasible, however, to develop nuclear power, at least for the near future, with a genetic exposure that is a very small fraction of the natural background, and less than one percent of present radiation protection guides."[3]

It seems, therefore, that diagnostic radiation used in medical practice will continue to be for man by far the major source of *man-made* radiation. Animal populations, by contrast, are subjected to virtually none of this kind of radiation, nor are they subjected to any dosage through "occupational hazard." Barring any major holocaust, therefore, it would seem that animal poplations, both domesticated and wild, will continue to be exposed only to the unavoidable levels of natural radiation plus any amount which may be released as a result of man's activities. Such doses will inevitably cause genetic damage but, as previously pointed out, at low and probably undetectable rates.

Genetic Effects of Chemicals

The array of chemicals being used by man today for many purposes (pesticides, herbicides, fertilizers, etc.) has in the last few years multiplied alarmingly; well over 400 chemicals used as pesticides alone are listed by Epstein and Legator (1971). Very little is known about the mutagenicity of these compounds. None has been shown conclusively to be a mutagen, but neither can any be categorically excused, since they simply have not yet been adequately tested. To be sure, work is in progress to evaluate many of them, but the surface has scarcely been scratched. Relative to our knowledge of radiation, the chemical picture is extremely unclear.

However, at this time we do have some general guidelines. Chemicals have long been known to be mutagenic; colchicine, applied directly to dividing plant tissue, arrests cell division while permitting chromosomes to continue replicating, producing the beforementioned effect of "polyploidy," or multiple sets of chromosomes. It seems to be as readily possible to induce by chemicals the same kind of point mutations, chromosome aberrations and even genome duplications as are induced by ionizing radiation, or as occur spontaneously. As with radiation, males again seem to be more readily affected than do females. But the most susceptible cell stage seems to differ frequently from the stages observed for radiation, and the various chemicals tried differ also among themselves regarding cell stage most affected. In addition, we still have virtually no idea how frequently these chemicals will cause mutations, especially point mutations, or whether their mere presence in the environment, as opposed to direct application to the cell, has any effect at all. The extensive experimentation necessary to obtain this information, especially in animals, has scarcely begun.

However, since mutations once established in populations do represent rather permanent changes, since they do add to the genetic burden of the population, and since they affect

[1] *The rem is the measure of radiation dose; dose is the energy absorbed per gram, of biological tissue in this case. 1 rad = dose in rads x the relative biological effectiveness of the type of radiation.*

[2] The Effects on Population of Exposure to Low Levels of Ionizing Radiation, *page 45.*

[3] The Effects on Population of Exposure to Low Levels of Ionizing Radiation, *p. 50.*

individuals as yet unborn and even many generations hence, all due caution and restraint should be exercised while experimentation continues. There seems, on the other hand, to be no cause for alarm or hysteria in the meantime. In order to cause mutations which may be passed on to future generations, the changes must find their way into the germ line. Most chemicals which are absorbed either by ingestion or via the skin, and which are not fatal to the animal, are denatured before reaching the gonads. Furthermore, even if a chemical reaches the female uterus during early gestation (a particularly sensitive period during embryonic differentiation), the damaged embryo becomes frequently nonviable, so that most genetic damage is removed from the population before it even has a chance to appear in a living progeny. Add to this the propensity of DNA to repair itself, a phenomenon more frequently evidenced than was formerly supposed possible, and we have a reassuring degree of genetic stability.

Perhaps the greatest genetic impact of chemicals such as pesticides on animal populations has been, and likely will continue to be, as selective agents; the more sensitive organisms die off under the influence of the chemical, but any resistant members of the population survive, reproduce more freely in the lessened competition, and proceed to repopulate the area with the resistant strain. We have seen this in the case of the housefly and DDT. The genetic constitution of the population is thereby altered, sometimes severely, but not through a true mutagenic influence. It is instead by a selective elimination of the "unfit" in essentially the same fashion as has been carried out in nature since time immemorial. Even so, the reasonably frequent appearance of genetically weak individuals must be expected because of "genetic load."

"Genetic Loads" and Environmental Threats

Numerous studies of natural populations have revealed surprisingly large stores of hidden genetic variability. Since most of the genes involved are recessive, and also harmful to a greater or lesser degree when revealed in the homozygous state, Muller coined the term "genetic load" to describe this burden. Some of the load in any generation of any population is caused by new mutations from either spontaneous or other causes. But a far greater fraction of the genetic variability is composed of genes which are retained in the population because in the proper combinations they add to the fitness of the population. A fit and adapted population, far from being in the pure and homozygous state formerly envisioned by many biologists, seems instead to be very highly heterozygous. It then becomes inevitable that many of these heterozygous loci will segregate out fairly frequently some of these recessive genes in the homozygous condition, thus revealing some of the hidden "genetic load."

The significance of the existence of such genetic variability in animal populations is that it tends to obscure the adverse influences of the environment. More importantly, an increase in the mutation rate must reach reasonably high levels before it contributes significantly to the genetic deterioration of the population. At the present time, and even in the foreseeable future, no environmental threat looms large enough to jeopardize the genetic constitution of our animal populations. This is especially so when contrasted with the human population, where the appearance of a single genetic defect frequently spells tragedy in a family. In domestic animals the breeder simply exercises his selection privileges to remove the genetically defective animal from his herd or flock. In wild populations, natural selection accomplishes the same end, and the reproductive rates are such that numbers are easily maintained despite the increased genetic load.

This situation, however, is perhaps not as characteristic of our populations of domestic animals as it is of the wild populations because of the "purifying" effects of inbreeding to which they have all been subjected. Man's selection practices may indeed prove to be the greatest threat to the genetic constitution of domestic animals; by constantly selecting them for ever increased usefulness for his own immediate purposes with an almost total disregard for their real biological fitness, man has been for centuries, but especially in the last few decades, narrowing the genetic base or restricting the gene pool of his populations to the point of decreasing their flexibility. Should a major environmental threat in the form of radiation or chemicals appear, it could eventually prove fatal to some of his species. There must be a continued existence of adequate genetic variability to give assurance that the species could adapt by rapid multiplication of those strains which prove resistant.

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Environmental Threats to Plants — Biotic and Physiochemical Stresses

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A lot has been written about air pollution, water pollution, poisons in our food, plant-disease epidemics, noise levels, flood control, over-population, the cementing and asphalting of our countryside, and the rest of man's alterations of his environment. Little has been said, however, about the fact that the health and welfare of man are not rooted in air, but in a complex system made up of *all* the facets of his habitat, including man himself, interacting with and on each other. No study of our physical environment makes sense if it focuses on one without the others.

The environmental threats on plants involve environmental stresses which may be either *biotic or physiochemical* in nature. The biotic stresses usually involve plant pathogens (disease producers) or competition by other organisms. The physiochemical stresses to which a plant is exposed involve temperature, water, radiation, chemical, wind, pressure, sound, magmetic, electrical, etc. Each kind of stress must be examined individually in order to find out whether the plant has succeeded in developing any kind of resistance to these stresses.

Environmental factors that produce injury in the growth and development of host plants cause disorders referred to as *physiogenic diseases* which are not contagious like pathological diseases. Physiogenic diseases are caused by environmental stresses, which include extremes in soil moisture, unfavorable atmospheric and soil microclimates, chemical damage, and mechanical injuries.

Environmental factors that produce physiogenic diseases will, in addition, create conditions that predispose host plants to pathogenic microorganisms. In all instances an interrelationship exists between the environment and pathogen development.

Biotic Threats to Plants

Climate and weather have a great effect on disease. Climate determines whether a pathogen will flourish or can persist under normal conditions in a given locality. Weather, and more specifically, microclimate, determines whether a pathogen-host relationship will develop into disease. All stages in the life cycle of a pathogen have an optimum temperature range. Temperature, at certain critical stages in the development of a pathogen, host or vector (disease carrier), appears to be the limiting factor in the behavior of some diseases. Humidity appropriate to the requirements of a pathogen is necessary for all its active stages and low humidity ordinarily retards or prevents the development of a pathogen. Few plant diseases are severe under conditions of consistently low humidity. Within limits, an organism's need for moisture varies with the temperature.

If we assume that there are mutual interactions between the *pathogen,* the *host,* and the *environment,* then most of the physiochemical stresses above influence the following:

1) perpetuation of the pathogen from one crop season to the next, 2) building up of early inoculum, 3) formation of spores, 4) dissemination of inoculum and primary infections, 5) development of disease after infection, 6) production of secondary inoculum and survival stages of pathogens, and 7) insect vector development.

Temperature Stresses

Low Temperatures. — A detrimental effect from temperature may be due to either low temperatures or high temperatures. Most plants in the growing state are killed by *internal freezing;* and even dormant plants may be injured by *freezing,* or *frost injury.* Some plants (mainly from tropical regions) are also injured or killed by exposure to low temperatures above the freezing point. This is called *chilling injury.*

Plant protoplasm can survive the lowest temperatures attainable (0°K approximately), if no ice crystals form in the tissue. Even if frozen, it may survive the lowest temperatures, provided that the freezing process is of a specific kind. This is true, for example, if the ice crystals are so small as to require x-ray analysis for detection. Under normal conditions, however, only air-dry plant parts (e.g., seeds) can show the first kind of survival, and the second kind occurs only under artificial conditions. Frost resistance of all except dehydrated plant parts (with a few exceptions) should be considered as a degree of tolerance since the vast majority of plants cannot avoid freezing on exposure to extreme subfreezing temperatures. But this tolerance exists only toward extracellular (i.e., intercellular) ice formation. No plant can survive the formation of microscopically visible crystals within their living cells (intracellular freezing), at least not *if* the ice is formed within the protoplasm.

Since the extracellular freezing removes water from the cell, the cell becomes more and more dehydrated as the temperature falls farther and farther below the freezing point. In many plants it is not until the temperature drops to -20° to -30°C that 95% of the cell's water may be removed in this way. If the cell cannot survive such a profound dehydration, it will obviously be killed. It is therefore logical to conclude that when plants are frozen extracellularly, any injury that occurs is likely to be a dehydration injury. Once the cell has nearly all of its water frozen (at about -30°C) without injury, it can also survive subsequent immersion in liquid air or liquid nitrogen and may logically be expected to survive absolute zero.

Frost resistance varies seasonally, so that even the most resistant plants of midwinter, which survive temperatures of -50°C (or even -190°C under artificial conditions), are killed by about -5°C in early spring. During the fall, the plant "hardens"; that is, it slowly develops a greater and greater tolerance or hardiness, until the maximum is reached in midwinter; and then it dehardens slowly until the minimum is reached in spring. Hardening can be induced artificially by exposure to low temperatures (e.g., 0° to 5°C), dehardening by exposures to high temperatures (e.g., above 10°C).

The inescapable conclusion is that *low-temperature resistance is really low-temperature tolerance.*

High Temperatures. — The range of high temperatures survived by plants is narrow compared to the range of low temperatures. The highest temperature that air-dry cells have been able to survive is about 140°C (284°F), and normally moist vegetative cells are usually killed by 40°C (104°F) to 50°C (122°F). As in the case of frost resistance, heat resistance is nearly always tolerance. Exceptions have been found among plants of the Sahara Desert. Some of these normally survive air temperatures of 50°C by absorbing and transpiring such tremendous quantities of water that their leaves are cooled as much as 10°C below that of the air. Although heat injury is not a dehydration process, heat tolerance is frequently (but not always) correlated with frost and drought tolerance.

It is possible to classify organisms on the basis of their response to the stress. (1) *Psychrophiles* (lovers of cold) grow and develop in a temperature range that includes chilling temperatures (0° - 20°C). Any temperature above 15° to 20°C may be a heat stress for them. The term has been used mainly for bacteria and fungi. Algae belonging to this group may actually grow on snow(2). *Mesophiles* (lovers of middle temperatures) grow and develop at temperatures of about 10° to 30°C. Any temperature above about 35°C may be a heat stress for them. (3) *Thermophiles* (heat lovers) may grow and develop at temperatures between 30° and 100°C. Only temperatures above 45°C (moderate thermophiles) or much higher (extreme thermophiles) are heat stresses for them,. Thus, a quantitative evaluation of high-temperature stress might be defined as the number of degrees above 15°C, since this is the approximate threshold of heat injury for the least heat-resistant group — the psychrophiles. No quantitative definition for heat stress is, therefore, possible. It can only be said qualitatively that the specific heat stress for any organism increases with the temperature above the lowest one that causes stress.

Soil Temperature. – Our prior references have been to air temperatures, but soil temperatures surrounding the root of the host can also be detrimental. Temperature affects the rate of moisture absorption. High soil temperature can induce host disorders such as diseased tissue, soil cracking and root damage. The freezing of soil directly kill the roots of many tropical and subtropical plants. Persistent and unseasonable low soil temperatures usually stunt plants. Soil temperature may affect disease either by its effect on the host or on the soil-borne pathogen.

Cold soils affect mobility of nutrient elements (e.g., iron) and may cause temporary chlorosis (chlorophyll underdevelopment). Soil temperature is therefore closely connected to abiotic diseases. High soil temperatures may also cause heat cankers in woody plants at the soil line. Enlarged callus zones are produced above lesions, influenced perhaps by the interrupted downward flow of carbohydrates. These weakened plants may eventually break and die if whipped by wind action.

Moisture stresses

Moisture may injure or kill plants if present in excess, but this is actually due to lack of oxygen and is called a *flooding injury*. A more common injury, however, is called *drought injury*.

Ecologists classify plants subjected to water stress according to the environmental water supply required for the normal completion of their life cycle. Those adapted to partial or complete submergence in free water are called *hydrophytes*. Land plants adapted to a moderate water supply are *mesophytes*. Those adapted to arid zones are *xerophytes*. There are, of course, all gradation between these groups, and it is, therefore, not always easy to place a plant in one or the other group. It is even possible for a plant to fit into more than one group. *Chamaegigas intrepidus* (an African resurrection plant) grows in shallow water pans in southwest Africa, but during the dry season it exists in the airdried condition. Herbarium specimens which had been dried for 4 years came to life when immersed in water, but this plant is an obvious exception.

In both drought-hardy and nonhardy plants, protoplasmic viscosity (thickening of the living material of cells) usually increases with desiccation, often to a point where the protoplasm becomes brittle. Xerophytes maintain protoplasmic elasticity to much higher levels of desiccation. Hydrolytic activities (an enzymatic process of decomposition involving the addition of water), including breakdown of metabolites in general, but particularly the hydrolysis of starch and protein, increase during desiccation. This general increase in rate of metabolic breakdown is probably the most universal characteristic of high-water stress. A result is damage to and destruction of the submicroscopic structure of protoplasm.

Agriculturists have long studied the induction of drought hardiness. Plants exposed to low water levels, high light intensities, and other factors such as high phosphorus and low nitrogen fertilization become drought-hardy compared to plants of the same species not treated in this way. This is a good example of a conditioning effect. Russian scientists have reported that plants may be induced to become drought-hardy by soaking the seeds in water for two days and then air-drying them. After the seeds are planted, the resulting plants are said to be much more drought resistant.

Soil Moisture. — Soil moisture affects both soil-borne and air-borne diseases of plants. High moisture can lead to root suffocation and injury through reduction in oxygen content. High soil moisture leads to lack of oxygen in soils. Over long periods, this high moisture can make plants so succulent that they become particularly sensitive to invasion by certain pathogens. Drying of soil is generally accompanied by reduced soil pathogen activity, with most of these organisms going into resting stages as free water disappears from the soil. Temperatures drop farther and faster in a dry soil in wintertime; therefore winter kill is prevalent in dry winters.

Radiation stresses

Visible radiations (light) are seldom directly responsible for death, although they are sometimes capable of causing *radiation injury*. Radiation below the wavelength of light may, however, be highly injurious or fatal. This does not commonly occur in the natural habitat of the plant, since only the ultraviolet radiations are of shorter wavelength than light in the radiation received on earth from the sun, and they are usually of too low an intensity to injure most plants. However, because of the modern interest in nuclear energy and in outer space, injury by radiations of lower wavelength is now receiving greater attention. Injury caused by infrared radiation is actually heat injury.

Ionizing radiations are highly penetrating and highly absorbed by the plant. Plants that survive such radiations must possess tolerance. Ultraviolet radiations may, however, be largely reflected, transmitted, or absorbed by the plant surface. Survival of these radiations may therefore be due to avoidance. In the case of temperature and water, however, a level of illumination below the light compensation point can lead to a slow, indirect injury, due to starvation. Shade plants are adapted to low illumination and are therefore more "shade resistant" (i.e., resistant to light deficit) than sun plants.

One of the better examples of how light influences diseases and causes stress on plants is illustrated with *Helminthosporium* of turf. This is often called a low-sugar disease. Extensive cloudy periods of 2 to 3 days duration reduce the carbohydrate level in grass leaves. This then predisposes the grass to *Helminthosporium.* With lowered "leaf sugar content" a narrower carbon-nitrogen ratio develops and since both carbon sources for energy to germinate and nitrogen required for penetration are at levels favorable to the pathogen, *Helminthosporium* does indeed invade host tissue.

One aspect of radiation is the influence of radiation on air pollution in producing toxicants which will harm plants. Examples of such environmental threats follow.

Photochemical or Oxidant Smog. — This kind of gas stress is mainly due to two substances — ozone (O_3) and peroxyacetyl nitrate (PAN), although other injurious substances may also be present. In some respects, the actions of these two substances are directly opposite to the action of SO_2. They are oxidizing substances while SO_2 is a reducing substance. They injure the lower surface of the leaf while SO_2 injures the upper. Although PAN injury is increased by high light intensity and greatly decreased by darkness (as in the case of SO_2) its absorption is unaffected by the opening and closing of stomata. Finally, both O_3 and PAN may inhibit plant growth, as well as increase the respiratory rate and decrease the rate of photosynthesis. Thus, unlike SO_2, they can produce both direct and indirect injury.

Direct injury involves interference with cell-wall metabolism or it may involve a minute blistering of the undersurface of the leaf. These changes were identical with those previously observed in cells damaged by peroxyacetyl nitrate, and were probably related to the oxidative properties of both molecules.

Besides these direct types of injury, indirect injury affects rates of respiration and photosynthesis.

Ozone damage has also been related to SH (sulfhydryl). Ozonation lowers the SH content of bean, spinach, and tobacco plants. The tobacco variety resistant to ozone was also more resistant to damage by SH reagents. The older the leaf, the more severely it was damaged by SH reagents and by ozone. The younger, more ozone-resistant leaves have higher concentrations of SH. Leaves of the resistant variety, however, contain lower concentrations. It has even been possible to reduce ozone injury to bean plants by spraying with special compounds that function as reducing agents.

Salt stresses or chemical stresses

Salt stress can be produced by an excess of any one of a large number of salts.

Most of the salt stresses in nature are due to Na salts, particularly NaCl. The term *halophyte* literally means "salt plant," but is used specifically for plants that can grow in the presence of high concentrations of Na salts. Plants that cannot grow in the presence of high concentrations of Na salts are called *glycophytes* ("sweet" plants).

It has long been known that halophytic plants contain high cell sap concentrations due to absorption of large quantities of salts. Even when care is taken to wash off surface-excreted salt, high osmotic values have been found, (100-130 atm) and these plants must therefore possess salt tolerance. In the case of varietal differences in mildly resistant plants (e.g., barley), it has been found that the more resistant variety excludes the salt better than the less resistant variety and therefore owes its resistance to avoidance.

When a plant is exposed to a salt stress, this means that the chemical potential, activity, or more simply the concentration of the salt is higher outside the plant than some arbitrary normal value. If the salt follows its diffusion gradient and penetrates the plant cells, two changes must accompany the internal salt stress or increase in concentration: (1) a change in ionic balance, and (2) a decrease in water potential. If the salt does not enter the cell, then only the second change will occur. These are elastic strains which would be immediately reversible on removal of the external salt stress.

The general conclusion from all the above examples is that in the case of nearly all stresses that have been investigated, plants have succeeded in developing both tolerance and avoidance.

Tolerance seems to be the more primitive adaptation, and avoidance more advanced. Tolerance merely permits the plant to survive until such time that the stress is removed and the plant can resume its normal metabolism, growth and development.

Some halophytes are referred to as salt accumulators. In these plants the osmotic potential continues to become more negative throughout the growing season as salt is absorbed. It should be noted, however, that even in these plants the soil solution is not taken directly into the plant. It is easy to calculate, based upon quantities of water transpired by the plant, that if the complete soil solution were absorbed, the plant would contain ten to one hundred times as much salt as is actually observed. Instead, water moves into the plant osmotically and not simply in bulk flow. The endodermal layer in the roots probably provides the osmotic barrier.

Halophytes in which the salt concentration within the plant does not increase during the growing season are known as *salt regulators*. Often the salt does enter the plant, but the leaves swell by absorbing water, so that concentrations do not increase. This leads to the development of succulence (a high volume/surface ratio), a common characteristic of halophytes. Sometimes excess salt is exuded on the surface of the leaves, helping to maintain a constant salt concentration within the tissue. In certain halophytes there are readily observable salt glands on the leaves. These salt glands accumulate and secrete salt on the leaf surface. Actually, it has been shown by several workers that large quantities of both organic and inorganic materials may be leached from the leaves of many plants, both halophytes and glycophytes.

Some crop plants (e.g., beets or tomatoes) are much more salt hardy (tolerant) than other (e.g., onions or peas), and salt hardiness can be increased somewhat by exposure to saline conditions. Lists of plants exhibiting varying degrees of salt hardiness have been published by Levitt (4).

Stresses due to air pollution

If we take a typical legal definition of air pollution (Oregon Revised Statutes, 1956) as: "The presence in the outdoor atmosphere of substances or contaminants, put there by man, in quantities or concentrations and of a duration as to cause any discomfort to a substantial number of inhabitants of a district or which are injurious to public health, or to human, plant, or animal life or property, or which interfere with the reasonable, comfortable enjoyment of life and property throughout the state or throughout such territories or areas of the state as shall be affected thereby." (9) Assuming the above to be acceptable, then the following compounds constitute air contaminants or air pollutants:

Group	Examples
Solids	Carbon fly ash, ZnO, $PbCl_2$
Sulfur compounds	SO_2, SO_3, H_2S, mercaptans
Organic compounds	Aldehydes, hydrocarbons, tars
Nitrogen compounds	NO, NO_2, NH_3
Oxygen compounds	O_3, CO, CO_2
Halogen compounds	HF, HCl
Radioactive compounds	Radioactive gases, aerosols, etc.

We have previously discussed the air pollutants that are affected by radiation and so we will limit our discussion to several of the other air contaminants.

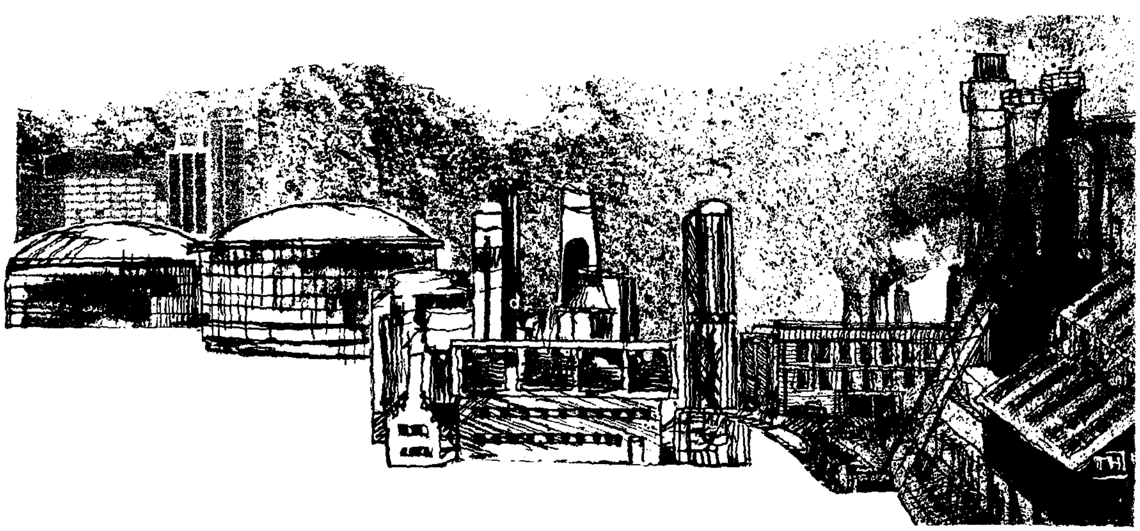
There are three principal air pollutants of major interest to agriculture — viz., sulfur dioxide, fluorine compounds, and smog. The last is a complex mixture, only partially understood at this time. There are at least two distinct types of smog, with many intermediate grades: the London type, which is a mixture of coal smoke and fog with enough sulfur dioxide to impart reducing properties to the mixture; and the highly oxidizing Los Angeles type, which usually contains neither coal smoke nor fog, but rather is a mixture of ozone and peroxidized organic compounds formed by photochemical reactions between oxides of nitrogen and innocuous organic compounds such as gasoline vapours or partially burned fuel. In addition to the two types of smog, certain organic compounds, such as ethylene, DDT, and some heterocyclic bases, are known to have powerful phytotoxicity and have done considerable plant damage in some locations.

Sulfur dioxide has been studied longer and more intensively than the other pollutants. The effects of sulfur dioxide on plants are fairly well understood. The gas is absorbed into the mesophyll of the leaves through the stomata. Toxicity is due largely to the reducing properties of the gas. When extensive areas are killed, the tissues collapse and dry up, leaving a characteristic pattern of interveinal and marginal acute injury. If only a few cells in an area are injured, this area may become chlorotic or brownish-red in color, owing to chronic injury. Sulfate toxicity is a form of chronic injury manifested by white or brownish-red turgid areas on the leaf caused by the rupture of some cells or of chloroplasts within the cells. Leaf fall often occurs at or before this stage.

Injury caused by sulfur dioxide is usually local. No systemic effects have been observed. While the injured areas of the leaves never recover, the uninjured areas quickly and fully regain their functions and new leaves develop normally once the polluting source has been removed.

It seems clear that the toxicity of sulfur dioxide is caused primarily by its oxidation-reduction properties rather than by its acidity. Sulfur dioxide is considerably more toxic than hydrogen chloride.

Fluorides in general, and gaseous fluorides in particular, have assumed great importance as air pollutants during the past decade, first, because hydrogen fluoride and silicon tetrafluoride are toxic to some plants in concentrations as low as 0.1 parts per thousand million (p.p.t.m.) and secondly, because all fluorides, particulate as well as gaseous, may be accumulated by forage to build up concentrations in excess of 30-50 p.p.m. on the inside and outside of the leaves. No lesions are ordinarily observed in the forage. This vegetation,



when consumed by cattle or sheep, can cause fluorosis (bone and teeth malformation) in the animals. This phase of the problem often has even greater economic significance than the direct plant-damaging effects of fluorides (9).

The toxic effects of fluorides on vegetation present many paradoxes. Some plants are injured by extremely low concentrations in the atmosphere and/or in the tissue; others can withstand more than a hundredfold as much. The reason for this enormous range of tolerance is not apparent. A few factors may be mentioned which perhaps play a part.

Though fluoride is generally present in soils to the extent of several hundred parts per million, plants show little tendency to take it up, first, because of its insolubility and secondly, because the fine roots have an effective mechanism for excluding it, especially if the pH of the soil is high. Sodium fluoride is taken up rather readily but, of course, it is rarely present. Consequently, when a plant contains more than a few parts per million fluoride, atmospheric contamination is indicated. An exception is camelia, which took up 1500-2000 p.p.m. while peach took up 20 p.p.m. (9).

Many field studies of the effects of fluorides on vegetation have been made. Fluoride injury usually has occurred in industrial areas, particularly near aluminum and fertilizer plants. Apricot, peach, prune, fig, apple, pine, and gladiolus injury has been described, including abscission of leaves and dropping of fruit.

Acute fluoride lesions on plants are quite characteristic, but are not the same in all species. The lesions vary also according to the gas concentration and length of exposure that produce them.

Injury to gladiolus starts at the tip, and gradually extends down the blade as ivory colored necrotic tissue sometimes streaked with brown. A somewhat uniform front with a very narrow chlorotic band between the healthy and necrotic tissue is usually maintained. Islands of injured tissue surrounded by healthy tissue do not occur except with high fluoride concentrations. The pattern is similar on iris and the small grains. The current year's needles on pine, which are the most sensitive, are also similarly injured, except that the necrotic tissue is reddish brown. In apricot, prune, peach, grape, and other netted leaves, the injury is marginal with a sharp line of demarcation between healthy and necrotic tissue. At times the narrow transitional area is red. In the peach, the necrotic areas tend to become detached, leaving the leaf apparently healthy except for reduced size and a serrated edge. Abcission of the leaves of the fruit trees occurs readily even with moderate amounts of leaf destruction (9).

Summary

Control or reduction of damage from these environmental stresses is possible with appropriate technological advances.

Control of biotic threats involves an understanding of how the physical environment interacts not only with a host plant but also with a pathogen that will affect this host plant. Preferably controls are manifest by selecting and breeding varieties of plants that are resistant or tolerant of disease and by using biological controls in the environment which will alter nutrition of pathogens or competition between pathogens and thereby reduce ravages of disease on host plants. Crop rotations are effective methods of reducing levels of plant pathogens. And, lastly, if all the above methods are difficult to cope with reduced biotic threats, then one can always resort to the wise and limited use of pesticides to control particular diseases.

Control of temperature threats and moisture stresses involves, either directly or indirectly, some form of weather control which means weather modifications. Hopefully it may be possible to reduce these threats. Another means of coping with temperature stresses would be to select crop plants that are adaptable to various temperature stresses. That is to say, select plants that can be cold tolerant or select those host crops in which hardiness can be increased by altering soil constituents or plant surfaces to make these plants more cold tolerant. In tropical environments it is possible to select and grow particular groups of plants that can tolerate heat, drought, and salinity. It is also possible in warmer climates to grow several crops per year, and here again, a selective evaluation of crops to fit the season of the year could avoid stresses.

With threats of air pollutants, the best approach appears to be the various attempts to control environmental air pollution as established under the *Air Quality Standards Act* of 1971. This act is to be implemented by 1975 with minimum standards set by Federal agencies for air quality. In addition to this act, Public Law #92-516 was passed by the Congress October 21, 1972. This law will regulate pesticide use thereby aiding in the reduction of pesticide pollution of the environment (both soil and air). This law is to take effect October 21, 1976. Hopefully, this will reduce some of the air pollution threats. Researchers in various countries are also attempting to select various strains of plants that may be either tolerant of or immune to air pollution damage. With regards to some chemical threats such as salt toxicity to plants, there have been developed several agricultural and horticultural management practices that can reduce salt toxicity and permit normal growth. Examples of these are; planting on beds; flooding and draining, and consequently leaching soils high in salts prior to planting; planting on the sides of beds to permit the saline water front to migrate past the plant stem; and lastly, the use of salt-tolerant crops or varieties of crops.

The reduction of the environmental threats to plants involves a three way interaction to implement the suggested control measures cited above. This involves an interaction between the consumer, the producer, and state and federal regulatory agencies. If attempts to reduce environmental threats are recognized now and solutions to reduce these threats are begun now, then the approach of a time when threats to crop production are reduced or eliminated and crop production to feed the world's burgeoning population becomes a realistic goal.

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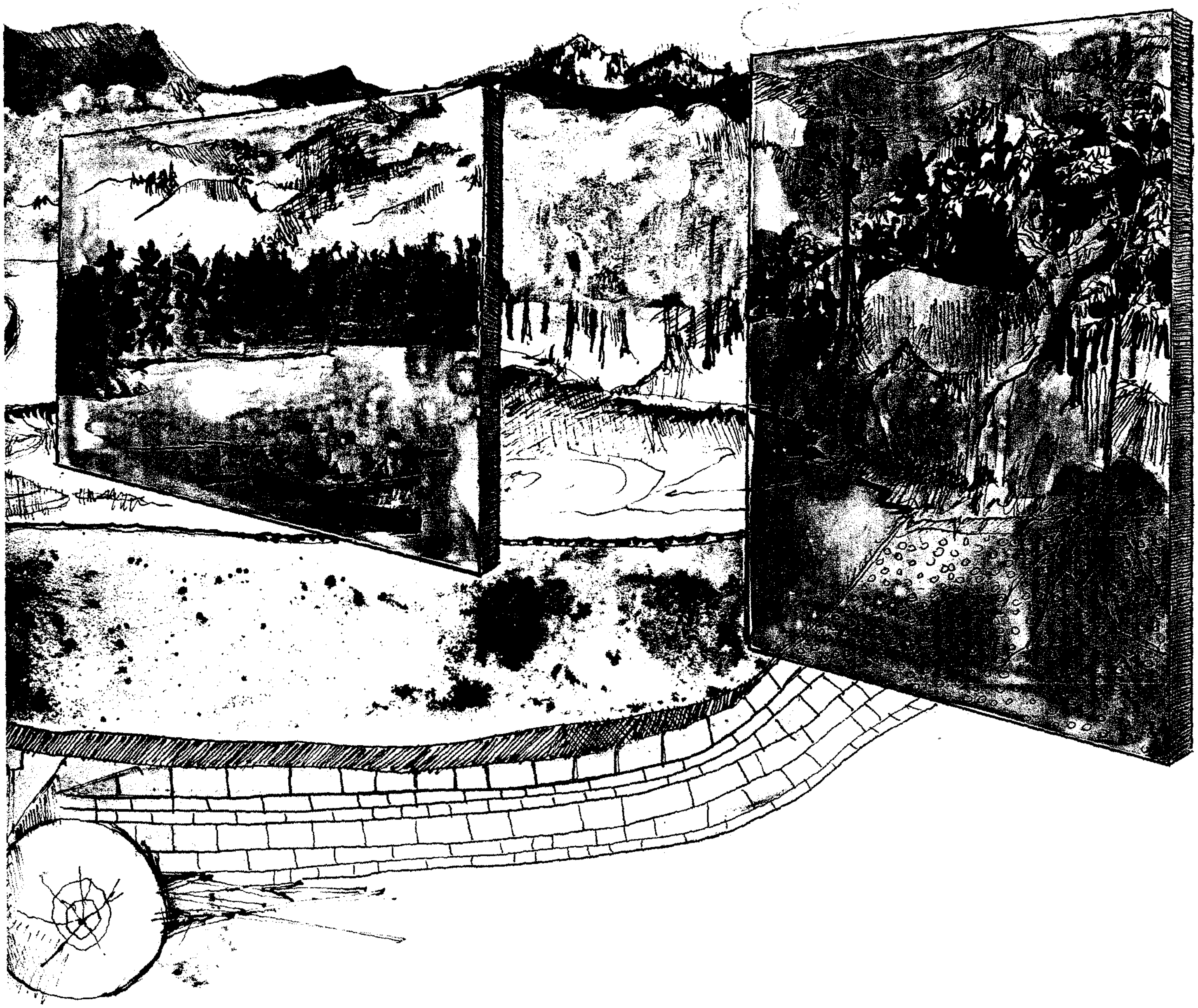
REGAL

Pollutants in the Ecosystem

Pollution affects the most vital elements of the ecosystem – air, water, and soil. If man is once again to view a clean environment, pollution of these resources must be stopped.



Origin and Effect of Pollutants in Water

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Pollutants in Water

A wide variety of kinds and sizes of particles are found in water, affecting its quality. All waters contain some of these particles, but their presence doesn't necessarily mean that water is polluted. Determination of the state of pollution of water must be based on the concentration of pollutants. Trout require dissolved oxygen to survive, whereas irrigation water need not have any dissolved oxygen to be suitable for crops. Therefore, considering only dissolved oxygen, a river with a low dissolved oxygen concentration would be polluted from the standpoint of maintaining a trout population, but unpolluted in terms of a satisfactory supply of irrigation water.

Size is a useful means of categorizing pollutants. Generally speaking, pollutants can originate from natural and/or man-made sources. Natural sources include the atmosphere, mineral soils and rocks, living organisms, and organic decomposition. Domestic wastewaters (sewage), irrigation return flows, runoff from animal feedlots, and a wide variety of industrial wastewaters are the common manmade sources. Pollutant sizes, ranging from large to small, are: suspended particles, colloidal particles, and dissolved molecules and ions.

Suspended particles are large enough to settle out or be filtered out of the water, and they are large enough to absorb light and make water appear cloudy or murky.

Colloidal particles are so small that their settling rate is insignificant, and they pass through most filters. They cause turbidity. Water containing colloidal particles appears clear in the direct path of light that illuminates it, but can appear turbid when viewed at right angles to the light beam. The colors of natural waters, such as the blues, greens, and reds of lakes or seas, are caused mainly by the presence of colloidal particles.

Consisting of molecules and ions, dissolved particles in water are impossible to see with the naked eye. Molecules are electrically neutral, whereas ions have an electrical charge (cations are positively charged; anions are negatively charged). Sugar, alcohol, and automobile antifreeze are examples of substances that dissolve in water as molecules. Table salt (sodium chloride) is an example of a substance that dissolves as a positive sodium cation and a negative chloride anion.

With the exception of oxygen demand, all of the particles listed as molecules in Table 1 are gases at room temperature and pressure. Natural dry air contains carbon dioxide, oxygen, and nitrogen, while sulfur dioxide is an air pollutant.

Another category of pollutants is not entered in Table 1. This category is floating materials such as oils, greases, foam, and other solids that are lighter than water.

Effect of Water Pollutants

The pollutants listed in Table 1 can have a wide variety of detrimental effects depending on their concentrations. These effects are listed in Table 3. In the case of gases, the effects refer to the presence of the gases dissolved in water. Exceptions to this are hydrogen and methane. In certain highly polluted waters, methane is produced and bubbles to the surface, escaping into the atmosphere. If the area isn't ventilated, methane can mix with air to produce explosive air-gas mixtures.

One common indicator of water quality is pH, a number which has a practical range of 0 to 14 at 25°C. At a pH of 7, the water is neutral (as is the case with distilled water). Water with a pH less than 7 is acidic, and water with a pH greater than 7 is alkaline. The pH of water depends on the concentration of hydrogen ions (listed in Table 1). Alkalinity is the sum of the concentrations of the bicarbonate, carbonate, and hydroxide anions. Most natural waters have a pH within the range of 4 to 9, and most have a pH somewhat above 7. Table 2 gives the pH of some common substances.

The total concentration of all the cations and anions is the salinity, and waters with high salinity have a laxative effect. Salinity is the single most important water quality problem in the western 2/3 of the U.S. Therefore, any use of water that adds cations and anions increases its salinity, and there is no use of water that does not increase its salinity. (Because of electrical neutrality, the total concentration of cations is always equal to the total concentration of anions.)

Table 1. Origin of water pollutants.

Source	Particle Size Classification				
	Suspended	Colloidal	Dissolved		
			Molecules	Cations	Anions
From the atmosphere	Dusts		Carbon Dioxide Sulfur Dioxide Oxygen Nitrogen	Hydrogen Ion	Bicarbonate Ion Sulfate Ion
From Mineral Soils and Rocks	Clay, Sand, Other Inorganic Soils	Clay Silica Ferric Oxide Aluminum Oxide Manganese Dioxide	Carbon Dioxide	Sodium Ion Potassium Ion Calcium Ion Manganous Ion Ferrous Ion Manganese Ion Zinc Ion	Chloride Ion Fluoride Ion Sulfate Ion Carbonate Ion Bicarbonate Ion Nitrate Ion Hydroxide Ion Monohydrogen Phosphate Ion Dihydrogen Phosphate Ion
Living Organisms	Fish, Algae, Diatoms, and minute animals	Viruses, bacteria, algae, and diatoms			
From Organic Decomposition (also decomposition products of living organisms)	Organic Soils (top soil) Various organic wastes, some of which produce odor and color	Vegetable Coloring Matter	Carbon Dioxide Ammonia Oxygen Nitrogen Hydrogen Sulfide Methane Hydrogen	Sodium Ion Ammonium Ion Hydrogen Ion	Chloride Ion Bicarbonate Ion Nitrite Ion Nitrate Ion Hydroxide Ion Hydrosulfide Ion Organic Radicals
From Domestic Wastewaters	(Oxygen Demand)			Calcium Ion Magnesium Ion Sodium Ion Potassium Ion	Bicarbonate Ion Sulfate Ion Chloride Ion Nitrate Ion
From Irrigation Return Flows				Calcium Ion Magnesium Ion Sodium Ion	Bicarbonate Ion Sulfate Ion Chloride Ion
From Animal Feedlots	(Oxygen Demand)		Carbon Dioxide Oxygen Demand	Potassium Ion Sodium Ion Calcium Ion Magnesium Ion	Bicarbonate Ion Chloride Ion Fluoride Ion Nitrate Ion Sulfate Ion Orthophosphate Ion

Table 2. pH of some common substances.

Substance	pH
acidic hot springs	1-2
soft drinks	2-4
vinegar	2.4-3.4
wines	2.8-3.8
cider	2.9-3.3
club soda	3.8
beer	4-5
human urine	4.8-8.4
rainwater	6
cows milk	6.3-6.6
maple syrup	6.5-7.0
drinking water	6.5-8
river water	7
sea water	8-9

Oxygen demand is an indirect measure of the concentration of organic materials in water or wastewater; it may depend both on biological and chemical processes. The BOD (Biochemical Oxygen Demand) is a measure of the concentration of organic materials that act as sources of food for microorganisms. As they consume these organic materials, aerobic microorganisms use dissolved oxygen in the water. COD (Chemical Oxygen Demand), on the other hand, is a measure of the concentration of organic materials that can be oxidized by chemical means. Some substances can be oxidized both by microorganisms and by certain chemicals. At any rate, oxygen demand is a measure of the concentration of oxygen that will be consumed by a given substance in water. Oxygen demand may reduce temporarily the dissolved oxygen concentration in a stream, the amount of the reduction involving many factors.

Floating materials such as oils, greases, foams, and other solids that are lighter than water may, in addition to making the stream or lake unsightly, retard plant growth by reducing the intensity of sunlight through the water. Oil, in particular, interferes with the natural reaeration of a stream or lake, destroys natural vegetation along the banks, and is toxic to fish and aquatic life. A fire hazard is also created when there are excessive amounts of oil on the water surface.

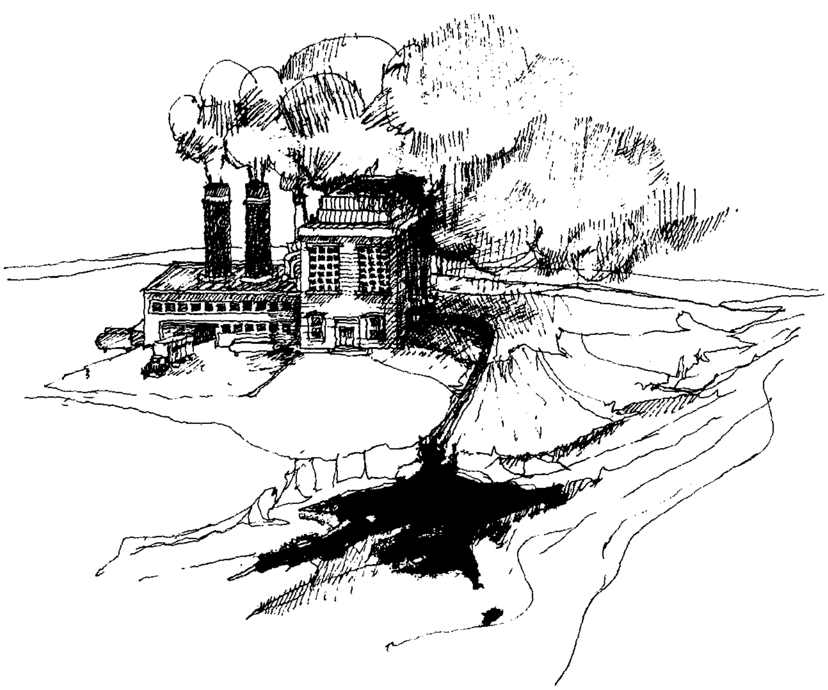

Table 3. Effect of pollutants in water.

	Pollutant		Effect of pollutant if present in sufficient concentration
	Symbol	Name	
GASES	H_2	hydrogen	mixtures of H_2 and air are explosive in improperly ventilated areas
	N_2	nitrogen	can kill fish exposed to supersaturated nitrogen concentrations in water that sometimes occur below dam spillways
	CH_4	methane	can cause the accumulation of explosive air-methane mixtures in improperly ventilated areas
	O_2 or DO	oxygen or dissolved oxygen	makes water corrosive, but is necessary for fish life
	CO_2	carbon dioxide	also makes water corrosive
	H_2S	hydrogen sulfide	may destroy cement and concrete
	SO_2	sulfur dioxide	reduces the pH of water
	NH_3	ammonia	harmful to fish
CATIONS	NH_4^+	ammonium ion	combines with OH- to produce NH_3
	Zn^{++}	zinc ion	taste-producing
	Fe^{++}	ferrous ion	taste and color-producing
	Mn^{++}	manganous ion	taste and color-producing
	Ca^{++}	calcium ion	may precipitate out of solution
	Mg^{++}	magnesium ion	cathartic
	K^+	potassium ion	cathartic; causes foaming in boilers
	Na^+	sodium ion	causes foaming in boilers; physiological effect on persons with cardiac, renal, or circulatory disease
	H^+	hydrogen ion	causes low pH
ANIONS	OH^-	hydroxide ion	contribute to alkalinity
	$CO_3^=$	carbonate ion	
	HCO_3^-	bicarbonate ion	
	Cl^-	chloride ion	taste-producing
	$SO_4^=$	sulfate ion	taste-producing
	HS^-	hydrosulfide ion	combines with H^+ to produce H_2S
	F^-	fluoride ion	may cause mottled enamel in the teeth of growing children
	NO_2^-	nitrite ion	produces methemoglobinemia in infants (blue babies)
	NO_3^-	nitrate ion	produces methemoglobinemia in infants (blue babies)
	$H_2PO_4^-$	dihydrogen phosphate ion	phosphates from detergents appear to be responsible for the increased nourishment of algae. Phosphates contain the elements P, O, and perhaps H. In addition to the 3 listed, other examples of phosphates are PO_3^- (metaphosphate) and $P_2O_7^{-4}$ (pyrophosphate)
	$HPO_4^=$	monohydrogen phosphate ion	
	PO_4^{-3}	orthophosphate ion	

Table 3. Effect of pollutants in water.

Category	Pollutant: Symbol	Pollutant: Name	Effect of pollutant if present in sufficient concentration
SUSPENDED, COLLOIDAL, AND DISSOLVED MOLECULES	OD	oxygen demand	may reduce the dissolved oxygen (DO) concentration to the point that fish are killed. If the DO concentration is reduced to zero, anaerobic conditions may cause the production of CH_4, CO_2, NH_3, and H_2S. If the DO concentration is greater, than zero, aerobic decomposition will produce CO_2, NH_3, or NO_3^-, PO_4^{-3} $SO_4^=$, and H^+.
	BOD	biochemical oxygen demand	
	COD	Chemical oxygen demand	
	TOD	theoretical oxygen demand	
COLLOIDAL	Al_2O_3	aluminum oxide	dissolves in water with a high pH
	Fe_2O_3	ferric oxide	causes red water in distribution systems
	MnO_2	manganese dioxide	causes black water
	SiO_2	silica	diatoms utilize SiO_2 in their skeletal structure
		clay	causes turbidity
		vegetable coloring matter	causes color
		bacteria	may cause typhoid fever, cholera, paratyphoid fever, bacillary dysentery, tularemia, and Weil's disease
		viruses	may cause poliomyelitis, infectious hepatitis, conjunctivitis, gastroenteritis, and diarrhea
SUSPENDED AND COLLOIDAL		diatoms	1 of 5 divisions of fresh water algae
		algae	cause eutrophic deterioration of lakes
		various organic wastes	some produce odor and color
		dusts	cause turbidity if colloidal; otherwise cause settleable solids
SUSPENDED		clay, sand, and other inorganic soils	may increase salinity
		organic soil	may produce some OD
		fish	produce OD
		minute animals	can cause amebic dysentery and swimmers itch

Control of Water Pollutants

Some pollutants in water never disappear, some change form through natural or man-made processes, and some are removed by either nature or man.

When water containing sulfur dioxide, ammonia, hydrogen sulfide, methane, and hydrogen is exposed to unpolluted air for a long time, the gases escape into the atmosphere and their concentration in the water tends to become zero. However, this is not the case with nitrogen, oxygen, and carbon dioxide. Unlike the other gases that exist in insignificant amounts in unpolluted air, oxygen and nitrogen constitute the bulk of the atmosphere, and carbon dioxide is also naturally present. Eventually the concentrations of these latter 3 gases assume equilibrium concentrations that depend on atmospheric pressure and water temperature.

Natural Processes

The ultimate fate of the various ions and molecules listed in Table 1 depends on a number of conditions such as pH, temperature, salinity, alkalinity, acidity, presence of certain bacteria, and presence of other ions and molecules. There are a large number of chemical, biological, and physical processes involved. For example, the concentration of the calcium ion depends on pH and alkalinity, and may be reduced by precipitation out of solution as calcium carbonate. Another example is ammonia; in the presence of certain bacteria, it is oxidized first to nitrite, then to nitrate.

Other ions increase in concentration in the hydrologic cycle from the time water first tumbles down high mountain creeks to the time it reaches the ocean. These ions include sodium, chloride, and sulfate; they constitute 88.3% of the salinity of sea water. On their way to the ocean, these and other ions cause salinity in rivers. This is particularly a problem in the western U.S. where warm water temperatures, frequent sunshine, and low humidity create high evaporation rates that are in excess of precipitation. Salinity can only be removed in desalinization plants at great cost. Further, desalinization plants produce waste brines containing very high salinity.

Ultimately, most of the biochemical oxygen demand in streams is removed by natural mechanisms. But along certain heavily polluted streams, oxygen demand enters the stream faster than the mechanisms can remove it. This can create foul-smelling, aesthetically unpleasing stretches of streams as much as 100 miles long.

Most of the nonliving colloidal matter remains in suspension all the way to the ocean, while most of the nonliving suspended material settles out on the bottom of streams and especially lakes and reservoirs. In fact, all existing lakes and reservoirs will eventually fill with nonliving, settled, suspended particles.

A silica cycle occurs in many bodies of water containing organisms, such as diatoms, that utilize silica in their skeletal structure. The silica removed from water may be slowly returned by re-solution of the dead organism.

Bacteria and viruses eventually die away in rivers, but the time required for 99.9% of them to die is over four months. The death and decay of algae creates an oxygen demand.

Treatment

Modern conventional water treatment plants can remove most of the bacteria, color, turbidity, odor, and taste of natural waters. However, these plants increase the salinity of water somewhat. Most of the ferrous and manganous ions can be removed after aeration, which also reduces the corrosiveness of water somewhat by removal of carbon dioxide, but, at the same time, increases the corrosiveness of water by the addition of dissolved oxygen from the atmosphere. The corrosiveness and scaling properties of water can be readily controlled by other methods.

Modern conventional biological wastewater treatment plants can remove about 98% of the bacteria, 90% of the suspended solids and BOD, and a maximum of 80% of the COD. Physiochemical wastewater treatment plants in general are more effective (BOD removals are as high as 97%). Both biological and physiochemical wastewater treatment plants increase the salinity of water, but they also remove floating material from water.

This paper is a highly oversimplified view of water quality and by no means covers all water pollutants, such as temperature and waterborne poisons (which include toxic substances leached from mineral formations, heavy metals, radioactive substances, pesticides, etc. or phytotoxins manufactured by specific algae). However, the need and demand for healthful, unpolluted water is daily becoming more urgent.

Air Pollution

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Air pollution is always defined with respect to the "normal" atmosphere, a mixture of permanent and trace gases. The presence of measurable quantities of foreign matter is termed "air pollution;" the extent of such pollution is determined by the concentration of foreign materials and their effects upon man and his environment. Air pollution is not necessarily manmade, as evidenced by volcanic action or forest fires. The scale of pollution is significant. On a global scale we may have interference with global radiation balance and potentially marked and dangerous climatic changes; on a regional scale there may be an effect upon cloud cover and precipitation; on the local scale effects are directed toward the health of individuals and the esthetics of their environment.

In the State of Colorado we are primarily concerned with the local scale. The major problems involve (1) carbon monoxide and photochemical smog along the Front Range; factors include poor air circulation, bright sunlight, high automobile traffic density, and inefficiency of the internal combustion engine at high altitudes. (2) Massive increases in electrical generating facilities in the western portion of the state are also a problem. Even though low sulfur coal is used, the magnitude of the required fuel supply will cause the emission of large quantities of particulate matter and sulfur dioxide. (3) Possible air pollution associated with oil shale development, and (4) pollution resulting from the development of high density communities in poorly ventilated mountain valleys are two more problems to be considered.

The effect of air pollution on human health is well documented. The individuals affected are those already suffering from respiratory or circulatory handicaps. The toxic effects are related not only to the nature and concentration of specific pollutants, but also to the general pollutant mix. The esthetic effects are somewhat more subtle. The presence of particulates reduces visibility and we lose our view of the mountains. This reduction in visibility was the first consequence of air pollution to draw public attention. Particulate emissions were the first to be subject to controls, because it is a common view that air pollution is visible. This is false. Invisible gases may be of greater significance than visible particles.

Air pollution may also have drastic effects upon plants. Destruction of forests has been reported in the Los Angeles basin and in Pennsylvania downwind of coal fired electrical generating plants. Sulfuric acid obtained by oxidation of sulfur dioxide attacks building materials and plastics, while photochemical oxidants react strongly with rubber.

The concentration of air pollutants is determined by (1) the rate of emission, (2) the atmospheric transport and dispersion effects, (3) the rates of chemical reaction in the atmosphere and (4) the removal processes. Pollutants are classified as primary if they are emitted as such and secondary if they are formed in the atmosphere. The major factors determining the concentration are to some extent a function of location. Atmospheric mixing is usually classified with respect to two components, (a) horizontal and (b) vertical. The horizontal component is governed by wind speed; the vertical by the temperature structure of the lower atmosphere. Under unstable conditions good vertical mixing occurs; the same conditions generally lead to high wind velocities and good horizontal mixing as well. Stable conditions lead to poor mixing. The extreme case of stability is the temperature inversion, in which the pollutants are trapped below an inversion "lid" perhaps only 300 feet above the ground. Such inversions are frequent along the Front Range. Large scale weather systems to some extent control stability — a stagnant high pressure system with associated poor circulation is often responsible for pollution episodes. In Colorado, local terrain conditions are also important, with cold air drainage down slopes contributing to inversions. For example, in Denver, the air mass containing pollutants generally moves down the valley of the South Platte in the morning, reverses direction and moves up the valley in the afternoon. Precipitation tends to clean the air.

The Primary Air Pollutants

The Environmental Protection Agency (EPA) and the Colorado Air Pollution Control Commission have adopted ambient air quality standards for six major pollutants. These standards define maximum concentrations permitted for specific times of exposure and relate primarily to human health. Five of these pollutants are gases, sulfur dioxide, carbon monoxide, nitrogen dioxide, hydrocarbons, and photochemical oxidants. The other is composed of particulates, i.e., finely divided solids, stable because of their slow settling velocities. Three of the six are pure chemical substances: hydrocarbons are gaseous mixtures, photochemical oxidants are similar mixtures with ozone predominating, and particulates are mixtures of many solid chemical species.

Sulfur Dioxide

Sulfur dioxide is a colorless irritating gas, produced by the combustion of fuels containing sulfur or sulfur compounds, which strongly attacks the lining of the upper respiratory tract of man and animals. It dissolves in water to form acids and it can be tasted at a lower concentration than it can be smelled. In the presence of particulate matter, sulfur dioxide may penetrate into the alveoli of the lung and cause extensive damage. High concentrations cause leaf damage in plants. Sulfur dioxide can be oxidized to sulfuric acid, which exists in the form of a fine mist. This acid does not penetrate into the lungs; it does, however, cause extensive damage to building materials and plastics. Sulfur dioxide does not, at present, provide a major problem in Colorado due to the extensive use of sulfur-free natural gas as fuel. However, in the future it may present a problem with the increasing use of coal as a fuel for industry and electrical generation.

Carbon Monoxide

Carbon monoxide is an odorless, tasteless, colorless gas produced by incomplete combustion of carbonaceous materials. In terms of weight it is the major air pollutant. In Denver, for example, 850,000 tons of carbon monoxide were emitted in 1970; 91% originated in automobile exhausts. At Denver's 5000 foot altitude, 60% more carbon monoxide is produced per car mile than at sea level. The ambient air quality standards were exceeded 17% of the eight hour measuring periods during the year and close to 30% during November.

While carbon monoxide is poisonous to man, it has little effect upon plants and materials. It combines with hemoglobin in the red blood cells and drastically reduces the oxygen-carrying capacity of the blood. The first damage from this oxygen deficiency occurs in the nervous system, and subacute poisoning can lead to decreased visual perception and lack of judgment. Death will not occur at ambient levels likely to be encountered.

Even with the 90% reduction in carbon monoxide emission scheduled for 1975 automobile models, the Denver problem will not be solved. The State of Colorado is required to submit to EPA a plan to reduce ambient air concentrations by a drastic reduction in automotive density. The same situation, although unmonitored, probably exists in other cities along the Front Range.

Gaseous Hydrocarbons

These are mixtures of individual chemical compounds. The major source is the automobile, both through exhaust and by evaporation from the fuel tank or carburetor. There is some emission from industry. With few exceptions, hydrocarbons are harmless to man, plants, or materials; they are, however, a basic ingredient in photochemical smog formation and hence are subject to ambient air control. Hydrocarbons differ greatly in their participation in the photochemical smog reaction.

Nitrogen Dioxide

Nitric oxide is formed in any high temperature process by reaction between the nitrogen and oxygen of normal air. Oxidation then occurs at lower temperatures to form nitrogen dioxide, a reddish-brown irritating gas that dissolves in water to form acids. Nitrogen dioxide is toxic and has been reported to decrease resistance toward bacterial and viral infections; it is also an essential component in the formation of photochemical smog. Principal sources are industrial combustion and the automobile. The importance of nitrogen dioxide pollution in Colorado is largely smog related. No successful control techniques are currently available and no emission standards for fixed sources have been adopted.

Particulate Matter

Particulates are a complex mixture of finely divided solids and liquids. The unit of size is

the micron (1/25,000 inch) and the typical size distribution ranges from very small to 15 microns. They may be primary or secondary pollutants.

Particulates were the first pollutants subject to major control efforts and are, legally, the prime offenders in Colorado — at least from fixed sources. (This is probably due to the visibility of a plume originating from a stack; in fact, for several years in Colorado the only emission standard was the opacity of the plume as estimated by trained observers.) The particle size is related both to effects on visibility and retention in the lung. Particles ranging from 0.2 to 5 microns are retained in the lungs and hence are far more dangerous than smaller or larger particles. This particle size effect is not reflected in the emission control or ambient air quality standards; to date, experimental difficulties have interfered with such specifications.

The fate of a particle retained in an alveolus is determined by its chemical nature. Soluble substances may dissolve in the lung fluids and cause damage to the alveolar wall, or they may be transported into the blood. Insoluble material may be deposited on the walls, or it may be ingested by white blood cells and hence transported to the blood. Heavy metals may be systemic poisons; certain complex organic molecules can act as carcinogens for the production of lung cancer (asbestos also acts in this fashion); and soluble materials act as carriers for toxic gases.

Photochemical Smog and Oxidants

Photochemical smog is formed through a complex series of chemical reactions involving nitrogen dixoide, oxygen, and hydrocarbons. Sunlight at the blue end of the spectrum is also required. The result is a mixture of gases and particulates irritating to the respiratory tract and the eyes, the severity of which depends on the oxidant concentration. The purpose of nitrogen dioxide and hydrocarbon emission controls is the minimization of photochemical smog formation.

Photochemical smog episodes, characterized by brownish, low-lying haze, are frequent along the Front Range in winter due to poor air circulation and high automotive traffic density. This smog is intensely irritating to the lungs and can produce very dangerous effects in individuals already subject to respiratory handicaps such as asthma and emphysema. The oxidants also attack plants and plastics.

Many other chemical compounds polluting the atmosphere not currently covered in ambient standards or emission controls include lead arising from the use of leaded automotive fuels, asbestos, mercury, beryllium, arsenic, etc., all arising primarily from industrial activity. The presence of materials with intolerable odor is also not adequately covered by controls.

Social and Economic Aspects

Air pollution, a single aspect of a general pollution situation, may be viewed as a measure of an affluent society in which affluence is defined in terms of material benefits and the liberal use of natural resources. In some circles the extent of power use becomes a quantitative measure of "civilization." For example, the population of the United States, six percent of global population, uses thirty-five percent of global energy. The use of electrical power in the United States has increased at a compounded rate of better than eight percent per year, leading to a doubling every nine years; electrical power use per individual has increased at a compounded rate of five percent per year. Along with this rapidly increasing use of electrical energy requiring massive quantities of natural gas, fuel oil, and coal, is the constantly increasing consumption of petroleum products as automotive fuel. The energy crisis predicted years ago is now with us. This constantly increasing use of fuel in fixed and mobile sources leads to increased air pollution which is noticeable in those geographical regions unable to bear the increased burden.

How may this situation, dangerous at present and frightening in its potential, be controlled? Essentially there are three possible approaches.

(1) Reduce emission rates on both fixed and mobile sources while continuing the increased power production, automotive usage, and industrial activity. This reduction would be accomplished by the development and application of technology in air pollution control. This is the approach currently being attempted. It is expensive and will result in increased rates for power, increased cost for automobiles and the fuel to drive them, and increased costs for industrial products. It will cause some inconvenience (no open trash burning, for example) and will eventually lead to exhaustion of natural resources.

(2) Develop a land-use control system which will place high pollution sources in areas which (a) have favorable meteorological conditions for rapid dilution or (b) are far removed from centers of population so that few people are affected. Essentially this is the point of view leading to the rapid construction of major electrical generating facilities in the open spaces of New Mexico, Arizona, Utah, Colorado, and Wyoming, located next to large coal deposits. Much of the power produced will be exported to heavily populated southern California where strict emission controls are in effect; some will be transmitted to Colorado's eastern slopes. Air pollution dispersion in these areas is poor and population density is low.

(3) Develop a philosophy which looks upon the preservation of man's environment as sufficiently important to restrict those activities which tend to destroy it. This alternative demands sacrifices in terms of affluent "life style" and "progress," but we would use less power, conserve resources, develop mass transportation, etc.

Currently the choice is the first alternative, with major support for the development of the necessary technology. The legislation in force deals with this alternative in terms of emission standards. The second alternative is coming in via "the back door." It is a matter of concern. The State of Colorado now requires permits to construct, as well as to operate, and demands assurance that all emissions will meet standards leading to acceptable air quality in all regions. The third alternative is now considered largely "blue sky," and its application seems unlikely in the immediate future.

Philosophy of Air Pollution Control

Both the EPA and the State of Colorado, at the directive of EPA, are basing their emission control strategy on the attainment of ambient air quality as defined by standards. This approach will require the use of validated mathematical models to assess the complex system of emissions, dispersion, atmospheric reactions, and removal processes. The model will predict pollutant concentrations in space and time as a function of emission inventories and other parameters including local terrain factors. Such models have been used with fair success in the Los Angeles basin, not only to provide correlations but also to optimize control strategies on a long-term and episode basis. These models have been challenged in the courts but no final decision has been reached.

Economic Factors in Air Pollution Control

It is quite obvious that the costs of air pollution control will be passed along to the consumer. The notion of tax incentives or rebates is not currently being considered. The costs are high — wet scrubbers run to 3 million dollars; electrostatic precipitators cost somewhat less. It has been estimated that the total cost of cleaning up the CF&I plant at Pueblo will run close to 40 million dollars. The 1975 automobile with carbon monoxide and hydrocarbon emissions reduced by 90% will cost on the average close to one thousand dollars more than 1974 models; there will be increases in fuel consumption and maintenance costs. It may well turn out that this increased cost of production will drive certain industries out of Colorado because of their inability to compete. This is an argument for national standards and enforcement.

Air Pollution Control Agencies

Federal control, (under the provisions of the Clean Air Act of 1970) is centered in EPA; the agency is charged with the research, monitoring, and approval of state ambient air standards and implementation plans. EPA may also step in as an enforcement authority if state efforts are considered unsatisfactory. Colorado control is exercised through the Colorado Air Pollution Control Commission, authorized by 1970 legislation, which sets standards, determines policy, and formulates implementation plans. Enforcement, research, measurements, and planning are the concern of the Division of Air Pollution Control in the State Health Department. Some of the enforcement functions have been delegated to county or regional health departments. Under the law a Variance Board is required to hear requests for permission to violate emission standards while means of abatement are designed and installed. Decisions of the Commission and the Variance Board are subject to court appeal. Economic factors must be considered in the granting of a variance. Enforcement of the emission standards is civil rather than criminal; violation of a "cease and desist" order is subject to a maximum fine of $2,500 per day.

Future Aspects of Air Pollution in Colorado

Improvement of air quality demands sacrifice both in terms of money and convenience. It involves abandonment of the concept of "progress" in terms of rapidly increasing population and location of new industry. It demands rather severe land use controls at the state level, and it is expected that further restrictions on pollutants currently not specified by EPA will be imposed. The effect of environmental education — the increasing number of well informed citizens capable of realizing the benefits of a given action and prepared to accept its consequences — must be considered. Essentially the degree of air quality attained is the choice of the citizens of Colorado, as reflected through legislative action.

Origin, Effect, and Fate of Pollutants: Soil

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Next to its human population, the soil is the greatest resource any nation possesses. Without soil there can be no agriculture, and without agriculture the world cannot be fed. To understand the interaction of soil and varied pollutants, it is imperative that we briefly review what comprises the soil environment and define the term "soil."

Let us consider soil to be that part of the solid crust of the earth which is the seat of biological activity. Below the soil layer there is a soil-like material devoid of biological activity which is usually known as the mineral crust. However, there is no sharp line of division between soil and crust. The biological activity in the soil decreases with depth until it becomes negligible. The soil, then, can be considered a zone which can support plant life and microorganisms.

Although the soil is a zone of physical (mechanical), chemical, and biological activity, when we think of pollution we are concerned ultimately with the latter activity. The biological activity characteristic of soils consists of two general processes. The first involves incorporation of energy-rich organic substances derived from the photosynthetic processes of the plants growing in the soil. The second involves the decomposition of these substances by the organisms living in and on the soil.

The soil contains a great variety of organisms which are ultimately dependent on plant material for their energy supply. They include the microorganisms which principally are the bacteria, actinomycetes, fungi, and protozoa; the meso- or meio-fauna which include nematodes, mites, and collembola; and the macro-fauna which include enchytraeid and lumbricid worms, myriapods, and many insect groups such as ants, termites, beetles, and the

The primary role of soil microflora and fauna is as decomposers and reducers. Autotrophic producers and heterotrophic consumers return their bodies to the soil in the form of organic matter. This organic litter is decomposed or reduced by soil organisms which releases nutrients for reutilization by producers, yields byproducts such as humus, and supports a vast array of saprovorous and carnivorous organisms. Other processes are mineralization, nitrogen fixation, nitrification, symbiotic activities of the microflora, the mechanical fragmentation, mixing, and channeling, and aggregate forming actions of the soil animals. All of these processes are interrelated in maintaining the fertility of the soil system.

Various processes are used to grow agricultural crops, such as the use of fertilizers and pesticides, soil cultivation, crop rotation, irrigation, and drainage, all of which affect soil biological activity and hence soil fertility. However, only pesticides will be discussed here.

In Colorado, water is intimately associated with the soil, since the principal water usage is for irrigation. Polluted water, therefore, can cause polluted soil. In a similar way, polluted air can result in polluted soil through atmospheric fallout. Therefore, it is difficult to separate pollution of one medium from another. In the reverse sense, polluted soil can result in polluted water through leaching and run-off of pesticides, fertilizers, and other soil components, as well as the soil itself. Similarly, volatilization of pesticides can increase the pollution burden of the air. At the present time, the most important soil pollutants are the insecticides, herbicides, fungicides, and fumigants that are used on crops and timberlands.

Soil pollution has not received the publicity that air and water pollution have because it is less visible and is minute in comparison. The soil, being a dynamic, living system has great absorptive capacities. It is this capacity to absorb insult that is a favorable trait. Over the years, it has become generally agreed that ultimate disposal of animal, other agricultural and food processing wastes, as well as domestic and industrial wastes, must be on the land and not in surface waters. The soil, if properly managed, should benefit from this disposal scheme since many soils are low in organic matter and lack trace elements and other nutrients that these wastes would furnish. The key here is proper management. Much research has been and is being done in utilizing the soil as a sort of self-regenerating disposal site. Yet much research still is needed. Let us now look at some specifics.

Pesticides

The term is very broad and its Latin roots mean to kill disease or, more specifically, pests. Pes-

Pesticides include numerous less inclusive categories such as insecticides, herbicides (plants), fungicides, nematocides (nematodes), bacteriocides, fumigants, acaricides (mites), etc. In man's unending struggle against his pest enemies, chemical warfare has come to play the most important role. From a humble beginning 100 years ago, several hundred chemicals are now in commercial use, and the annual value of the chemical industry is measured in billions of dollars. Recent statistics on population growth indicate that the world's population will probably double by the year 2000. Producing food and fiber necessary for this increased population will likely necessitate the continued, and even accelerated, use of pesticides to control insects, plants, and disease.

Much remains to be learned regarding the chemistry and mode of action of pesticides, the relation of their structure to toxicity, their metabolism in plants, animals, and the soil, and their toxic hazards to man and other life forms. For pesticides that are applied to plants and the soil, the many possible interrelations that must be studied are their persistence in plants and soil, plant toxicity, leachability to the ground water, adsorption on the clay complex, and the effect of, and their effect on, soil biological activity.

The persistence of pesticides (primarily agricultural) in the environment has caused considerable controversy in recent years. Many have questioned the need for chemical pest control. However, the need can be justified by a wide variety of evaluation techniques. An economic analysis based on costs and benefits and the resultant increases in production efficiency is often sufficient justification. Yet, in many instances, chemicals are the only efficient means of controlling damaging pests. One need only remember the insect ravages of the past and the many diseases they vector. Or consider the problems caused by poison ivy or common ragweed or the infestation of waterways by the water hyacinth. Many of these are difficult to put a dollar value on and in each case there are no known practical natural, ecological, or biological solutions.

What is the origin of pesticides in the soil? Generally, there are four entrance routes: direct soil application, sprays that settle out from foliar application, plowing treated plant remains into the soil, and from atmospheric fallout. Fortunately, most pesticides in soil are metabolized by microorganisms which render them nontoxic and transform them eventually into compounds which can be utilized by other organisms. Some pesticides (notably the organochlorine insecticides, such as DDT and dieldrin, and the organochlorine herbicides, such as 2, 4, 5-T) have been the target of environmentalists because of either their persistence or other side effects. Let us first consider insecticides.

Insecticides

Insecticides can be divided into four major categories: (1) organochlorine compounds, examples not mentioned being aldrin, heptachlor, endrin and chlordane; (2) organophosphates, with parathion, malathion, and diazinon being representative; (3) carbamates, with examples being carbaryl and zectran; and (4) a miscellaneous group including botanical (pyrethrin and rotenone) and inorganic insecticides like calcium and lead arsenate and mercuric chloride. There is a fundamental difference between the organic (first three categories) and the inorganic insecticides. The latter group is based on such toxic elements as lead, mercury, selenium, and arsenic; once applied to the soil, they remain there unless leached away by water. Since most have poor water solubility, they remain where applied. On the other hand, the organic compounds are transient and range from those being very unstable to those that remain in the soil for several years.

What is the effect of these chemicals on the soil environment? Not all soil fauna, as discussed earlier, are beneficial. Some beetle, fly, and moth larvae are serious crop pests. Other arthropods, millipedes, several mites, and symphilids occasionally damage crops. The quandary, therefore, is to control the harmful pests without disrupting the beneficial organisms. Insecticides by their nature are intended to be insect poisons and many lack specificity and can be toxic to other life forms. Any lethal effect will vary greatly with the type of chemical, dosage, soil properties, and various environmental factors. In general, insecticides in amounts commonly applied have had little measurable effect on soil microorganisms.

The effects of insecticides on soil animals are least severe when the chemicals are on the soil surface, for example as a result of spraying. These surface residues are much less persistent than those incorporated into the soil. However, when the soil is cultivated, and the insecticide is mixed with the soil, it comes in contact with many more soil animals. Soil animals vary widely in their susceptibility to the many kinds of insecticides that may reach the soil. One chemical may leave a species unaffected whereas another may completely eliminate it. Also, many species are either resistant or susceptible to all of the wide range of insecticides that differ widely from one another in chemical structure, persistence, and activity. Many different insecticides do not affect earthworms, enchytraeid worms, symphylids, and most families of springtails but are lethal to larvae of flies, predatory mites, pauropods (primitive arthropods), and springtails of the isotomid family.

The population of soil animals usually remains changed for months, regardless of whether the insecticide persists for only a few days or several years. The duration of effect depends on its absolute toxicity as well as its persistence. The more persistent insecticides, rather than the more toxic ones, affect soil animals the most. This is because short-lived insecticides will disappear before too many animals receive a lethal dose. Agriculturists favor insecticides that last less than one growing season. However, these have not been as effective in controlling pests as the more persistent insecticides, nor have they affected soil animals as drastically. Soil animals live in a state of dynamic equilibrium and show marked seasonal changes in numbers. Since the animal populations are greatest in fall and spring, a persistent insecticide has its greatest effect at these times.

Earthworms are probably the most valuable to man of all the soil invertebrates. They break down much of the plant debris reaching the soil, turn over the soil, and aerate it. Fortunately, of all the insecticides tested, only chlordane, heptachlor, phorate (an organophosphate), and carbaryl caused serious decreases in populations. Other organochlorines did not affect them even with large doses. Other organophosphates sometimes reduced earthworm numbers slightly, but since these chemicals were relatively short-lived the populations soon recovered. Over all, the carbamate insecticides are highly toxic to earthworms. Earthworms, however, can concentrate organochlorine insecticides in their bodies. They provide food for other animals such as birds and moles, which in turn can concentrate these chemicals. Therefore, earthworms, as a lower link in a food chain, may be an important source of insecticide residues found in higher animals. The organophophates, which are replacing the organochlorine insecticides, have not been found to be concentrated by earthworms.

Herbicides

Most herbicides decompose rapidly in soils, chiefly through the action of microorganisms. Even after heavy applications, phytotoxic residues are rare after one year and usually dissipate much sooner. Herbicides have been found to have only limited direct effects on the soil community and do not pose a serious hazard; most of their influence is indirect. The weeds they destroy are an important food source for certain invertebrates which feed on the growing roots or digest their decaying remains. Once the weeds are gone, the soil animals dependent on them usually will decrease.

There are five major categories of herbicides: the phenylureas, including diuron, monuron, and fenuron; the phenylcarbamates, with CIPC (chlorpropham) as an example; the s-triazines, with simazine and prometryne being representative; the chlorinated aliphatic acids, which include dalapon and TCA; and the phenoxy-alkanoic acids, with 2, 4-D and 2, 4, 5-T as representatives.

Of the many herbicides tested for their direct effects on the number of soil animals, only DNOC (a cresol) and simazine significantly reduced the populations. These decreases usually did not persist after the chemicals dissipated from the soil.

Fungicides

These chemicals are designed to act principally against pathogenic fungi and, as a group, are chemically diverse. Besides inorganic compounds consisting principally of mercury, copper, and arsenic, the organic compounds consist primarily of dithiocarbamates, dicarboximides, chlorinated phenols, and organic mercurials. Some recent additions include derivatives of guanidine, triazine, and anthraquinone. In general, the mercurials are toxic to man and animals as well. Fortunately, outside of mercural seed treatments, fungicides have not been a problem.

Fungicides generally are considered to have only minor deleterious effects on soil microorganism populations. While there may be killing or selective inhibition of some species, others appear to rapidly replace the sensitive species, thus maintaining the metabolic integrity of the soil. Selective soil fungicides may produce an undesirable side effect resulting in a formerly unimportant disease becoming more damaging than the one which the fungicide controlled. This implies a disruption in the microbial equilibrium in the soil. This has been found to occur with PCNB. Broad spectrum fungicides, such as nabam, behave in soil as partial sterilants, not only killing parasites but also large segments of the saprophytic microbial population. Foliage fungicides are usually nontoxic to soil floral and faunal populations. Most fungicides are unstable and degrade in the soil quite rapidly.

Fumigants and Nematocides

Fumigants (including most nematocides) are injected into the soil in the form of a gas to control harmful microorganisms and other pests. Since the toxic gases can penetrate the smallest soil crevices, they kill almost all the soil animals in the treated area. Fumigants are relatively short-lived; most persist only for hours, while a few persist for a few weeks at most and seldom penetrate the soil more than 12 inches. Residues, therefore, are not a problem.

The extent to which the soil population is affected depends on the nature of the material and the rate at which they are applied. Broad spectrum fumigants, such as methyl bromide, chloropicrin, and 1, 3-dichloropropene, destroy a much greater proportion of the soil population than narrower spectrum compounds such as ethylene dibromide. Soil fumigants can be toxic to various species of fungi, bacteria, actinomycetes, seeds, nematodes, insects, and other invertebrates such as springtails. Even though these materials are transient in the soil, it has been shown that even after two years there may be fewer species of animals in a fumigated soil than in an unfumigated soil.

Arsenicals

Since arsenicals are found in all previous pesticide groupings, they will be treated separately. Despite the development of newer organic insecticides, substantial quantities of arsenicals are still used to control certain insects. Examples are lead and calcium arsenate, arsenic trioxide, and sodium arsenite. The latter three have also been used as rodenticides, general soil sterilants, and nonselective herbicides. These compounds are the most persistent soil sterilants and may remain effective for periods as long as 5-8 years, especially in low rain-fall areas. Sodium arsenite is widely used to kill potato vines, to defoliate cotton, and for aquatic weed control. The arsenicals have the disadvantages of being hazardous to man and domestic animals and are cumulative poisons when applied to the soil as soil sterilants or as run-off from dusts and sprays. In several areas of the U.S., primarily in orchard areas, arsenic residues had increased significantly in the soil. In orchards last treated about 25 years ago, a range of 18-2500 ppm (parts per million) arsenic, with an average of 304 ppm, was found in soils from several states. Subsequent crops often fail to survive on these abandoned orchard soils.

An endeavor has been made to cover briefly the effects and fate of a number of pesticide groups in the extremely complex soil ecosystem. The persistence of pesticides in soil depends on many factors. These include the physical properties and reactivity of the chemical, soil type, moisture, temperature, microorganisms, cover crops, degree of cultivation, mode of application, and formulation of the pesticide.

In general, the soil fumigants, nematocides, and fungicides which are general toxicants exert the greatest killing action on soil microorganisms, while the insecticides and herbicides in amounts commonly applied have little effect. There may be qualitative effects more significant than quantitative effects. Bacterial spore formers or *Pseudomonas* spp. may constitute the majority of the bacteria soon after treatment. Only a few species of fungi may constitute the majority of fungus colonies in treated soil, whereas 10-30 or more species may be found in untreated soils. *Trichoderma* often becomes the most common dominant fungus after use of soil fungicides.

Heavy Metals

Lead

Aside from the small amount of lead used in pesticides, the lead burden of soil comes almost entirely from atmospheric fallout. It has been estimated that particulate lead liberated into the atmosphere from automobile exhaust in the U.S. each year is about 500 million pounds. About 50 percent of this total is deposited within 100 feet of the roadways with the remainder deposited over large areas. The amount of lead found in soils near roads varies with traffic volume and decreases rapidly with distance from the road. Lead has been found in soils in amounts up to 700 ppm in soil adjacent to highways in Minnesota. In Colorado, 530 ppm were found in the top 6 inches and 1350 ppm in the top inch of soil adjacent to a heavily travelled highway. This indicates that lead does not migrate readily in the soil and, in fact, is known to be inactivated by soil constituents such as the clay and organic matter. Lead also can be transformed into the relatively insoluble phosphate or sulfate. Probably relatively little of these heavy lead burdens are biologically available, although grass samples from near a Denver intersection contained as much as 3000 ppm. At this time, very little is known about the consequences of lead in soil.

Mercury

Mercury in the environment has been of considerable concern recently. Although mercury is distributed naturally at low levels in soil, natural waters, plants and animals, and the atmosphere in forms and amounts that are harmless, it is residues from man's activities and biological concentration of mercury that give us justifiable concern. We will deal only with the soil implications.

In the U.S., the average level of mercury in soils is 71 ppb (parts per billion) and in the western states 55 ppb. Fossil fuels may contain quite high levels, with petroleum oils containing up to 20,000 ppb and coal 300,000 ppb. Combustion of these materials releases much of these residues into the atmosphere. However, it has been estimated that only about 0.002 pound of mercury is added to each acre of soil annually through atmospheric fallout. The major sources of environmental mercury are of industrial origin. Use of mercury compounds in pesticides comprised a very minor component of the total mercury problem, and now essentially all agricultural uses of mercury have been banned. The soil, fortunately, has not been the recipient of mercury residues of the magnitude that have bodies of water.

In soil all the organomercury compounds are decomposed to mercury salts or to metallic mercury, which are the active fungicides. The metallic mercury ultimately is converted to the sulfide by reaction with hydrogen sulfide liberated by soil microorganisms.

Summary

In summary then, since soil pollution is not as conspicuous a problem as is air and water pollution, perhaps more attention should be focused on the use of soil in pollution abatement. There are examples whereby substantial amounts of waste materials have been added to soils without detrimental effects to the soil and actually have greatly increased plant growth. Many water pollutants which are plant nutrients, such as nitrogen and phosphorus compounds, result in excessive plant growth in water bodies. If one could recycle these nutrients and cause eutrophication of the soil rather than water, this would enhance food production and generally improve the environment.

Urban and agricultural wastes are mostly products of the soil that are pollutants when in air and water but whose components are in short supply in the soil. The soil has been absorbing and recycling nature's wastes for billions of years and still has the capacity to absorb far more material than it has received.

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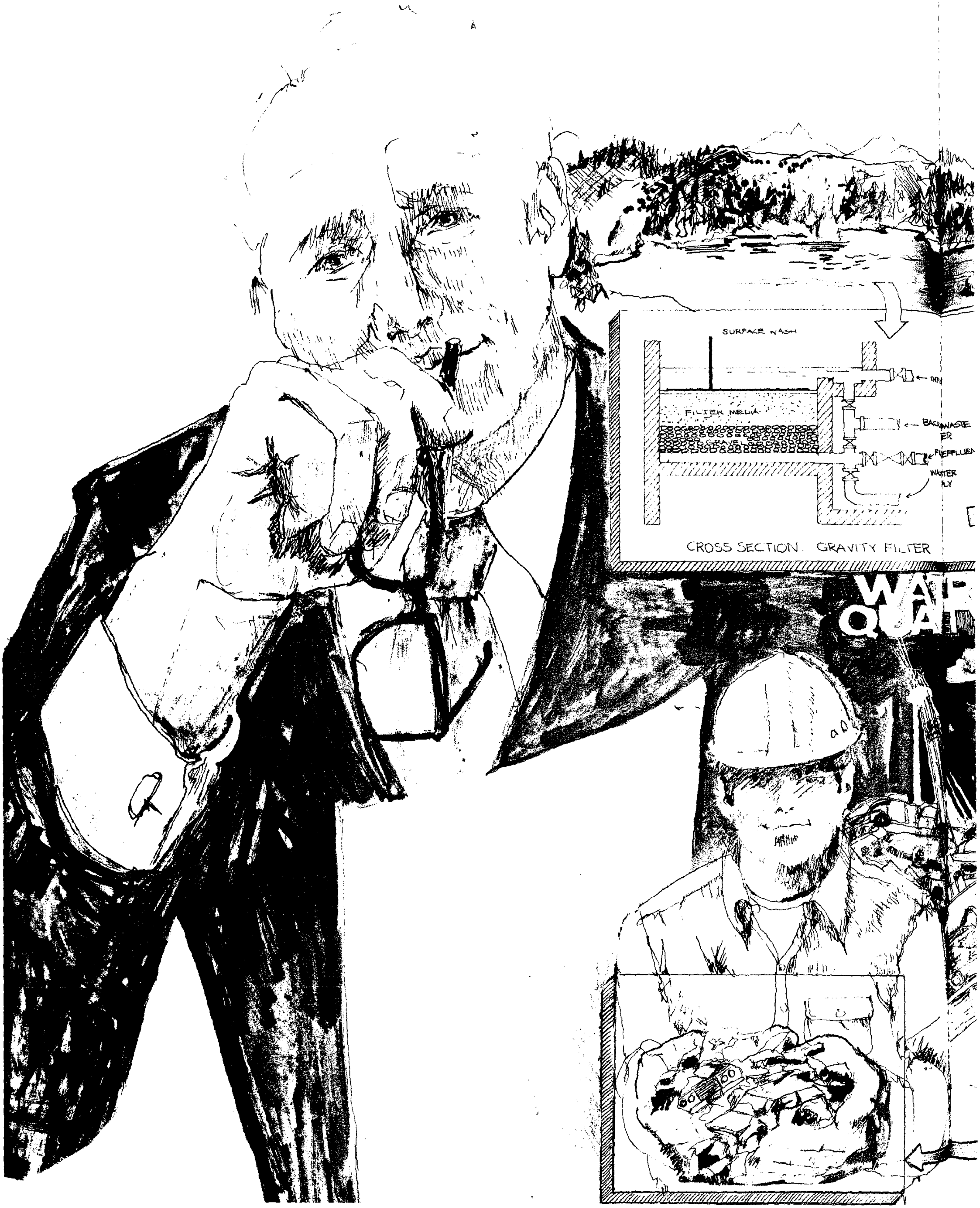
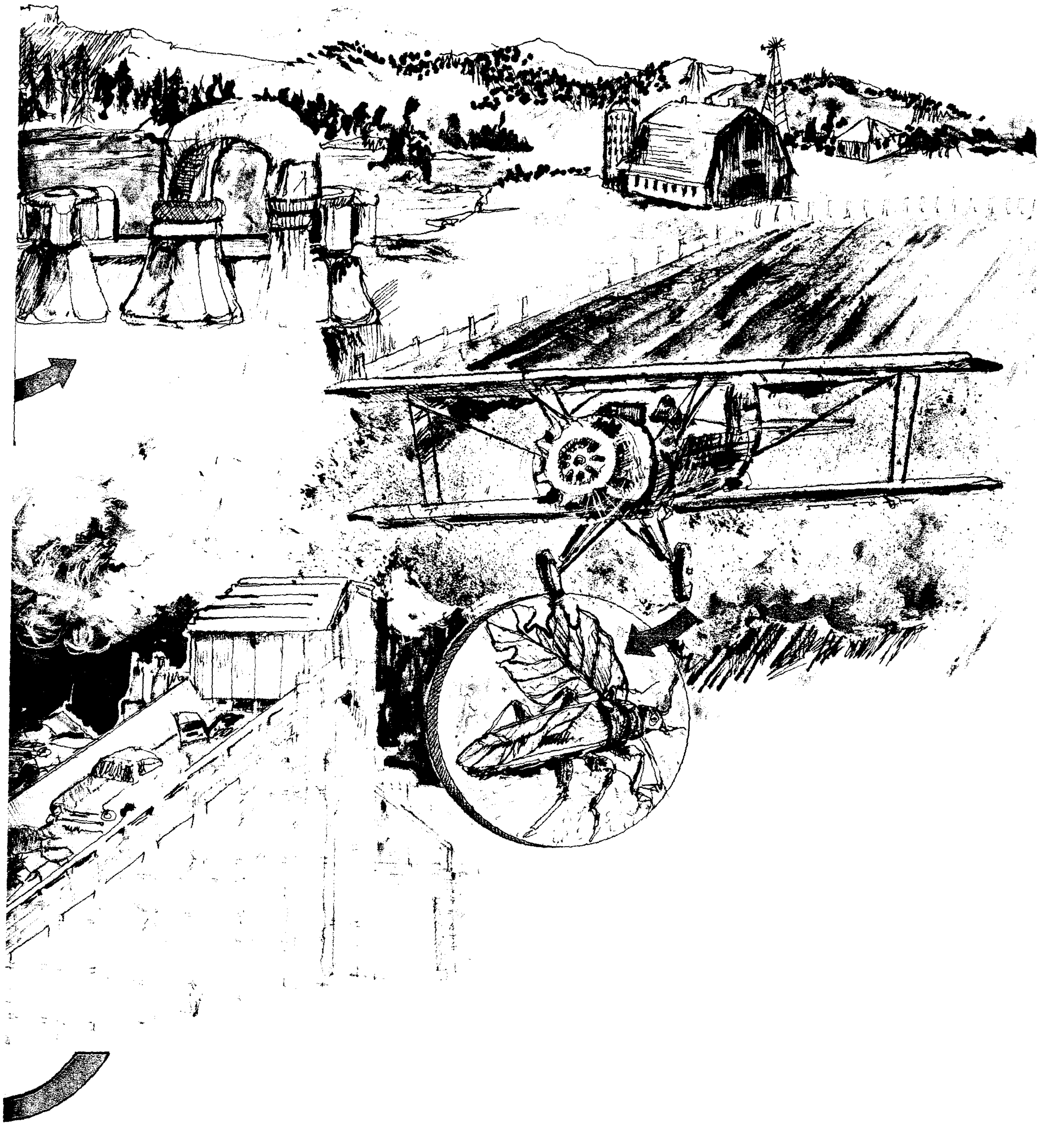

SURFACE WASH
FILTER MEDIA
CROSS SECTION. GRAVITY FILTER

Major Environmental Issues and Alternatives

Among the major problems man faces in his quest for a better environment are how to control water quality, how to properly use chemicals when necessary without harming other elements of the ecosystem, and how best to dispose of solid waste materials. New solutions to these problems are being sought, and on them rests the quality of man's future.



Water Supply and Quality

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The term "water supply" carries with it a professional connotation associated with the domestic-industrial category of water use. It is a major category of water resources development, accounting for about eighteen percent of the water consumptively used in the United States. The other major categories of use are agricultural and thermal power cooling. Noneconomic in-stream uses relating to recreation, and ecologic concerns are not prominent in formal water resources planning. Navigation and waste dilution, however, are in-stream uses important to some planning agencies.

Water Use

Water withdrawn from the resource pool is used for various purposes. Only a portion of this water evaporates or is used "consumptively." Table 2 indicates the scale of consumptive use of water for various purposes. This is only about 25 percent of the total water withdrawn. Also, we see that roughly half of the irrigation water withdrawn is used consumptively, while thermal cooling, on the other hand, consumptively uses only a very small portion of the water withdrawn for that purpose.

It is important to realize that any use of water will cause changes in water quality. For example, cooling water use will cause a rise in water temperature ranging from 1 degree, or less, to several degrees centigrade — depending upon the size of the cooling water stream and the job to be done. Industrial uses will cause a wide variety of changes, ranging from increases in biodegradable organics and suspended solids, such as in the food processing industries, to additions of heavy metals and other toxins in some metal industries. Domestic use will cause an increment in total dissolved solids of 300 to 900 mg/L (milligrams per liter), as well as significant additions of BOD (biochemical oxygen demand) around 200 mg/L and suspended solids also of around 200 mg/L. Irrigation, while it may not add anything except some mineral pickup, will leave a residue of salts due to evaporation, increasing total dissolved solids (TDS) by approximately a factor of two. Thus, water use and water quality are inseparable.

Trends in water use are also apparent in Tables 1 and 2 and in Table 3. Table 3 shows projected water demands beyond 1970 to the year 2020.

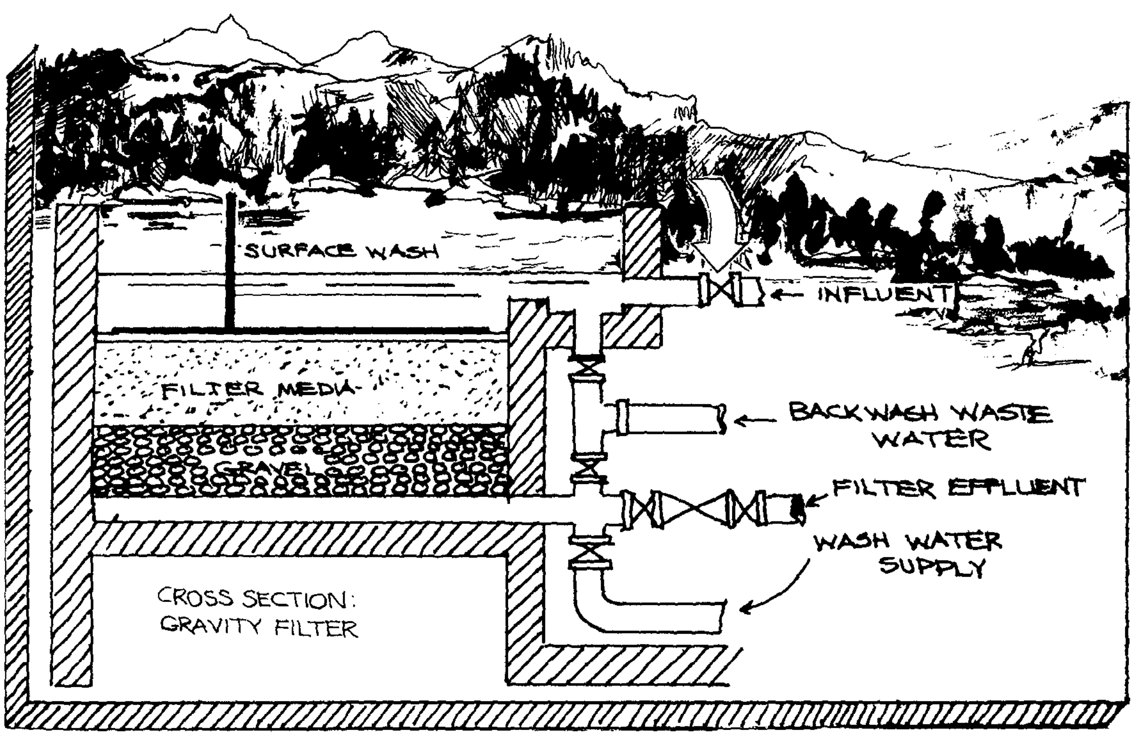

Table 1. Water withdrawals for selected years and purposes in the United States, including Puerto Rico.

(Billion gallons per day)

Year	Total Water Withdrawals	Irrigation	Purpose of Withdrawals Public Water Utilities	Rural Domestic	Industrial and Misc.	Steam Electric Utilities
1900	40	20	3	2.0	10	5
1910	66	39	5	2.2	14	6
1920	92	56	6	2.4	18	9
1930	110	60	8	2.9	21	18
1940	136	71	10	3.1	29	23
1950	200	110	14	3.6	37	40
1960	270	110	21	3.6	38	100
1970	370	130	27	4.5	47	170

SOURCES: Withdrawals reported for 1900 to 1940 are taken from PICTON, Walter L. (March 1960). *Water Use in the United States, 1900-1980,* prepared for U.S. Department of Commerce, Business, and Defense Services Administration. U.S. Government Printing Office, Washington, D.C. Withdrawals reported for 1950 to 1970 are taken from MURRAY, C. Richard & REEVES, E. Bodette (1972). *Estimated Use of Water in the United States in 1970, Geological Survey Circular 676.* U.S. Geological Survey, Washington, D.C.
(From National Water Commission Review Draft.)

Table 2. *Recent trends in consumptive use of water in the United States, including Puerto Rico.*

(Intake Uses Only Billion gallons per day)

Year	Total Consumptive Use	Irrigation	Public Water Supply	Purpose of Use Rural Domestic	Self-Supplied Industrial and Misc.	Steam Electric Utilities
1960	61	52	3.5	2.8	3.0	0.22
1965	77	66	5.2	3.2	3.8	0.41
1970	88	73	5.9	3.4	5.3	1.04

SOURCE: Figures taken from MacKICHAN, K. A. & KAMMERER, J. C. (1961). *Estimated Use of Water in the United States, 1960,* Geological Survey Circular 456. MURRAY, C. Richard (1968). *Estimated Use of Water in the United States, 1965,* Geological Survey Circular 556. MURRAY, C. Richard & REEVES, E. Bodette (1972). *Estimated Use of Water in the United States in 1970,* Geological Survey Circular 676. All published by U.S. Geological Survey, Washington, D.C. Estimates of consumptive use were not tabulated before 1960.
(From National Water Commission Review Draft.)

While the projected withdrawals are huge, the projected consumptive use is much less. These tables give a gross national picture of water demands. A better resolution to the regional and local levels, comparing supply and demands, is necessary to form a more accurate picture. Some regions of the United States have sufficient water supplies to sustain these large demands, while other regions—such as the Southwest — do not. From these projections in water use, it is clear that the need for pollution control will increase concurrently with increases in water use, since water use implies changes — usually deleterious — in water quality.

Sources of Water

Sources of water in our water resources pool are comprised of groundwater, lakes, and streamflow. Tables 4 and 5 give a picture of what is available in both annual flows and in storage. About 22 percent of all water withdrawals are from groundwater (underground supplies).

The physical aspects of water supply and quality, a major focus of this chapter, can be better understood in the context of the larger picture of water use and water supply outlined. But no less important are the organizational entities responsible for developing each of the water resources use categories. They are comprised of private, state, federal, and local organizations. Domestic and industrial water supply is largely a function of local government — though self-supplied industrial water is significant too. The collection of municipal water departments, together with associated consulting engineers and suppliers of chemicals and equipment, comprises the water works industry. It is both the charge and the dedication of this industry to deliver water that is both safe to drink and sufficient in flow to meet the demands of consumers.

Technically, the problems of water supply are: (1) finding a source of supply, (2) regulation of that supply in time by impoundments and storage (if it is a stream), (3) distribution in space by transmission lines to the city and distribution networks for delivery within the city, and (4) treatment to make the water safe and palatable to drink.

Water Quality

Water quality is a general term used in place of a more quantitative and detailed description of dissolved and suspended material contained within a specific water body or water sample. The chapter "Pollutants in Water" describes many of the substances which may be contained in water. The quantities of these substances are expressed as concentrations — usually as milligrams per liter for dissolved gases, dissolved solids, and suspended materials. Bacterial quality is usually expressed as number of organisms per 100 milliliters.

For any type of use, water quality is important. To assure compatibility between a given water source and an intended use, *standards* — often measured in terms of *indicators*—are necessary. Standards have been developed for almost every use. McGauhey (1968) summarizes water quality standards for such uses as recreation, irrigation, industrial, and drinking water. Table 6 contains excerpts from the *Public Health Drinking Water Standards, 1962*. The *Drinking Water Standards* is the basis for water quality standards used by many State Health Departments to regulate quality of domestic water supplies. These standards may vary among countries and among standard setting groups. For example, the American Water Works Association recommends a turbidity standard of 0.1 Jackson Candle Unit for drinking water, while Table 6 lists 5 Jackson Candle Units.

Table 6. Excerpts from *Public Health Drinking Water Standards, 1962.*

Bacterial Quality	
Coliforms	1/100ml
Physical Characteristics	
Turbidity	5 units
Colora	15 units
Threshold Odor Number	3
Chemical Characteristics	
Arsenic	0.01mg/L
Copper	1.0
Chloride	250
Iron	0.3
Nitrate	45
Sulfate	250
Total Dissolved Solids	500

Table 3. Projected water use, by purpose, United States.[1]

(Billion gallons per day)

Type of Use	Projected Withdrawals			Projected Consumptive Use		
	1980	2000	2020	1980	2000	2020
Rural domestic	2.5	2.9	3.3	1.8	2.1	2.5
Municipal (public supplied)	33.6	50.7	74.3	10.6	16.5	24.6
Industrial (self-supplied)	75	127.4	210.8	6.1	10	15.6
Steam-electric power						
Fresh	134	259.2	410.6	1.7	4.6	8
Saline	59.3	211.2	503.5	.5	2	5.2
Agriculture						
Irrigation	135.9	149.8	161	81.6	90	96.9
Livestock	2.4	3.4	4.7	2.2	3	4.2
U. S. Total	442.6	804.6	1,368	104.4	128.2	157

[1]*U.S. WATER RESOURCES COUNCIL (1968). The Nation's Water Resources. U.S. Government Printing Office, Washington, D. C. Part 1, p. 8.*
(From National Water Commission Review Draft).

Table 4. Sources of supply — flows of water.

Source of Supply	Amount of flow (BGD)
Streamflow, mean annual	1201
Groundwater recharge, mean annual	43

(From Data in National Water Commission Review Draft).

Table 5. Sources of supply — flows of water.

Source of Supply	Amount of Storage (billion acre feet)
Larger lakes in North America	27
Groundwater in conterminous United States to about 8000 feet depth below the surface	180

(From Data in National Water Commission Review Draft, 1973).

Drinking water must be both safe to drink and palatable. Turbidity, color, and threshold odor number relate to its palatability; these measures are actual *indices* of palatability. The coliform count is also an index to the health hazard of water, and so a standard of 1/100 ml is set (actually this standard is related to the number of samples also, but for these purposes the description is not elaborated). The health hazard is due to the possible presence of pathogenic bacteria or viruses; the absence of coliform implies the absence of pathogenic organisms. On the other hand, arsenic and copper are toxic metals which are directly harmful, and the standards have explicit meaning. By contrast, some of the units given to some of the standards have no special significance. Total dissolved solids is an example; a limit is necessary, and it was chosen as 500 mg/l, but without any compelling rationalization. Water quality criteria for recreational use of a water body, such as swimming, comprises another set of standards. So do water quality criteria for a warm water fishery, a cold water fishery, and various industrial purposes.

Usually in the search for a water supply, those sources containing impurities that are difficult to remove (in excess of the standards for a given purpose) are avoided. If this cannot be done, then the standards may be violated or special treatment undertaken. For example, the arsenic standard of 0.01 mg/L is slightly exceeded by a small community in Utah simply because no other water except the groundwater is available. Boiler plants, however, cannot accept what is available; in order to avoid scale problems, all mineral ions must be removed by ion exchange resins.

Conventional water treatment for domestic use consists of sedimentation, coagulation, filtration, and chlorination. Raw surface waters vary greatly in composition, but normally they may contain turbidity, color, coliforms, etc. in excess of standards. The water treatment plant is perfectly capable of reducing concentrations of these constituents to meet the required standards. However, unless softening is employed as well (to remove calcium and magnesium ions), the mineral constituents will remain unchanged by conventional treatment. Thus, if some of the mineral substances, such as heavy metals, are contained in excess of recommended standards to the point of substantial uncertainty in the respective health hazard, another source is sought. In regions profuse with water, or in prior years when competition for water was not a major factor, finding another source was less a problem than today. In recent years, however, competition for water has become more intense, particularly in the arid west. So we see that two related problems have emerged: (1) the absolute quantity of water in some localities is insufficient, necessitating import from outside basins, and (2) the quality characteristics of some sources restricts the uses of water unless further treatment is used (such as desalting, adsorption, etc.).

This brings us around to the concept of trying to reuse some of our supplies of wastewater and to desalt brackish waters (waters having greater than 2000 mg/L TDS), and sea water. Though these methods are not yet used on a wide scale, they are emerging as a prominent part of our thinking about water supply. These are classed as "secondary sources," whereas the virgin supplies of freshwater are primary sources. These supplies need to be factored into the water supply system — not in terms of a closed loop of recycling municipal wastewater back again to drinking water, but as a supply for another use having less stringent standards. Planning then must be accomplished in terms of the total system of all sources of supply and all proposed uses, including recreational and aesthetic uses.

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Agricultural Chemicals and the Environment

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History

History records that agricultural chemicals have been used since ancient times; the ancient Romans are known to have used burning sulfur to control insects. They were also known to have used salt to keep weeds under control. The 9th century Chinese used arsenic mixed with water to control insects. Early in the 1800's, Pyrethrum and Rotenone were discovered to be useful as insecticides for the control of many different insect species. Paris green, a mixture of copper and arsenic, was discovered in 1865 and subsequently used to control the Colorado potato beetle. In 1882, a fungicide known as Bordeaux mixture, made from a mixture of lime and copper sulfate, was discovered to be useful as a fungicide for the control of downy mildew in grapes. Mercury dust was developed in 1890 as a seed treatment, and subsequently, in 1915, liquid mercury was developed as a seed treatment to protect seeds from fungus diseases. Mercury was banned from use in 1970 primarily because of the adverse national publicity concerning an accidental exposure of a family to mercury through the ingestion of pork that had been produced from seed screenings contaminated with a mercury fungicide.

The first synthetic organic insecticides and herbicides were discovered and produced in the early 1900's; this production of synthetic pesticides preceded the subsequent discovery and production of hundreds of synthetic organic pesticides, starting in the 1940's. Chlorinated hydrocarbons came into commercial production in the 1940's, and organic phosphates began to be commercially produced during the 1950's. In the late 1950's, carbamates were developed and included insecticides, herbicides, and fungicides. The 1960's saw a trend toward specific and specialized pesticides which included systemic materials and the trend toward "prescription" types of pesticides. Presently there are over 900 active pesticide chemicals being formulated into over 60,000 commercial preparations.

The Situation

Despite the fears and real problems they create, pesticides clearly are responsible for part of the physical well-being enjoyed by most people in the United States and the Western world. They also contribute significantly to the existing standard of living in other nations. In the United States consumers spend less of their income on food (about 17%) than any other people anywhere. The chief reason is more efficient food production, and chemical pesticides make an important contribution in this area. In spite of pest control programs, United States agriculture still loses possibly one-third of its potential crop production to various pests. Without modern pest control, including the use of pesticides, this annual loss in the United States probably would double. If that happened it is possible that 1) farm costs and prices would increase considerably; 2) the average consumer family would spend much more on food; 3) the number of people who work on farms would have to be increased; 4) farm exports would be reduced; 5) a vast increase in intensive cultivated acreage would be required.

In most parts of the world today pest control of some kind is essential because crops, livestock, and people live, as always, in a potentially hostile environment. Pests compete for our food supply, and they can be disease carriers as well as nuisances. Man coexists with more than one million kinds of insects and other arthropods, many of which are pests. Fungi cause more than 1500 plant diseases, and there are more than 1000 species of harmful nematodes. Man must also combat hundreds of weed species in order to grow the crops that are needed to feed our nation. Rodents and other vertebrate pests also can cause problems of major proportions. Many of these pest enemies of mankind have caused damage for centuries.

Modern farm technology has created artificial environments that can worsen some pest problems and cause others. Large acreages, planted efficiently and economically with a single crop (monoculture), encourage certain insects or plant diseases. Advanced food production technology, therefore, actually increases the need for pest control. Pesticides are used not only to produce more food but also food that is virtually free of damage from insects, diseases, and weeds. In the United States, pesticides are often used because of public demand, supported by government regulations, for uncontaminated and unblemished food.

In the past, pest problems have often been solved without fully appreciating the treatment and effects on other pests or on the environment. Some of these effects have been unfortunate. Today, scientists almost unanimously agree that the first rule in pest control is to recognize the whole problem. The agricultural environment is a complex web of interactions involving 1) many kinds of insects; 2) relationships between insects and their natural enemies; 3) relationships among all of these and other factors, such as weather, soil, water, plant varieties, cultural practices, wildlife, and man himself.

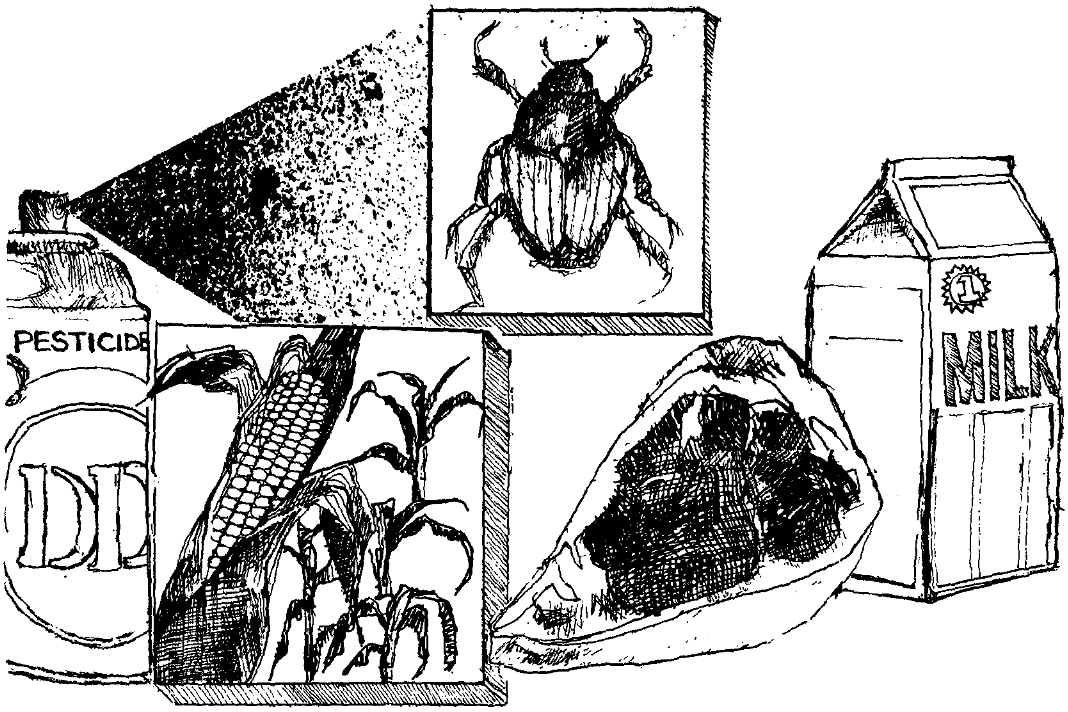
Pesticides are designed simply to destroy pests. But they are applied to an environment that includes pests, crops, people, and other living things, as well as air, soil, and water. It is generally accepted that pesticides which are specific to the pests to be controlled are very desirable, and some are available. However, these products can be very expensive because of their limited range of applications.

Few responsible people today fail to recognize the need for pesticides and the importance of learning to live with them. Several national scientific committees in recent years have reiterated the need for pesticides now and in the foreseeable future. These same committees also recommended more responsible use and further investigation into long-term side effects on the environment. It is generally agreed among scientists that there is little if any chance that chemical pesticides can be abandoned until such time as alternative control measures are perfected.

Pesticides, like automobiles, can create environmental problems, but in today's world it is difficult to get along without them. Those concerned about pesticides and pest control face a dilemma. On one hand, modern techniques of food production and control of disease-carrying insects require pesticides. On the other hand, many pesticides can be a hazard to living things other than pests, sometimes including people.

Residues of some persistent pesticides apparently are "biologically magnified." This means that they may become more concentrated in organisms higher up in a food chain. When this happens in an aquatic environment, animals that are at the top of the chain, usually fish-eating birds, may consume enough to suffer reproductive failure or other serious damage. Research has shown that some pesticides decompose completely into harmless substances fairly soon after they are exposed to air, water, sunlight, high temperature, or bacteria. Many others also maydo so,but scientific confirmation of that fact is not yet available. When residues remain in or on plants or in soil or water, they usually are in very small amounts (a few parts per million or less). However, even such small amounts of some pesticides, or their breakdown products,which also may be harmful, sometimes persist for a long time.

Pesticides are very rarely used in a form of a pure or technically pure compound, but rather are formulated to make them easy to apply. Formulations may be in the form of dust or granules,which usually contain 5 to 10% of active ingredients, or wettable powders or emulsifiable concentrates, which usually contain 40 to 80% active ingredients. It is important to remember that the formulations which are used as sprays are further diluted with water, oil, or other solvents to concentrations of usually only 1% or less before application. The amount of active ingredient, therefore, which is eventually released to the environment is generally extremely small. Unquestionably, pesticides will continue to be of an enormous benefit to man. They have helped to produce food and protect health. Man-made chemicals have been the front line of defense against destructive insects, weeds, plant diseases, and rodents. Through pest control, man has modified his environment to meet aesthetic and recreational demands. However, in solving some environmental problems, pesticides have created others of yet undetermined magnitude. The unintended consequences of the long-term use of certain pesticides has been injury or death to a variety of life forms. Much of the information on the effects of pesticides comes from the studies of birds, fish, and the marine invertebrates such as crabs, shrimps, and scallops. It is clear that different species respond in different ways to the same concentration of a pesticide. Reproduction is inhibited in some and not in others. Eggs of some birds become thin and break, while others do not. No clear



evidence exists on the long-term effects on man of the accumulation of pesticides through the food chain, but the problem has been relatively unstudied. Limited studies with human volunteers have not shown that persistent pesticides, at the normal levels found in human tissues at the present time, are associated with any disease. However, further research is required before results are conclusive about present effects, and no information exists about the longer-term effects. Meanwhile, decisions must be made on the basis of extrapolation from results on experimental animals. Extrapolation is always risky, and the judgments on the chronic effects of pesticides on man will continue to be highly controversial.

Public concern about the possible dangers of pesticides is manifested in legal actions initiated by conservation groups. Pesticides, like virtually every chemical, may have physiological effects on other organisms living in the environment, including man himself. The majority of the established pesticides have no adverse effect on man, animals, or the environment in general as long as they are used only in the amount sufficient to control pest organisms.

Pest control is never a simple matter of applying a pesticide that removes only the pest species. For one thing, the pest population is seldom completely or permanently eliminated. Almost always, there are at least a few survivors to recreate the problem later on. Also, the pesticide often affects other living things besides the target species and may contaminate the environment.

There have been and continue to be unfortunate and generally inexcusable accidents where workers become grossly exposed due to improper and inadequate industrial hygiene or carelessness in handling and use. Children sometimes eat, touch, or inhale improperly stored pesticides. Consumers have been inadvertently poisoned by pesticides spilled carelessly in the transportation of pesticides in conjunction with food products. These cases are, however, no indictment of the pesticide itself or the methods employed to establish its efficacy and safety. They are purely due to the irresponsibility of the user.

Present and Needed Regulations

Long before the environment was a subject of concern, relatively strict regulations and inspections protected consumers against harm from pesticide residues on food. Still, the most controversial question is what amount of residue on food is "safe"? That question will probably never be answered to everybody's satisfaction, but most scientists are convinced that the consumer is well protected. Federal and state laws regulate where, when, and how much pesticide can be applied to a specific crop. They also restrict legal residues on food to no more than one-hundredth of the largest amount that causes no effect on pest animals. Most public health officials agree that this amount of residue as a maximum is harmless.

The Environmental Protection Agency was created in 1970 and the responsibility for registration of pesticides was transferred to this agency. A new Federal Environmental Pesticide Control Act was passed in 1972 and is the law which regulates and controls the registration and use of all pesticides. It replaces the old Federal Insecticide, Fungicide, and Rodenticide Act which had been in effect since 1947. The new law also provides penalties for misuse for different categories of application and for a permit system that will differentiate between general and restricted use categories. It also tightens and simplifies enforcement procedures.

Many suggestions have been made by scientists, conservationists, legislators, and others that would help to further strengthen the control and regulation of the use of pesticides, including the following. More critical evaluation should be made of existing pesticides to identify those with higher risks than benefits. Such materials could be eliminated or severely restricted, as some already are. A better system of testing pesticides before they are registered and used would be helpful, specifically improved laboratory tests to evaluate potential biological effects of extended low-level exposure to pesticides, and an organized program to test environmental effects of pesticides under actual field conditions. There is a need for licensed pest management practitioners who would diagnose the grower's pest problem and issue a prescription for treatment. (The Environmental Protection Agency is moving in this direction.) Requirements for permits for commercial pesticide users could be established. (The Environment Protection Agency is also considering this.) Even tighter regulations on handling, transporting, and disposing of pesticides and containers should be enforced. For instance, trucks carrying hazardous pesticides might be banned from city streets and suburban freeways during rush hours. In many cases, the problem today is not lack of regulations but lack of manpower and methods for enforcement. The Environmental Protection Agency is taking steps to initiate a detailed reporting system to keep track of pesticide use. Better monitoring networks are needed in order to detect pesticides in the environment. (The EPA is empowered to monitor the environment for pesticides.) Government help is necessary to provide financing of at least part of the cost for developing new and better pesticides, particularly the much needed selective materials for limited uses. And last, there is the possibility of establishing different quality standards for pest damage to fruit crops which would continue to protect health but would place less emphasis on blemishes as a measurement of food quality.

The pesticide industry is presently one of the most highly regulated industries in the world. With careful and continued research on pesticides, we can rest assured that we will have adequate pesticides for our needs and yet will be protected from the adverse effects that they might create.

Alternatives

Scientists generally agree that there is little, if any, chance that chemical pesticides can be abandoned in the foreseeable future. There are several alterntives, however, that can be used to help reduce the introduction of unnecessarily large amounts of pesticides into the environment. One approach is called "integrated control" or "pest management." Integrated pest control combines all of the traditional methods of killing and managing pests. But it also takes into account and makes use of the complex relationship among pests, beneficial organisms, and the environment, by considering the total pest population in an area, not just one infestation in any particular field. The strategy is to rely as much as possible on natural enemies and other pest regulating forces such as weather, meanwhile carefully watching the pest population. Selective pesticides are used only when they are available, effective, and required. Obviously, integrated control demands a good deal of knowledge of the agriculture-ecosystem, and of pest biology, ecology, and behavior.

Integrated control combines several methods. Biological, cultural, and chemical control are often combined with the use of pest resistant plant varieties to control various pests. Integrated control differs from conventional pest control in at least two important ways. Its goal is not necessarily to eliminate pest damage but to keep it at acceptable levels. This calls for answers to an often ignored question: How many pests does it take to cause unacceptable damage? Integrated control is much more complex and difficult than relying solely on chemicals. Progress is needed in certain areas, however, such as 1) Better use of existing pesticides. Because of government regulations and more enlightened grower practices in recent years, many pest control techniques already are fairly sophisticated. But more progress is possible even with existing information. Pest control researchers say that enough know-how is at hand today to reduce significantly the amount of insecticides applied on some major crops if growers were given enough technical guidance. 2) More trained pest management specialists. Lack of on-the-spot expertise is one reason why existing pest control know-how is not being fully utilized. 3) Development of less disruptive chemical pesticides. Compounds are needed that break down in a short time and hence do not accumulate as residues, that are more selective, and that are less likely to induce resistance. Few available chemicals will do all of these things. Researchers are confident that more such materials could be developed, but at present there is little economic incentive to do so. The reason is that millions of dollars are needed to develop and test a new pesticide, while the market for a selective material is usually limited. 4) More resistant plant varieties, biological control agents, and other nonchemical pest control methods. Some of these are available and are performing well, but many more are needed. These techniques usually take years and a corresponding amount of money to develop. 5) More scientific understanding of agricultural ecosystems. Pest control scientists insist that a vast amount of new information is needed before a very large scale effective, integrated program is possible. A good deal is known already about pesticide effects on target organisms and residue on harvested crops, but much more research is needed on the newer chemical materials and on agricultural-ecosystems in general, particularly the interactions of pests, parasites, predators, host plants, and weather factors.

Biological control methods used alone are effective on some insects, plant diseases, and weeds. But this effectiveness is limited to a rather small group and therefore cannot be assumed to be the final answer in its application to all pest problems.

Cultural control methods have been in use for centuries, and, of course, should continue to be used where they are efficient and effective. In the long run, however, it is a combination of biological, cultural, and chemical controls that will work best in a combined effort of pest management.

Summary

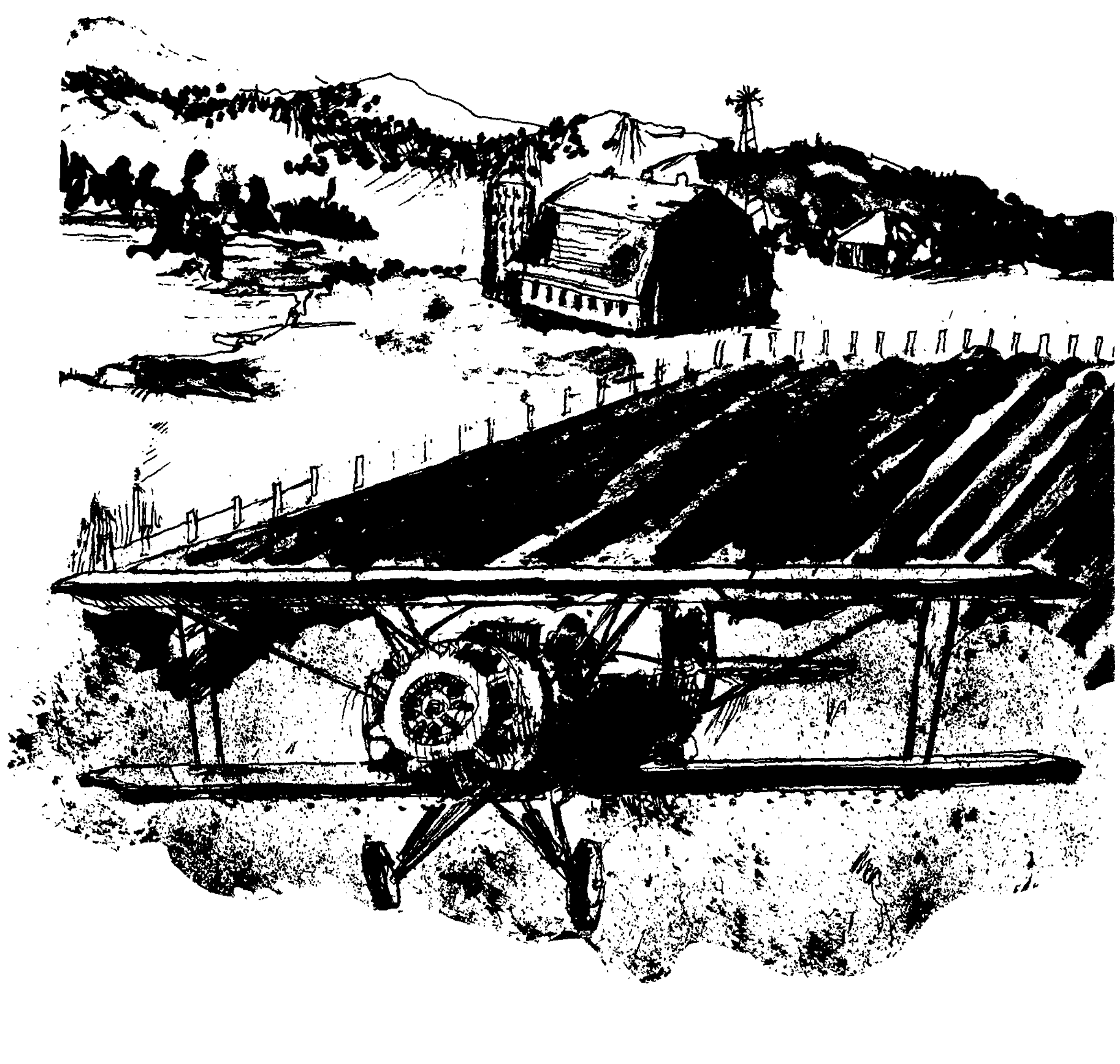
Chemical pesticides have played and will continue to play an invaluable role in the control of pests that cause serious and fatal diseases in man and which destroy essential food. Like drugs, pesticides should always be used with discretion and in conjunction with other general measures in order to achieve effective pest control.

Whether persistent or easily degraded, a pesticide may be detrimental to nontarget organisms which it contacts. It may reduce the numbers of predators and accentuate the problem of pest control. It may decimate harmless and desirable wildlife. Thus, all pesticide users should employ every means possible to minimize pesticide pollution. As hazards in the general environment, pesticides have been responsible for their quota of accidents to children and other innocent bystanders, but there is no evidence that their contribution in this respect is in any way outstanding among other causes of similar types of accidents.

The worst aspects of pesticides usually are those that are most news worthy. Consequently, it seems that pesticides are credited with more than their share of the overall pollution problem. When properly used, pesticides are tools. When they move off target or are otherwise misused, they become pollutants. In order to retain the necessary use of pesticides, it is imperative to use all possible means to minimize or prevent their becoming pollutants.

Pollution of the environment is a problem of vital importance. It is recognized that there are many pollutants arising from many activities, including various forms of industrial fallout and radiation. Ways to reduce various types of pollution must be found and are being sought at the present time. To single out pesticides, as so many do, as the main pollutants of the environment is to misjudge the situation. Wrongly or carelessly used, pesticides can certainly be harmful, but if properly used, they are an ally in a struggle to preserve a healthy environment.

There is a basic need for public support and understanding of pesticides. Individuals, besides being cautious in using pesticides, can 1) accept the need for some inconvenience from annoying pests and possibly some visible evidence from insects or insect damage on food; 2) be prepared to pay, mainly through higher food prices, for increased costs of environmentally responsible pest control; 3) support research programs to find the many unknown answers; 4) support educational programs to put existing knowledge to work; 5) support regulatory programs to assure com-



pliance; 6) understand the risks which, in today's crowded and technological world, seem to be the price of plentiful food and an environment relatively free of pests.

Our attitude toward use is due for some updating and for some overhauling. We must make decisions in pesticide usage that will both control pests and maintain the environment. Some suggestions to aid in these decisions have been made in this paper. There are many others, but these suggestions at least indicate the direction in which we should be thinking. The suggestions made and considerations proposed are not new but if widely practiced will do much to reduce pesticide pollution.

The great pesticide debate is proceeding slowly from a dimly lighted and confusing beginning to a gradually brightening stage, despite the creation of fears in the mind of the public by misleading statements and half truths. With our continued efforts to learn the facts and convey them to the public, people can begin to draw conclusions that will preserve not only nature but a progressive and healthy mankind.

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The Solid Waste Problem: A Portrait

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Solid waste management is one of the American's oldest and most perplexing problems. Indeed, we Americans are among some of the most prodigious wastemakers in the world, discarding five billion tons of solid wastes each year, 30 million tons of paper, 4 million tons of plastics, 100 million tires, 30 billion bottles and 60 billion cans. Waste is the effluent of American affluence. The more the American's technology and skill to use his resources has grown, the more he has wasted. Unfortunately, he has been far less assiduous about technological applications to the solution of waste problems.

A major problem has always been: What is to be done with the wastes? Early solutions primarily sought to get them "out of the way." Solid waste might be simply defined as solids or resources which have reached such a state that they are evaluated as being of no further use or utility to the owners or users, whether those users are actual or potential. So defined, it seemed enough to get them out of the way.

As could be expected, early answers to getting solid wastes out of the way were simple. All systems, including the human system, have several characteristics which tend to be common to all. One of these is the tendency to seek courses of least resistance and follow them. Watch a bearing in a machine system as it wears out. The earliest answers to the solid waste problem had this characteristic: Get it out of the way, out of sight, out of mind in a manner that would not interfere greatly with human activity, convenience, or health, or cause too much unpleasantness.

Gradually, as years passed, it became apparent that other criteria had to be met if disposal management was to be adequate, indeed, if we were not to be buried under our own wastes. With the growth of private, industrial, commercial, and agricultural wastes, public agencies were, by necessity, developed and pressed into service. In many ways they have become a type of public utility. Their appearance surfaced the collection problem and brought it into a more direct relationship with disposal. Now some 80% of the solid waste management dollar goes into collection. As the solid waste problem grew in proportions, it became apparent that it was necessary to manage waste disposal in a manner that would not have severe side effects and long-term consequences. It became obvious that some convenient processes poisoned the environment and had adverse short-and-long-run effects on human life.

As somewhat of a corollary development, solid waste management has generated the notion that all wastes are not wastes in fact; rather, many are resources for which use can be found if they are processed (recycled) correctly. Indeed, the idea that wastes are "resources out of place" has had wide currency in efforts to transform them into resources. This phenomenon is seen in the junk yard and in attempts to develop fertilizers and animal feed from biodegradable agricultural, household, and even industrial wastes (e.g., the rendering works). The problem was not simply to get rid of waste safely; it was to do it in a manner that resources could be retrieved and conserved. This is now called the "resource recovery" problem.

While resource recovery makes common sense and, environmentally speaking, seems to be almost a patriotic act, economic problems inhibit its general acceptance. For example, preferential freight rates currently rule out use of certain recycled materials in favor of virgin stock. Many community recycling efforts fail because no one wants their collections of cans, bottles, or newspapers.

Another type of story emerges from a review of current processes and mechanisms for managing solid wastes. This makes a fascinating tale which culminates in vast improvements in processing as a result of technological development with the appearance of large-scale conversion devices. Looking backward many people may recall that one of the commonest forms of solid waste disposal is unused space — garage corners, the backyard, basements etc. They are also apt to forget that this form is still extensively used. In basements and cellars across the continent, waste materials are collected and piled in resting places where they will lie or have lain for decades. In certain urban areas many backyards have become automobile graveyards, with the attendant problems of rodent infestation and vermin breeding.

Two closely allied and about equally old processes of solid waste disposal are the town dump and the traditional junk yard. Both exist today and carry within them many inherent dangers to human health and environmental quality. One is largely public, the other private, but both involve more than mere aesthetic repugnance.

Another early disposal process that has served man since his appearance on the planet involves the use of rivers, streams, lakes, wetlands, and even the oceans. Indeed, many governments, including our own, use ocean floors and deep lake beds as graveyards for unwanted liquid and solid materials (e.g., canned atomic wastes). Man has long viewed his rivers and streams as an excellent carrier to get his unwanted materials and sins against nature out of sight and out of mind. Witness the old bedsteads recently retrieved from the Thames, the crates lying in the bottom of the harbors, the beer cans and other debris floating in Colorado's Big Thompson, the industrial solids in Montana's Clark's Fork or Colorado's South Platte. For many years there was a standing joke about Pennsylvania streams that were deemed to be too thin to cultivate and too thick to navigate. In many rural areas farmers often piled animal dung and other wastes on a stream's ice cover during the winter months. In the spring it would disappear. It would indeed be illuminating to know the type and amount of solids carried and/or processed by the Mississippi River over the decades.

Especially vulnerable to indiscriminate solid waste use and processing in recent years have been the urban streams. Disposal problems of liquid wastes in streams under the theory that the solution to pollution is dilution, (which is only partly true) have been compounded by use of such streams by citizens, governments, and industries for disposal of solids. While standing under a bridge on Nancy Creek in urban Atlanta, one of the authors and a city official were showered with a bushel basket of rotten fruit and other debris. The hole-riddled basket was included as a bonus. Close examinations of many urban creeks have found them to be carrying incredible amounts of various solids. Streams have not, by any means, ceased to be "dumps."

The above processes, as well as others, have not disappeared, but their use and the adverse consequences have been reduced as public waste management has developed and become more fully operable as a public utility. The town dump, so familiar to most people, is probably the first clear expression of a solid waste public utility. Inadequate as it was in meeting the problems, it did illuminate the relationships of collection, final disposal, and recovery of materials.

Until the mid-sixties, Loveland, Colorado, maintained what in fact was a city dump with land-fill characteristics. Residents hauled their own waste or hired a private agency to do it. Debris was pushed in piles and burned, then bulldozed into the Big Thompson River flood plain and covered. The process was supplemented by permitting the use of backyard incinerators. These processes transferred waste problems to the atmospheric system (air pollution) and to the hydrologic system (filling the flood plain lowers channel capacity during high flows). Eventually a new land-fill was established several miles to the north, along with a ban on burning and a public collection system, thus ending the polluting processes.

Here, in brief, is a Colorado example of the demise the old-fashioned public-dumping ground process. Its disappearance has corresponded closely with population growth and increased pollution (with attendant regulation). This is, in fact, a rather familiar story for obtaining change. When population density and technological advances combine to create a high pollution load on certain systems, new conversion processes are frequently sought.

Perhaps the most popular solid waste processing technique which has tended to supplant dumps, or sometimes merely to supplement them until the dump is phased out, is the *land-fill* or *sanitary land-fill* process. A less popular process is *incineration*. Incineration involves burning, a process which often transfers waste problems to the atmospheric system. There is also the residue ash. Historically, the "sanitary" land-fill consisted of finding a hole or digging one and covering the buried matter with soil or inert material. Even this seemingly clean method, however, presents certain inherent dangers and transfers costs for processing to other systems. If water flows through the waste it becomes organically polluted. Highly poisonous substances may be deposited for decades or centuries, only to be released at some unexpected moment. Likewise, soil characteristics and soil mechanics may be subjected to dramatic changes.

A process which was once thought highly promising is composting. Composting consists of separating inorganic material (metals, glass, etc.) and converting the remaining organic material to a peat-like organic soil conditioner. It has recently become unpopular due to high costs.

Selection of land-fill, incineration, and other processes has been left almost exclusively to local decision-makers. However, the introduction of environmental standards by an act of Congress has spurred attendant development, system upgrading, and changes in local choices and processes. Recently, incineration processes and related air pollution controls (e.g., electrostatic precipitation and wet scrubbing) have been improved and upgraded sharply to meet these standards. Soaring costs of such improvements, however, have rendered incineration questionably feasible in many cases.

Recently, too, more productive uses have been sought for the incinerating processes. St. Louis, for example, has now developed incinerating process for firing industrial furnaces with 20% solid wastes and 80% coal. Rosenheim, Germany, takes trash from 44 neighboring towns and combines it with its own waste materials to fire furnaces for electrical production and to provide steam heat for its citizens. Munich, Germany, has a plant which burns 45,000 tons of solid waste a month, or about 80% of the city's residential and commercial debris. Curiously, German solid waste has more heat value than the American. Related benefits of newer incineration processes are increased real estate values and a much cleaner environment. Ninety-eight per cent of the particulants and odors are removed. Nevertheless, high costs remain a problem.

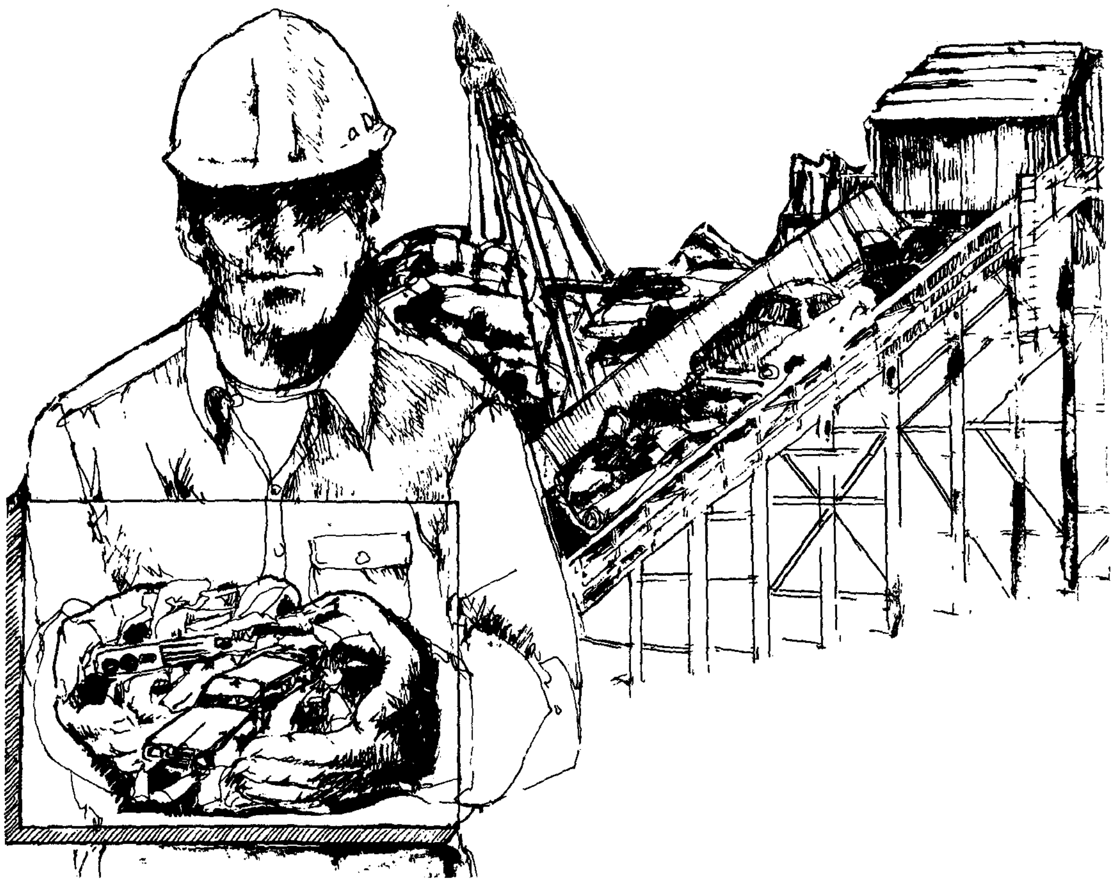
Despite the introduction of such innovations, incineration and sanitary land-fill operations face a continuing question of feasibility. Operations have been improved, and technological development has, in some instances, reduced land-fill processing costs. Completed land-fills can, and are being used for new construction starts and recreational facilities. For example, two cities have a recreation area developed on a covered mountain of trash (Mount Trashmore, in Virginia). But increased costs for such conversion methods as land-fill and incineration will be unavoidable if environmental standards are to be met. This has led to a search for alternate processing mechanisms.

One battery of alternates now developed involves on-site processes of compaction and/or conversion. The kitchen sink disposal is a ready example of this type of alternate. Such a process merely converts solids into a form compatible with liquid waste and transfers the responsibility and cost for disposal to the liquid waste treatment systems. It eliminates collection and costs for the converted solids by using water as a convenient and free carrier. Aside from the potential reduction in carrier and collection costs from such processes, an initial reduction in costs can be achieved by transferring conversion processes from the public to the private sector. Industries and householders buy and operate converters, as well as keep them in repair. When making such transfers, however, the public must expect to pay the costs in higher product prices.

A third alternate involves underground collection systems, which when properly developed could reduce operational cost substantially. Such collection systems could employ on-site compaction processes (e.g., wet oxidation) and on-site compaction that eliminates much multi-handling and thus lowers collection costs and enables better compliance with environmental standards.

Still another development which will help overcome sanitation problems and reduce the incineration and land-fill problems is new packaging processes, as well as new packaging materials for rapid packaging of biodegradable wastes. At present, it is difficult to estimate the gains from such processes because materials costs may run high.

Obviously, many of the recent efforts are directed at meeting environmental standards within cost constraints. Achieving this goal is especially important for municipal governments, since they (or rather, the people in them) generate enormous waste and cleanup costs. Industries also face similarly severe problems. Most of these efforts return to earlier and more traditional forms of processing. They are devoted primarily to development of conversion techniques which will enable sale and



use of the end product and thus lower the processing costs through sale of the products.

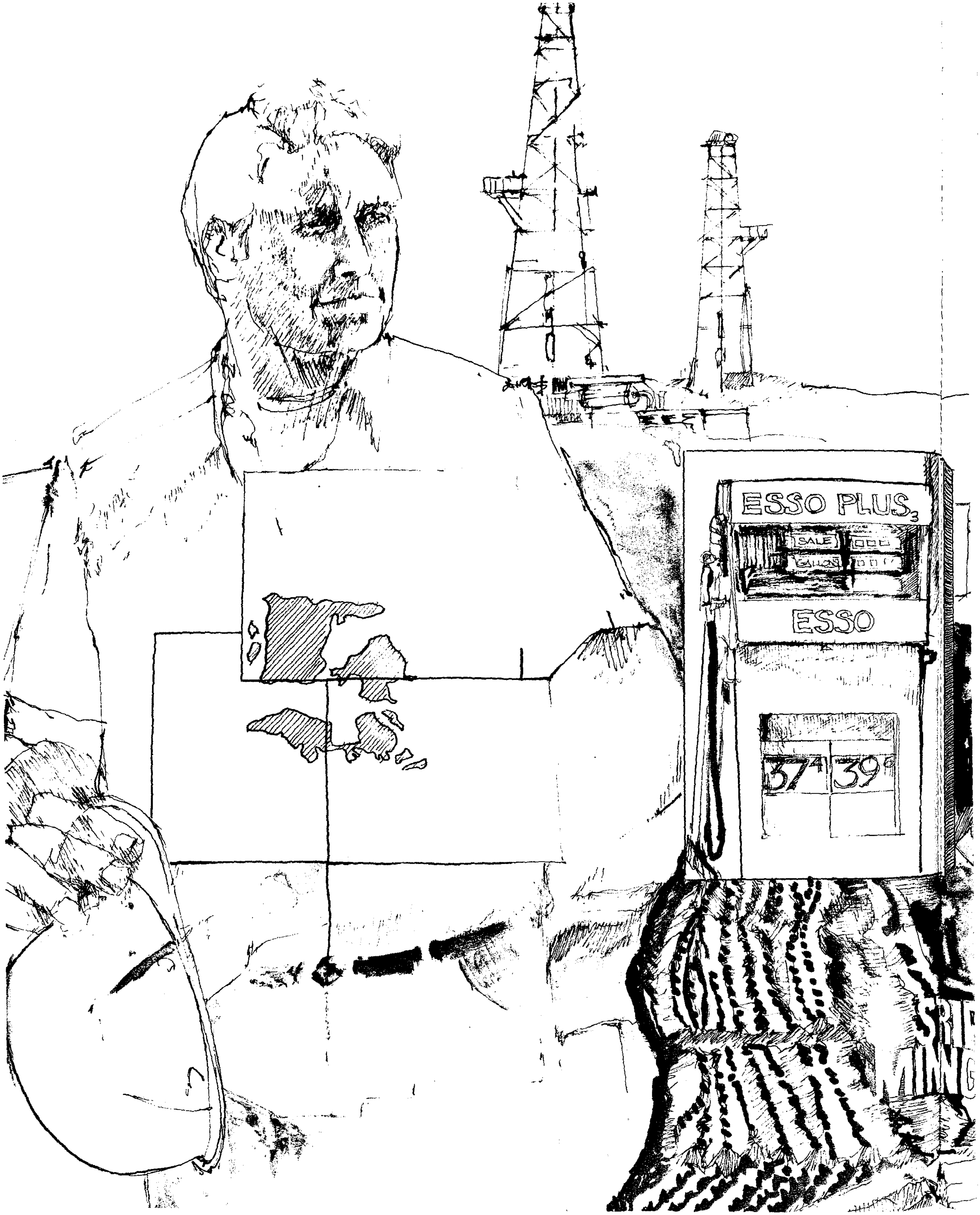
The rendering works is an early example wherein dead animals were converted (rendered) into fertilizer. In Germany, the Meyer-Caspari method, or "Brikoliare Process," developed in the 1960's, combines sewerage and refuse into bricks which, after being compressed, can be piled and cured. Fungi develop and weld the bricks. Vermin and spores are then killed, leaving an inoffensive high grade block which can be crushed and used as a high-grade compost. In Schweinfurt, sales of compost have lowered processing and collection costs by nearly 40 per cent.

In Chicago, techniques for emulsifying and converting sewerage sludge and other solids into a form compatible to spraying have been developed for applying the wastes directly to crop lands. Sewerage, of course, creates solid waste problems because effluent from secondary treatment plants is both liquid and solid (sludge). For a long time, Philadelphia disposed of its sludge by putting it into the sea. Recently other seaboard cities have returned to the "hole" as an alternative for sludge and refuse disposal when they noticed that the old mine shafts and strip mine holes were available. Attempts to use these "holes" for processing have often met with opposition from nearby residents.

In the U.S., many comprehensive efforts are now underway to solve the solid waste problem. Franklin, Ohio (population 10,000), has an advanced municipal waste treatment facility that treats solid, liquid, and industrial wastes at a single location. Recovered paper pulp is sold to local manufacturers. Armco takes the reclaimed iron. The ash from the incinerators is used in sewage treatment.

Solid waste management is important to us both because of environmental quality requirements and because of materials shortages. Trends in U.S. thinking on solid wastes can be seen in the U.S. Solid Waste Disposal Act of 1965 which was a federal initiative to help solve this essentially local problem. The 1970 U.S. Resource Recovery Act recognized the interdependence of environmental quality and materials needs, and recent actions have reinforced this recognition. Resource recovery will probably be a big industry in the U.S. as we change from a resource "have" to a resource "have not" country.

In summary, the solid waste problem literally crept up on us, and, if we are not careful, it could bury us. However, we are relatively close to solving the technological problems — if we are willing to pay the costs. Solid waste management is therefore more of a political, economic, and social problem than it is technical. The solutions to the problem have really become obvious and it is now mainly a matter of getting down to business.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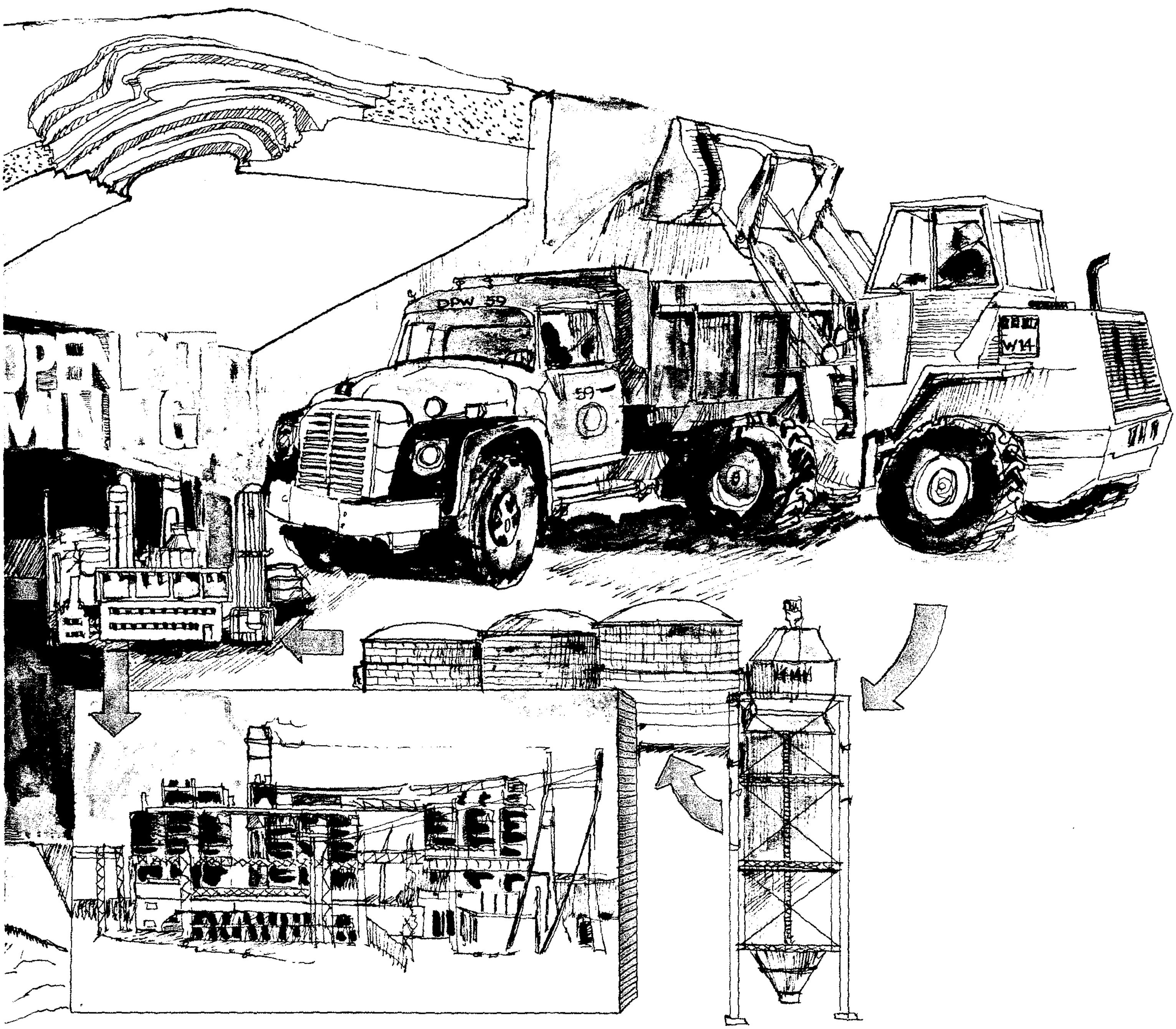
Use and Preservation of Energy Resources

The preservation and use of oil, natural gas, and other energy resources is vitally important to man's future environment. Ample resources still exist, as evidenced by the areas shown on the map. The problem lies in determining the best methods to extract and use them.



Energy and the Environment

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The noted environmentalist Barry Commoner has warned that regarding civilization's relationship with nature there is no such thing as a free lunch. By that statement he meant that everything taken from nature for human use carries with it some kind of environmental cost. This is certainly true of the contemporary use civilization makes of nature's energy resources, as can be seen when one views a stripmine from which coal is dug for burning in an electric power plant, or when one visits Denver and notices the smog caused in large part by the use of automobiles.

Concerning energy utilization there are, in addition to environmental costs, economic costs in terms of dollars paid out for various fuels and energy production processes, and in some cases costs in terms of national security considerations. In certain conditions these latter two types of costs are more important to some Americans than are the environmental costs. Taken together the three costs — environmental, economic, and national security, plus what is technologically possible — constitute the constraints within which the United States must make its national energy policy decisions in the 1970's and thereafter. (Today national energy policy results from the decisions of a number of governmental entities, plus decisions reached by private producers of energy and various consuming groups which purchase the energy. This somewhat fragmented situation is likely to change as both the Congress and the White House are working to develop a more comprehensive approach to energy utilization.) Generally such decisions will involve various types of compromises, or "trade-offs," involving at least the first two costs, and at times all three costs. In this article the emphasis will be upon the environmental costs of alternative fuel use. However, it will be pointed out that frequently the environmental cost must be considered in conjunction with the other costs.

Complicating the development of compromises regarding the various costs of alternative fuel usage is the fact that many Americans express a desire for a steadily increasing consumption of energy resources with the resultant increased pressure upon the natural environment. Further complicating matters is the fact that the United States is experiencing shortages of some traditional energy resources. This situation will increasingly require the development of new energy sources which will mean new and different impacts upon the environment.

A comprehensive perspective of the current relationships which exist between energy utilization and environmental impacts, as well as the relationships between environmental costs and the other two costs, may be obtained by reviewing the various energy sources now being used by the United States and those which are being proposed for the future.

Coal

The most abundant energy resource remaining in the United States is coal. Currently it accounts for approximately 20 percent of the energy used in America. Estimates of the U.S. coal reserves vary, but there appears to be more than one hundred years' worth of reserves of economically usable coal at current rates of consumption.

From an environmental point of view there are several costs associated with coal utilization. The so-called "hard" coals of the eastern United States, located near the largest population centers which require the most heat and electricity, contain considerable amounts of sulfur. This means that when such coal is burned, for example in a power plant producing electricity, sulfur dioxide, along with the particulate matter (fine gray ash emitted by the smokestack), is released up the stack into the surrounding atmosphere. Unfortunately, sulfur dioxide is a major air contaminant, and to date, efforts to remove it from stack gasses have not proved satisfactory, although much particulate matter can be removed by using expensive cleaning devices. Therefore, "hard" coal burning power plants may not often be located near large cities because of air pollution standards which prohibit their operation.

So-called "soft" coal contains less sulfur; hence it contributes less sulfur dioxide to the environment when burned. However, the "soft" coal is located in portions of the nation with relatively sparce population, causing less demand for electricity, and even "soft" coal burning may exceed the more stringent air pollution standards which are expected. Approximately 85 percent of the "soft" coal is found under western lands owned in various ways by the Federal Government. The primary states involved are the Dakotas, Wyoming, Colorado, Utah, New Mexico, Montana, and Arizona. In order to use the western coal deposits to produce electricity for large population centers, such as those in the midwest near Chicago and in southern California, extensive efforts have gone into building large coal-fired power plants in the area of the coal deposits, then transporting the electricity along power lines to the consuming centers. The greatest development of this type has been on the Colorado River plateau in northwestern New Mexico, southern Utah, and northern Arizona, with similar development possible for eastern Wyoming. Burning the low sulfur coal in these relatively low population areas is environmentally preferable to burning it in the heavily populated areas. However, there is concern among some persons that there is still some air pollution from the western power plants which enters the atmosphere of what many consider to be particularly scenic areas of the United States. Further, the western coal is typically located near the surface of the land, which encourages stripmining. This procedure involves stripping off the covering soil and vegetation so that giant scoops can scrape up the underlying seams of coal. Scars left from such operations are the subject of efforts to rehabilitate the land with new vegetation; however, this is a difficult undertaking because of the problems involved in starting new growth on the disturbed soil in arid and semiarid areas.

Where coal is used in power plants there develops a demand for water to use in the power plant for cooling purposes. In areas where water is scarce, the resulting thermal pollution is viewed as an additional environmental burden of significant proportions.

The demand for eastern and western coal will increase substantially should any of several methods of converting coal to synthetic pipeline gas or synthetic gasoline be successfully completed. Not only would such developments mean more stripmining, but since the coal gassification and liquification plants would require large amounts of water, further demands upon what is often a scarce resource would result. As natural gas and gasoline become more in demand and shorter in domestic supply, one may expect impressive efforts will be made to achieve coal conversion methods.

Nuclear Energy

Despite glowing predictions by possibly overly ardent champions of nuclear power, to date less than two percent of the electricity produced in the United States comes from nuclear power plants. A number of explanations exist for this situation. The nuclear power plants are expensive in relation to coal-fired plants, and they take several years to construct. Further, although nuclear plants do not pollute in the usual sense, i.e., release sulfur dioxide, particulate, and other objectionable emissions associated with combustion of fossil fuels into the atmosphere, there are significant environmental concerns about their operation. These objections have led to organized political opposition to the location of nuclear plants in specific sites, and to delays in their construction occasioned by environmental objections raised in the courts. The most dangerous environmental impact which could possibly be associated with a nuclear power plant, and one which has never happened during the several decades of nuclear power plant operation in the world, is an explosion which would spread radioactive debris over a wide area (there have been accidents involving small explosions of a conventional type and fires in nuclear plants — but no major explosion of the kind being discussed here). Other environmental impacts consist of thermal pollution of nearby lakes and rivers because of the necessity to use water from such sources to cool the nuclear reactors (with the water thus heated being returned to the environment) and very slight emission of radioactive substances — at levels far below the tolerances set for human exposure by the U.S. Atomic Energy Commission.[1] An environmental impact of nuclear power plants which often is of concern in areas miles from the plants is the necessity to dispose of radioactive wastes produced in the reactors when uranium or plutonium undergoes slow fissioning to produce heat which turns water into steam for driving generators to produce electricity. Such

[1] *Not all scientists are satisfied that the AEC exposure levels have been set sufficiently low to avoid harm to human and other forms of life. The bulk of scientific opinion, however, is of the belief that the levels of exposure permitted by the AEC are in fact safe.*

wastes are highly radioactive and retain their radioactivity for thousands of years. The standard method of storing such material away from human contact is to seal it into containers and bury it. Concerns have been voiced that disposal of large quantitites of radioactive wastes, as more nuclear plants are put into use, will pose serious environmental problems in terms of finding places to bury the material safe from earthquakes and water seepage over the centuries.

In his June, 1971, Energy Message to the Congress, President Nixon described a new type of nuclear reactor as America's best hope for a clean and plentiful supply of energy in the future. His reference was to the Liquid Metal Fast Breeder Reactor, or LMFBR in shortened form, which in 1973 received more Federal research monies than any other effort to develop new energy sources. The name of this remarkable new nuclear power plant is explained thus — *liquid metal* refers to the substance used to circulate about the reactor core to draw off heat which is used to convert water to steam for turning generators to produce electricity; *fast* refers to fast neutrons which are produced by the fission process in the reactor core; *breeder* refers to the fact that the reactor core is surrounded with a "blanket" of uranium which is useless for other purposes, but which when subjected to bombardment by fast neutrons can be partially transmuted into an artificial element (plutonium), which can be used as the fissionable fuel in other reactor cores. Thus it is claimed that a breeder reactor will operate over time to produce electricity while creating more fissionable fuel than that with which it is originally fueled! Breeders could greatly assist in the production of fissionable fuel for additional reactors at a time (the 1980's when they may enter commercial operation) when uranium suitable for reactor fuel will become relatively scarce and expensive. Proponents of the breeder, including President Nixon, claim that the LMFBR will be less creative of thermal pollution than the currently operating reactors, that radioactive emissions will be lower, and hence that breeders will usher in a new era of clean and abundant energy. On the debit side, it should be noted that extensive use of breeder reactors will create substantial amounts of radioactive wastes which must then be disposed of in some fashion, and that in the past nuclear power has often been oversold in relation to what actually developed.

Still another nuclear reactor is under research, and it is billed by advocates as being the "ultimate" source of energy. It is the fusion reactor. If it can in fact be built, such a device would create the same reaction which fuels the sun or thermonuclear weapons — the fusion of light elements such as hydrogen which produces awesome amounts of heat which can be converted into electricity. Difficult technical and engineering hurdles remain to be solved before the fusion reactor can become a commercial reality. However, the AEC continues to work upon fusion year after year and slow progress is reported each year.

Fusion reactors would probably involve some very low level emissions of radioactive substances such as tritium, and might cause some thermal pollution of nearby water sources as water which was heated during cooling of the reactor would be returned into the environment. There would also be some long lasting radioactive wastes which would require disposal. On the positive side of the environmental ledger are the facts that successful fusion reactors would produce immense quantities of electricity which would reduce substantially or eliminate the need to produce electricity in coal-fired or oil-fired power plants, thus reducing or eliminating the need for stripmining and greatly clearing the atmosphere of the pollution products of fossil fuel burning. Further, it appears that large explosions in fusion plants are almost impossible because of the physical properties such plants would possess.

An interesting possibility that has been mentioned in regard to fusion reactors is the "fusion torch." This concept would utilize the tremendous temperatures produced in a fusion reactor to reduce garbage and even metal rubbish, including car bodies, to their basic constituent elements — a kind of recycling which has no counterpart at this time.

Natural Gas

Of all the fuels now being widely used in the United States, natural gas has the least impact upon the environment because little air pollution is caused by its burning. Because of this and the fact that the price of natural gas has been kept artificially low by government regulation, it is the preferred fuel for heating many homes and buildings. Since it is cheap in relation to other fuels and nearly pollution free, natural gas is being used in huge quantities in the U.S. — supplying 32 percent of the total energy consumed in America. Because of this heavy use and because of dwindling domestic supplies, the United States faces a real possibility that if demand for this premier fuel continues unabated, Americans will not be able to meet the demand from domestic reserves. At this time it is not clear whether efforts to convert coal to synthetic gas, increases in gas prices to stimulate further discoveries of gas fields, or importation from abroad will combine to enable Americans to use such environmentally desirable fuel; however, private producers and the government appear optimistic.

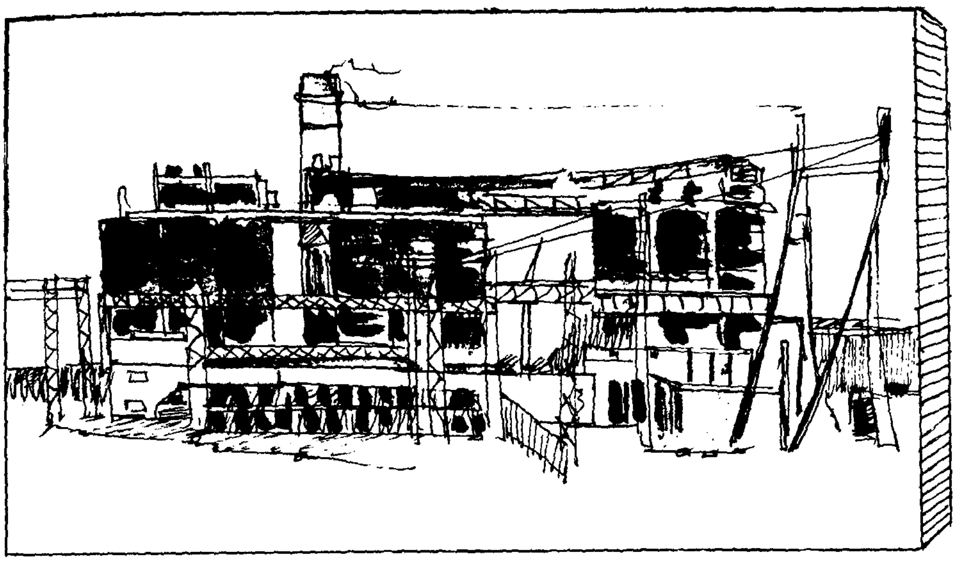
A very controversial means of increasing natural gas supply is to detonate nuclear weapons in underground strata containing natural gas, thus freeing the gas so it can be more readily pumped to the surface. This method, called gas stimulation by nuclear means, has been tried selectively in New Mexico and Colorado. The results have been ambiguous, with various groups claiming it is economic and does not involve radioactive gas, and others claiming the opposite.

Petroleum

Fuel oil for heating, fuel for diesel engines, gasoline for automobiles, and JP4 for jet aircraft engines constitute major energy requirements in the United States. Last year petroleum products accounted for 43 percent of all energy consumed in the country. As is the case with natural gas, the United States is not able to produce all the petroleum from domestic sources which it uses. This has led to increasingly greater reliance upon petroleum imports, most notably from the Middle East, with the possibility that some will come in the future from the Soviet Union. Some estimates are that by 1980 the U.S. may be importing something like 30 percent of its petroleum from abroad — a condition which creates fears in the minds of those responsible for national security as well as officials concerned with the economic health of the nation. The first group does not like to see the U.S. importing such an important necessity from an area of the world which is both politically unstable and possibly subject to controls imposed by the Soviet Union. The economic implications of such heavy imports arise from the possibility that the U.S. could soon be paying some $25 billion for petroleum bought abroad, and this would seriously undercut the efforts by the government to correct an already serious balance of payments problem.

Two types of general environmental problems are associated with the use of petroleum. One involves spills and leaks while the fuel is being transported — for example, the oil spill when a tanker sinks and the leaks and other environmental damage feared by some groups should the Alaska pipeline be built, which would bring oil from the North Shore field either directly to the "lower forty-eight" states or to southern Alaska, where it could be shipped by tanker the rest of the way. The other environmental problem associated with petroleum use is probably the pollution with which most Americans are now all too familiar — air pollution in major cities. This condition found in far more areas than Los Angeles — where the smog jokes started — is caused to a large extent by auto and truck exhaust which reacts chemically with sunlight to produce the yellow-brown smudge befouling many city skylines. As yet there seems to be no really good technical solution for the pollutants produced by internal combustion engines. This circumstance recently led Congress to pass the Clean Air Act, which requires the nation's automakers to increase their efforts to reduce auto emissions within the next few years. Success in this effort is not guaranteed, and another approach was suggested early in 1973 by the director of the Environmental Protection Agency. That was to ration gasoline in the Los Angeles basin as a means of greatly reducing vehicular traffic in that area, which would in turn greatly reduce the smog.

An alternative to importing more petroleum is to develop deposits of oil shale. These strata of rock are found in western Colorado and the nearby states of Utah and Wyoming, and a gasoline-like substance has been extracted from oil shale in a pilot plant. While the method is not yet economically competitive with



gasoline produced within and without the U.S., the rising price of gasoline in the future could make oil shale development attractive. The environmental impacts of oil shale development could be fairly substantial, according to some observers. For example, the process used would require water in a water-short region of the nation. Further, accumulations of spent oil shale, from which the synthetic oil had been removed, would require some type of disposal. This could be done by simply dumping the shale slag into deep uninhabited canyons of the area with what is claimed by petroleum interests to be of little environmental consequence to the nation as a whole. In time the slag might be rehabilitated with vegetation. Obviously, some conservation and environmental groups oppose such a plan. Fortunately, the oil shale may be dug from deep holes rather than stripmined so the problem so often associated with coal does not appear regarding oil shale. The scare created by the Arab oil cutoff during and following the 1973 Arab-Israeli war in October 1973, created pressure to develop oil shale. Part of the emphasis was supplied by President Nixon's goal to make the United States independent in energy production by 1980.

Hydroelectric Power

Electricity, which is produced when water stored behind a dam is used to spin turbines to produce electricity, does not create air pollution nor radioactive wastes. It does require, however, that valleys which are scenic or fertile be covered with water, which constitutes a significant environmental impact on the local area. Hydroelectric power no longer poses much of an environmental consideration because most of the areas suitable for dam building have been utilized and those remaining probably cannot be used because of determined opposition by environmental groups. Currently the amount of energy produced by hydroelectric dams is only slightly more than two percent, and the percentage of total usage will probably shrink as other sources are tapped.

Geothermal

Anyone who has watched in fascination as Old Faithful spewed forth steam and boiling water in Yellowstone National Park has witnessed a source of energy receiving renewed interest. Those who view geothermal power as a real energy alternative visualize pumping water deep into the earth where it would be turned to steam by heat radiating outward from the earth's core. The steam would be piped to the surface, where it would spin turbines and produce electricity, as is being done in a power plant north of San Francisco and in New Zealand and Italy. Aside from the construction necessary to drill the steam wells and build the plant itself, there would be little environmental degradation associated with geothermal energy utilization. While thus attractive from an environmental standpoint, geothermal energy may not be available at costs to make it competitive with other forms of energy for some time. Further, tapping geothermal energy requires the location of places where the earth's crust is sufficiently thin to permit drilling down to hot zones, and it appears that such places are not always available.

Solar Energy

The source of energy which may come the closest to breaking Barry Commoner's statement about no free lunches is energy from the sun, which in some instances may have no environmental degradation effects at all.

Anyone who has stood for a time in the direct rays of the sun in an Arizona desert in the summer will appreciate the tremendous amount of solar energy which strikes some parts of the earth each day. For some time men and women have dreamed of capturing a portion of this energy for use in producing electricity or in the heating and cooling of homes and buildings. Some success in research has been achieved. For example, there is a home in Denver, Colorado, upon whose roof there are solar energy collecting panels. The sun's heat captured is transferred to bins of rocks which gradually radiate the heat in the evening and on cloudy days to warm the house. About one-third of the home's heat is produced by solar energy. Built by a professor at Colorado State University, the process used in the home is now too expensive for commercial application. However, with rising fuel costs, such solar heating and cooling may become economical within this decade.

Other proposals exist for utilizing the sun's energy. One is to capture it with giant satellites operating above the earth and then to beam the concentrated energy down to receiving stations. Another is to cover portions of the Arizona and California deserts with solar collecting panels which would trap the sun's heat for use in turning water to steam for operating generators in the production of electricity. While the former would seem to pose no environmental problems, the latter would involve construction of solar panels in sizable areas of the desert and might involve utilization of quantities of water in an area where that resouce is quite scarce. Nevertheless, energy in the form of electricity thus produced might be less environmentally degrading than increased burning of coal and oil.

Hydrogen

If truly immense amounts of cheap electricity were to become available, say from the new types of nuclear reactors, collection of solar energy, or geothermal sources, one may consider the massive extraction of hydrogen from seawater by electrolysis. The hydrogen gas could then be used to heat homes and buildings in place of natural gas, and probably to operate internal combustion engines. In either case there would be little air pollution.

Future Predictions

Considerable savings in the consumption of various fuels are expected in the near future from developments which will increase the efficiency of current operating means of energy production. Further, impressive savings may also be expected from efforts to insulate buildings and homes to prevent the loss of heat in the winter and coolness in the summer. Higher prices for all fuels should also cut down wasted energy usage. Together these efforts will lighten the environmental impact of energy production and use.

When the various new energy sources are reviewed, and even considering the savings associated with increased efficiences and insulation, energy use in the near future in the United States must be viewed as continuing to place considerable burden upon the natural environment. This is particularly so if the assumption is made that energy use in the United States will continue to increase in support of a rising standard of living.

Several of the immediate means of producing additional energy — greater burning of coal to produce electricity, conversion of coal to synthetic gas or gasoline, and importation of oil and gasoline — all will contribute to greater environmental degradation. Only importation of natural gas, which has economic and national security implications, carries a reduced environmental impact. Thus for the near future greater energy use will mean generally greater environmental impacts, although the danger to human and other forms of life is debated. Clean energy must await further scientific development.

Nuclear Gas Stimulation

Norman A. Evans
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Nuclear energy offers attractive possibilities where large forces are needed for small packages. Such is the case in mechanical stimulation of natural gas reservoirs, a process by which tight, low-yielding formations are fractured in order to increase gas flow to a well.

A "Clean" Fuel

Energy produced from natural gas is considered "clean" because there are practically no waste products from its combustion. Most natural gas burns completely, leaving only carbon dioxide and water vapor which can be discharged into the atmosphere without contamination. It is also an economical form of energy to transport from one place to another through pipelines. It is, for example, more economical to transport one joule of energy in the form of natural gas between Colorado and Chicago than it would be to transport the same amount of energy in the form of electricity by wire conductor.

Shortage of Natural Gas Forecast

In 1973, natural gas provided 35 percent of the nation's energy consumption. But the inventory of proved reserves is dwindling. Natural gas discovery since 1968 has not kept pace with natural gas consumption. A 20-year forecast by the Federal Power Commission (FPC) indicates that the development rate of natural gas supplies (including coal gasification, gas from Alaska, liquified natural gas imports, and pipeline gas imports) will be inadequate to meet current projections of future demand.[1] Figure 1 shows that by 1990 the annual demand for natural gas will be about 45 trillion cubic feet, but the available supply will limit annual consumption to around 30 trillion cubic feet.

The reasons for the shortage of natural gas are (1) unprecedented increases in demand, and (2) regulatory policies that imposed artificially low prices so that exploration for new supplies has been curtailed. Demand has increased in part because of population increases, but also because of the desire for a nonpolluting source of energy. Price regulations are imposed by the FPC based upon a concept of fair "area rates," but there is disagreement between FPC and the gas producing industry on the fairness of established rates. Industry maintains that the cost of producing gas is higher than the FPC figures and, therefore, industry cannot afford the venture capital necessary for exploratory drilling and the discovery of new supplies.

Estimated Reserves

Natural gas reserves are estimated in three categories of decreasing reliability: probable, possible, and speculative. According to the Potential Gas Agency, Colorado School of Mines, most recent (1970) estimates in the three categories are:[2]

probable:	257 trillion cubic feet (including Alaska)
possible:	387 trillion
speculative:	1178 trillion

The amount estimated as *probable* is reasonably certain, the *possible* category is associated with a fair probability, while the *speculative* category would have an unknown probability. Figure 2 shows the probable estimates by regions.

Natural Gas Reservoirs

Natural gas is usually associated with oil reservoirs. Being lighter than liquid oil, the gas moves upward in open pores of granular formations, where it is trapped by overlying formations of clay and similar tight material through which the gas cannot flow. When a well is drilled into the gas-bearing formation, gas under high pressure in the formation flows through the pores and small cracks or fissures toward the well. The productivity of a well thus depends upon the ability of the formation to convey gas. The larger the pores and cracks and the better the connections between them, the more easily gas may flow and, therefore, the greater is well productivity.

There are some gas reservoirs containing large volumes of gas in which the granular formation cannot convey the gas rapidly enough for economic production. Such reservoirs are described as "tight," meaning that pore spaces are small and connecting paths for gas flow are restricted. Wells drilled into such a formation produce only a small amount of gas

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[1] *National Petroleum Council,* U.S. Energy Outlook — an Initial Appraisal 1971-1985, *Interim Report, Vol.1, July 1971.*

[2] *Potential Gas Committee,* Potential supply of natural gas in the United States, *Potential Gas Agency, Colorado School of Mines Foundation, Dec. 31, 1970.*

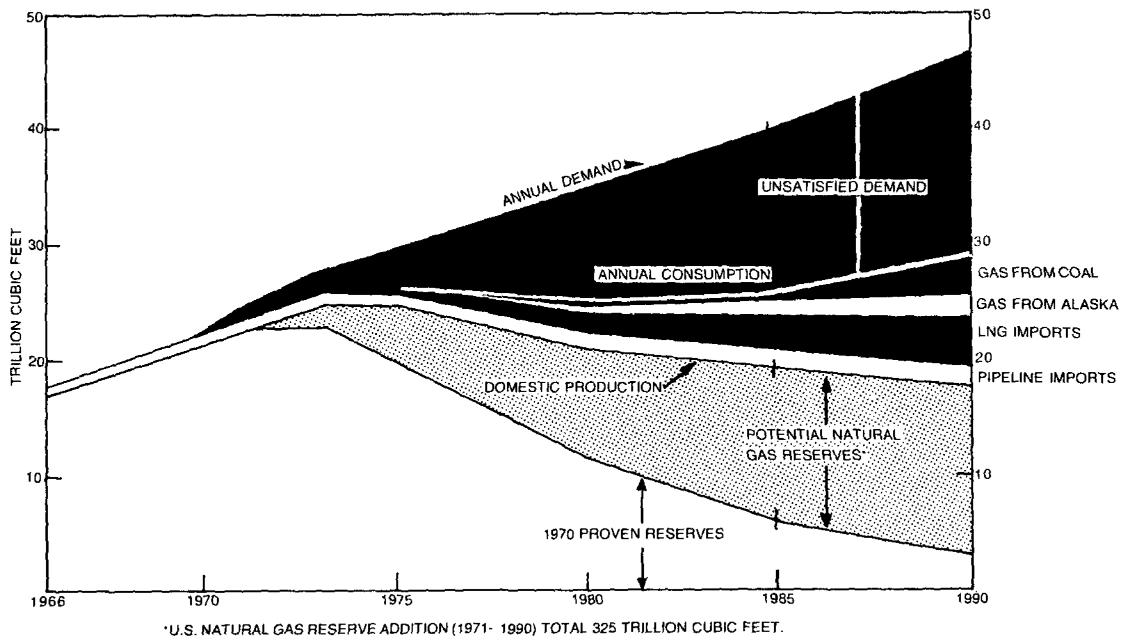

Figure 1. United States gas supply-demand balance (contiguous 48 states).

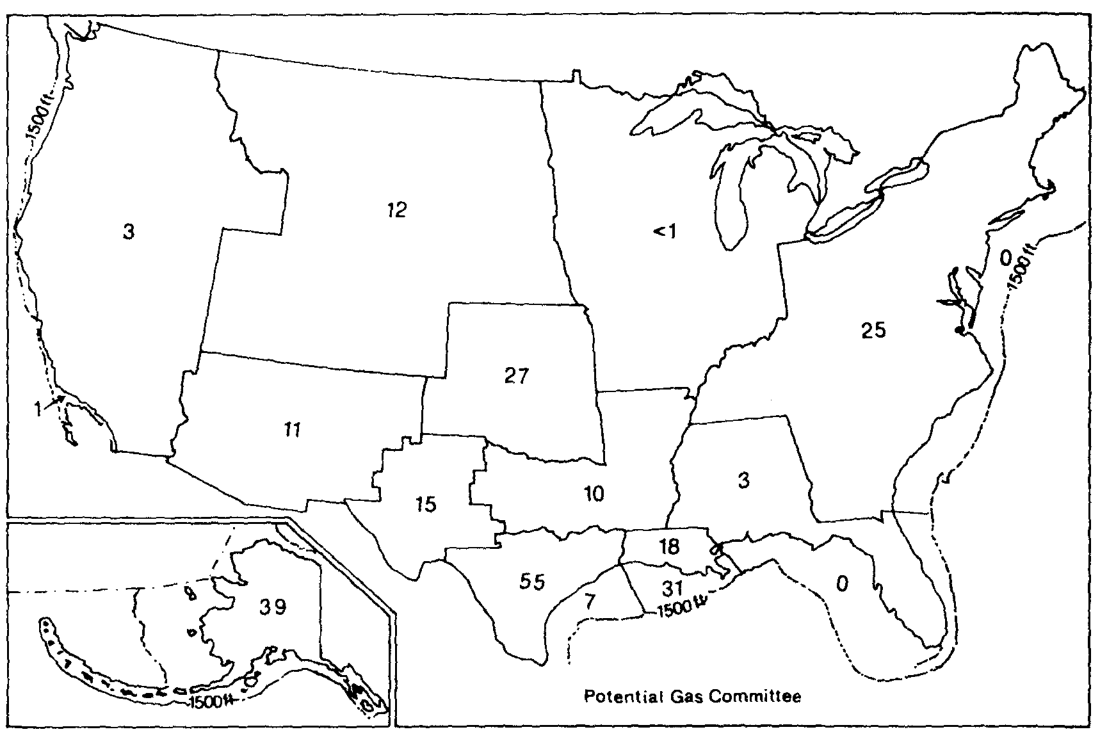

Figure 2. Probable category of potential gas supply as of December 31, 1970. (Total: 257 trillion cubic feet).

because the rate of gas flow through the formation, even under great pressures, is too slow. One such tight formation extends from northwestern Colorado and eastern Utah into southwestern Wyoming. Gas-bearing sandstone at depths of more than 6,000 feet below ground surface are thought to contain around 300 trillion cubic feet of gas.[3] This is a very large volume of gas, exceeding the 1970 estimated probable supply in the United States including Alaska.

Figure 3 shows the general location for the tight Rocky Mountain gas reservoir and Table 1 summarizes the dimensions and estimated gas yield (with new technology) in four of the six basins shown.

Mechanical Fracturing

Some tight gas reservoirs have been made economically productive by the use of chemical explosives and by hydraulic fracturing. The latter is done by forcing water into the formation through a well at great pressure sufficient to fracture or otherwise disturb the formation. This procedure has been found ineffective at the great depths where oil-bearing sands are found. Use of dynamite or a similar chemical explosive is limited by the size of the space into which the explosive can be placed (the well bore). This limits the amount of energy

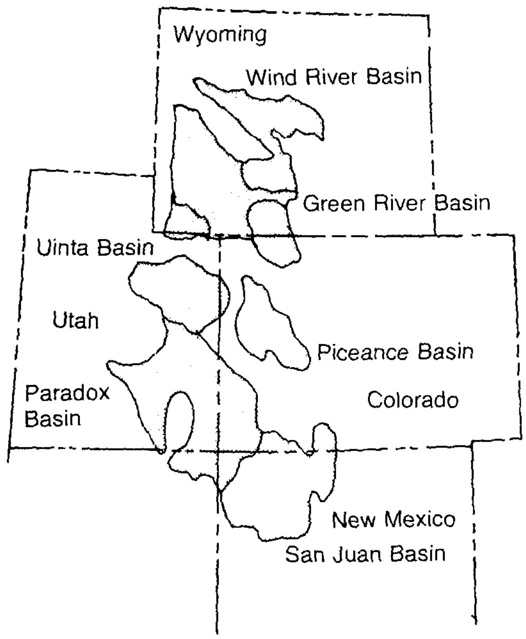

Figure 3. Basins containing substantial gas reserves.

which can be applied and, therefore, the amount of fracturing and the distance from the well bore to which fractures extend. Considering the cost of drilling to depths of 6,000-10,000 feet and the close spacing of wells which would

Table 1. Estimated increase in reserves of natural gas in four major Rocky Mountain basins, assuming the effective use of nuclear explosives.

Basin[a]	Aerial extent with productive potential (mi²)	Assumed productive area (mi²)	Number of known gas-bearing formations	Total sand thickness (ft)	Productive thickness (ft)	Increased recovery using nuclear explosives (Tcf)[b]
Uinta	8,900	1,800	4	1,700	680	61
Piceance	3,900	800	4	1,200	480	19
Green River	19,000	4,000	7	2,500	1,000	199
San Juan	10,600	2,000	3	1,100	440	38
						317

[a]The large Paradox basin is too sparsely developed to permit a reasonable evaluation.
[b]Tcf = trillion cubic feet.

[3]*Atkinson, C.H.,* "Nuclear fracturing prospects for low permeability hydrocarbon reservoirs in the U.S.," *Preshot Gasbuggy Symposium, Framington, New Mexico, Sept. 18, 1967.*

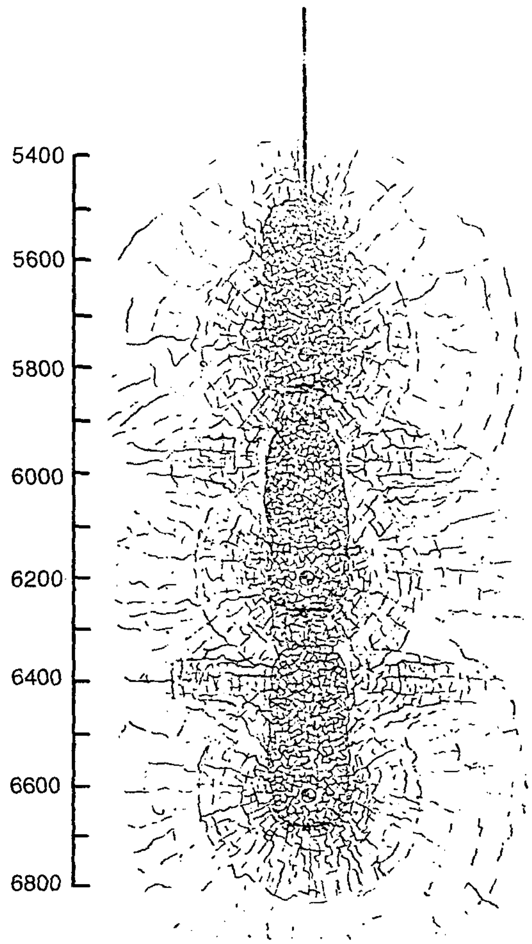

Figure 4. Chimney and fracture zone details expected from Project Rio Blanco.

have to be drilled in order to recover a significant amount of gas using chemical explosives, the procedure is not considered feasible for the Rocky Mountain region.

The tremendous amount of energy available in the small size of a nuclear device brings attention to the possibility of nuclear stimulation. It is a possibility which offers a peaceful use for nuclear energy to recover natural gas otherwise not recoverable. Given the apparent future shortage of natural gas in the United States, this new technology is attractive to both the gas industry as well as the Atomic Energy Commission, which would like to develop peaceful uses for nuclear devices.

The nuclear explosive adds a new dimension to the possibilities of stimulating tight gas reservoirs because tremendous energy can be packaged in a very small volume and emplaced through a drilled hole. The explosion produces a cavity of broken rock called a "chimney" and a surrounding system of fractures; as a result, instead of producing gas from a well six inches in diameter, the nuclear stimulated well produces gas from a much larger effective diameter.

Deep drill holes (6,000-10,000 feet) are expensive, and, therefore, several nuclear devices would be placed in the same hole to stimulate the greatest possible thickness of gas-bearing formation. The emplacement hole would be reentered after the detonation and used to withdraw gas. Figure 4 illustrates a stimulated reservoir following multiple explosions placed in the same well.

Stimulation Experiments

The Atomic Energy Commission, seeking uses of nuclear energy in nonmilitary applications, established a test site in Nevada for underground detonation.

Following a large number of experimental detonations at that site, the first nuclear gas stimulation experiment was conducted in northern New Mexico in 1967. This experiment was called "Gasbuggy," and used a 29-kiloton nuclear device at a depth of 4,240 feet. Post shot investigations showed the explosion created a cavity radius of about 80 feet and fracturing to a distance of 3.5 cavity radii. The chimney height (cavity) was about 400 feet.

Project Rulison in Colorado in 1970 was the second experiment. The nuclear device yielded 40 kilotons and was detonated at a depth of 8,427 feet at a site along the Colorado River near Rifle, Colorado. The cavity created by the explosion was determined to be 76 feet in radius and 250 feet in height. The fracture zone was three times the radius of the cavity (Figure 5).

Both experimental gas stimulation projects resulted in a satisfactory increase in gas production over that expected from a conventional well.

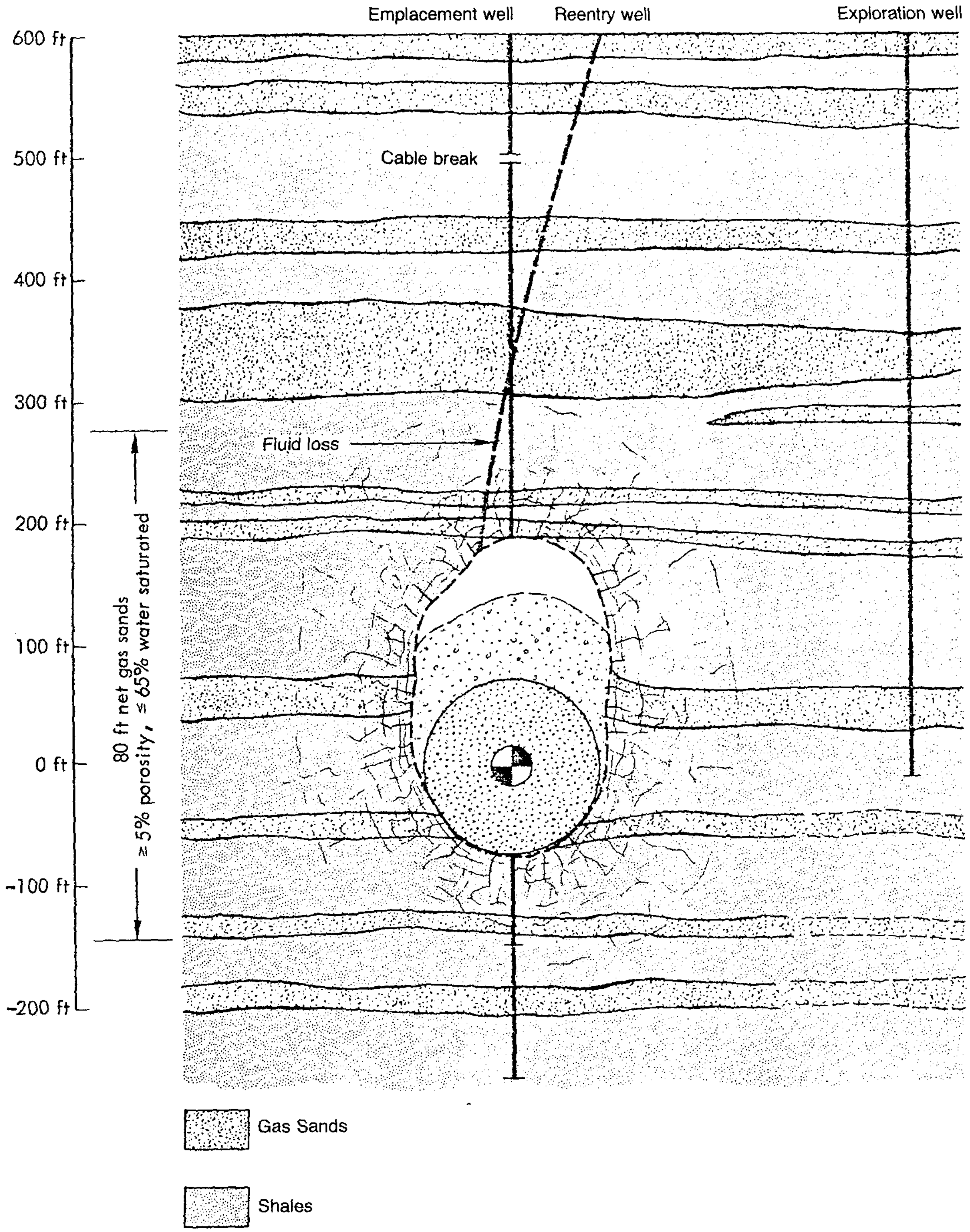

Figure 5. Rulison chimney. The cavity radius was 76 ft, the depth of burial was 8427 ft, and the explosive yield was 43 kt.

A third experiment in nuclear gas stimulation is planned for 1973 in Rio Blanco County within Piceance Basin. Three devices, each of 30-kiloton yield, will be placed between 5,800 feet and 6,700 feet below the ground surface. The explosive devices in this case will be especially designed for gas stimulation purposes. The three devices will be exploded separately at short intervals of time so that each of the series of three shock waves will be smaller than the shock from a simultaneous explosion. A chimney approximately 1,300 feet high and 160 feet in diameter is forecast. The radius of fractures is expected to be about five times the radius of the chimney.

Environmental Problems

Radioactivity in Gas

The principal radionuclides of concern in nuclear gas stimulation are tritium (^3H), krypton-85 (^{85}Kr), and carbon-14 (^{14}C). Tritium can be produced by the interaction of neutrons with materials in the explosive and with lithium in the rock surrounding the explosive. Because tritium is an isotope of hydrogen, it behaves chemically like hydrogen and can be bonded into the methane gas molecule. For this reason, gas stimulation should employ a nuclear explosive designed for minimum tritium production.

Krypton-85 is a noble gas produced in fission which does not chemically react with natural gas but is carried along with it. Carbon-14 is produced by the interaction of neutrons with nitrogen in the explosive and in the rock surrounding the explosive. Like tritium, it can be bonded into the methane molecule.

Tritium is also incorporated in water vapor molecules within the blast cavity. Gas produced from a nuclear stimulated well will therefore contain some tritium in gas molecules and additional tritium in water vapor. The latter can be removed from the gas before its delivery into a pipeline for domestic use. However, the bonded tritium will remain with the gas and will ultimately be released when the gas is burned.

To assess health hazards in commercial use of the gas, a study sponsored by AEC simulated its use for both residential and industrial purposes in a large metropolitan area (Los Angeles).[4] Under certain assumed conditions, the maximum total radiation exposure in the first year using Rulison gas for the entire city would be 26 mrem (compare with 85-155 mrem per year from natural background in the U.S. and a recommended maximum exposure of 500 mrem per year).

The foregoing estimates were based upon certain assumptions, and although the weighted average dosage that was estimated amounts to only 20 percent of the maximum mentioned above, there is room for question as to the possible dosages under specific unfavorable conditions in either residential or industrial use.

With proper management, radiated gas can be mixed with normal gas before delivery so that dilution would reduce radioactivity to such a low level that no health hazard would exist. However, the issue of public health in connection with commercial use of irradiated gas remains controversial.

Radioactivity in Air and Water

Air and water pollution by radioactive products from a nuclear explosion is another possible hazard to human and animal health. These possibilities depend much upon the depth of the explosion and the nature of geologic conditions at the site.

The only possibility for *air pollution* is leakage from the explosion cavity to the surface through fractures or along the well casing. The latter problem can be monitored and corrected if necessary by sealing any space around the casing with cement. In the two experimental projects, no leakage has been detected thus far.

Although the radius of fracturing is relatively small around a nuclear explosion, there is

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[4]*Werth, G. C., M. D. Nordyke, L. B. Ballou, D. N. Montan, L. L. Schwartz.* "An analysis of nuclear-explosive gas stimulation and the program required for its development," *UCRL-50966, Lawrence Radiation Laboratory, Univ. of Calif. (Livermore), April 20, 1971.*

always the possibility that extensive faulting in past geologic time might have left openings deep into the earth's crust through which radioactive gases could escape. The precaution against this occurence is careful geophysical investigation. Such investigations, coupled with information from conventional well drilling, can give reliable information on the existence of faults.

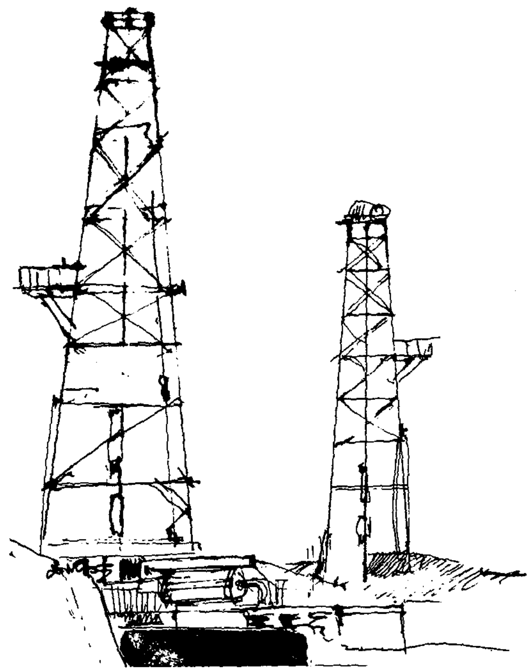
As in the case of air pollution, the hazard of *water pollution* with radioactive products of an explosion is related to faults, fissures, or cracks. Very often groundwater does occur in shallow formations near the earth's surface. If an explosion should cause a system of fracturing or displacement of old faults such that surface, or near surface, groundwater could flow downward into the explosion zone, then there would be a possibility of radioactive products migrating by diffusion through such water toward the surface. Again, the important precaution is adequate geophysical exploration in advance of any explosion.

Radioactivity in the Ground

Radioactive products of the explosion are thought to be trapped in molten rock which solidifies in the bottom of the cavity. It is contended that such radionuclides are immobilized and could not migrate even if groundwater were to move through the cavity. There are differences of opinion on this point, however, and to assure that no groundwater is contaminated with radioactive materials, the experimental explosions have been in zones where mobile groundwater does not occur.

Shock Effects

A nuclear explosion creates a strong shock wave in the geologic formation which compresses material as it moves through. Upon reaching the ground surface, the wave reflects back into the earth as a tension wave. This can cause separation of surface formations. The separation phenomenon, called "spall," has been observed and studied with many experimental detonations. The depth of spall depends on tensile strength of the earth material. Calculations for the Rio Blanco site indicate that spalling will be expected in the top 170 feet with some remote possibility that the spall depth might be as much as 360 feet. Beyond that



depth, the weight of overburden above cancels the tensile stress from the shock wave, and there is no separation or spalling.

As a shock wave reflects from the earth's surface and as spalling occurs, the surface is displaced momentarily, creating the effect of a roll or surface wave traveling outward from a point on the surface above the explosion. Vertical displacement at the surface may be as much as 20 cm immediately above the explosion, diminishing to a maximum of 10 cm at 2600 feet, and to less than 5 cm at one mile. Any building in that zone would experience a substantial shock and some damage would be expected. Building damage can be minimized by installing braces, reinforcing chimneys, removing china and breakable objects to a safe location, and similar precautions.[5]

[5]*USAEC, "Rio Blanco Gas Stimulation Project, Rio Blanco County, Colorado,"* Environmental Statement, *WASH-1519, Jan. 1972.*

A very important oil shale formation is located in Piceance Basin relatively near the surface above the Rio Blanco explosion. There is a great deal of concern because shock waves could damage existing mines. They could also open up faults and fissures in the oil shale formation which would permit overlying groundwater to flood the shale. If this occurs, mining of the shale might become impossible and that resource would be lost to the nation. Since it represents around 600 billion barrels of oil — a very significant supply compared to the 16.5 million barrels per day of United States oil consumption in 1973 — many contend that nuclear gas stimulation should be deferred until after the oil shale resource is exhausted in order that no risk be taken. AEC experts maintain that data and experience from previous stimulation experiments indicate that no damage to the oil shale formations will occur.[6]

Other Issues

With an energy shortage facing the nation, 6 trillion cubic feet of natural gas from the Rio Blanco reservoir represents a substantial amount of energy. Its recovery through nuclear stimulation may be feasible, but not without certain risks to environmental quality. Radioactivity and shock wave problems have been discussed above. Minor disruption in the regional ecosystem may be expected due to pipelines, access roads, and well drilling. Governmental control of those activities should easily keep their impact minimal. Relatively few permanent personnel are anticipated in the region since the gas would be piped away to urban areas.

The economic gain from nuclear gas stimulation in Rio Blanco County can be summarized as revenues to the state and county from the production of 6 trillion cubic feet of gas. Tax revenues to the state and county at full field development (140 wells) are estimated at 1.5 to 2.0 million dollars annually.

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[6]*Holzer, F. and D. O. Emerson.* "Possible effects of the Rio Blanco project on the overlying oil shale and mineral deposits," *UCRL-51163, Lawrence Radiation Laboratory, Univ. of Calif. (Livermore), Dec. 27, 1971.*

Oil Shale

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A sedimentary rock composed of lake bottom sediments deposited over 50 million years ago in Colorado, Utah, and Wyoming contains over 1,800 billion barrels of oil. This oil-bearing shale — in the Green River formation — underlies 17 million acres of the three states in strata up to 2,000 feet thick.[1] Figure 1 shows its location. Solid organic matter in the shale (13.8%) converts to oil upon heating to 900°F.

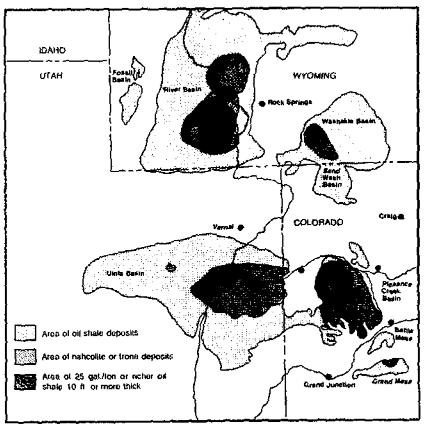

Figure 1. Oil shale areas in Colorado, Utah, and Wyoming.

One million acres of land within the Piceance Basin of Rio Blanco County, Colorado, contain about 80 percent of the estimated total oil in the shales of the three-state area. Although the Colorado area is small, its oil shale is in thick deposits of high grade, yielding more than 25 gallons per ton of shale.

Recovery of even a fraction of this energy resource can significantly supplement the growing U.S. consumption of oil, which now totals slightly over six billion barrels each year (1973). Because nearly 80 percent of the known reserves are on Federal land, the pattern of its development will be determined largely by Federal leasing policies. The Department of Interior has formulated guidelines for a prototype lease development program which is intended to allow limited, closely controlled exploratory development on two tracts of around 5,000 acres in each state.[2]

[1] *U.S. Dept. of Interior,* "Environmental Statement for the Prototype Oil Shale Leasing Program," *Sept. 1972.*

[2] *U.S. Dept. of Interior,* "Program Statement for the Proposed Prototype Oil Shale Leasing Program," *June 1971.*

The Piceance Basin

Piceance Basin is a synclinal basin at an altitude of 6,000 to 8,000 feet above sea level. It is a sub-basin of the White River Basin of western Colorado. Entering the Basin for the first time, one's reaction might well be, "Can man do any more damage to the environment here than nature has already accomplished?" Sharply eroded topography with a sparse covering of low-growing vegetation meets the eye. Present land forms have been created by geologic uplift, stream erosion, and the varying resistance of rock layers to weathering. Water erosion has produced ridges and valleys with local relief of 200 to 600 feet.

A unique beauty is to be seen in the geometric forms of the landscape and in the desert coloring of the scene. The inexperienced eye might easily overlook the large variety of low-growing plant species which together make up an ideal diet for the famous mule deer herd which winters in the Basin.

The unknowing observer might also fail to realize that arid landscapes such as this have extremely limited capacity to absorb man's waste and are exceptionally vulnerable to air and water pollution. It is an ecologically fragile environment where soils and vegetation are easily damaged and slow to recover.[3]

The Basin is sparsely settled, with a population of 100 people in an area of one million acres. Annual precipitation varies from 12 inches in the northwest to 24 inches in the southwest (half of which occurs as snowfall during the months of December to April). Thunderstorms contribute much of the summer precipitation and result in flash floods throughout the area. Summer temperatures reach 100°F and winter temperatures drop to -40°F; however, the climate is not severe because the limits occur infrequently.

Morphologically, the Basin is in subsequent and late youth. Typical valleys are V-shaped with narrow, flat alluvial floors. Down-cutting occurs in the valley floors if the delicate equilibrium is altered by increased runoff or removal of structural controls in the stream channels.

[3] *Clawson, M.D., "Economic Considerations in Arid Land Use,"* Proc. 1970 Western Resources Conference, *Colo. Assoc. Univ. Press, Boulder, Colo. pp. 189-96.*

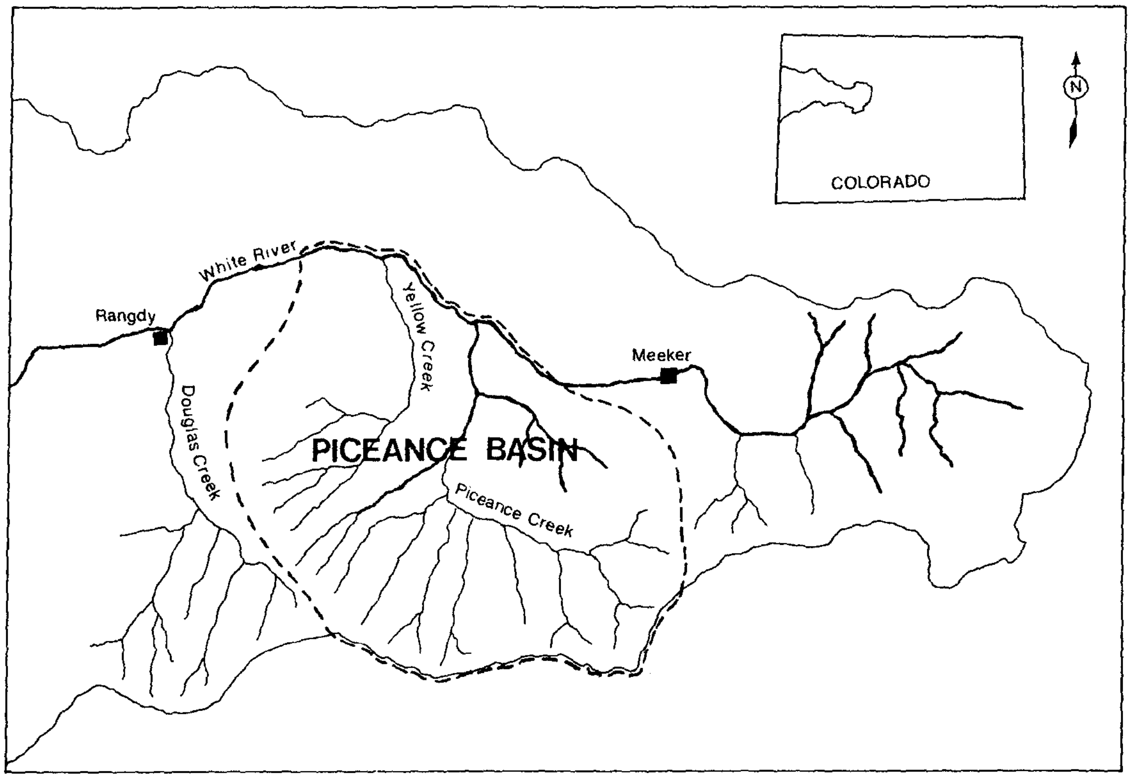

Figure 2. Piceance Basin within the White River Basin

If downstream erosion is controlled by bedrock or artificial structures, then the upper region of the valleys will remain untrenched. However, if trenching continues up the valleys, their tributaries will be rejuvenated and down-cutting will continue.

At the mouth of east Douglas Creek a small log cabin, probably less than 80 years old, stands partially buried in the alluvium. The front door opens directly onto a 20-foot drop into the incised channel of east Douglas Creek. There is little doubt that down-cutting has occurred since the construction of this cabin — clear evidence that the valleys of the Piceance Basin are fragile and susceptible to rapid erosion if stream conditions change.

Environmental Elements

Environmental elements of importance in Piceance Basin are grouped under the following categories: geologic, man-made features, water resources, vegetation, wildlife, climate, recreation, and cultural or aesthetic features.

Geology

Sedimentary rocks comprise a sequence more than 26,000 feet thick in the oil shale region. Oil-bearing shale rocks of the Green River formation are near the top of the rock column, extending to a depth of 3,000 feet. The region was warped into large structural basins, followed by later upthrust to several thousand feet above sea level. Stream erosion subsequently removed several thousand feet of sediments leaving the present condition. Overburden formations are of varying depth from 100 feet toward the rim of the basin to 1600 feet near the center (Figure 3).

Man-Made Features

The only features made by man in the Basin are an early school house, constructed of rock, and miscellaneous ranch buildings supporting the population of about 100. The schoolhouse has a local historic value. Power lines, pipelines, roads, and fences mainly associated

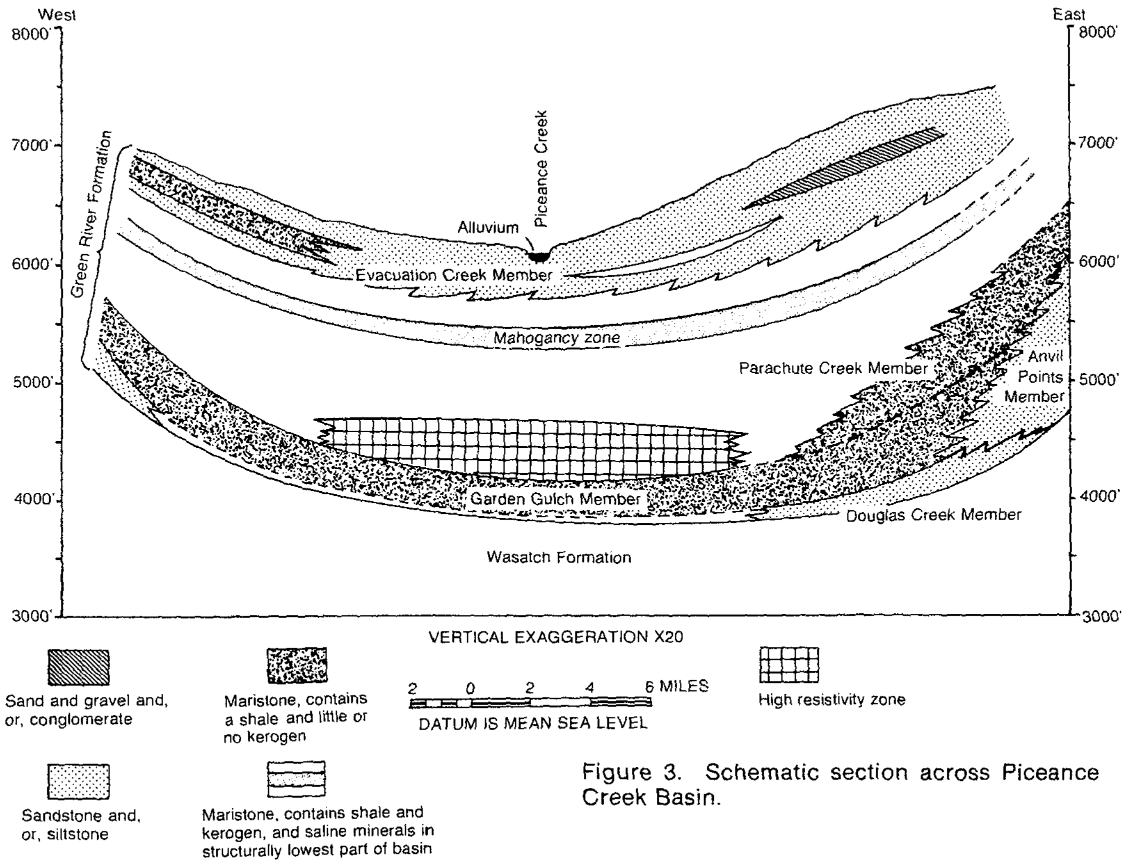

Figure 3. Schematic section across Piceance Creek Basin.

with oil wells, are encountered infrequently in the Basin. It is typically rough, open country.

Water Resources

Relatively little surface water is produced by the streams of Piceance Basin. Peak flows are reached during snowmelt in April-May, and the low flows occur in September or October. Many streams are dry from September to April. Piceance Creek, the major stream, has a mean discharge at the White River of 17.0 cfs (cubic feet per second); maximum recorded flow is 550 cfs. A substantial part of the mean discharge is groundwater picked up in the lower reaches of the stream.

Groundwater is recharged around the circumference of the Basin by snowmelt. Part of this recharge flows into the deep Parachute Creek recharging an aquifer containing an estimated 2.5 million acre feet of water. (Some estimates reach 10 million acre feet.) Unfortunately, much of this water is highly saline, containing up to 63,000 ppm of salt.[4]

Water in the shallower Evacuation Creek supplies numerous springs and shallow wells with good quality water. The springs are important to a deer herd wintering in the Basin, as well as to domestic livestock. Many springs flow year round, although those at higher elevations are intermittent. A few domestic water supply wells take water from this source.

Alluvium in major valleys supplies most of the domestic water for the Basin ranching population.

[4]*Environmental Resources Center,* "Environmental Inventory, Portion of Piceance Basin," *for Cameron Engineers, Inc., Colorado State University, Fort Collins, Colo., Dec. 15, 1971.*

Vegetation

There are 133 different species of vegetation identified in the Basin; some of them are rare or uncommon. Recently, personnel of the Colorado Division of Wildlife made a collection of deerbrush (*Ceanothus martinii*), which is known to occur sparingly in Utah but has never previously been found in Colorado. Botanists have suggested that rare species and ecotypes associated with the peculiar soil conditions or geological formations might be expected within the Basin. Isolated colonies of various flowers, shrubs, Douglas fir, and aspen are found which are common species for Colorado but not abundant in the Piceance Basin.

Wildlife

The most important game animal in the Basin is the Rocky Mountain Mule Deer; the herd is believed to be one of the largest in North America. Carhart[5] estimated that the herd numbered 20,000 animals in 1943 and characterized it as "the most important flock of wildlife stock in Colorado." Some estimates in more recent years have reached 100,000.[6] The herd summers on the higher mountain elevations east of the Basin and winters in the Basin itself, where winter habitat conditions are ideal. There is excellent vegetative interspersion, variety, and close proximity of suitable exposures, cover types, forage, browse, and water. Cedar groves serve as cover and also for temporary feed in emergencies.

Numerous other wild animals are found in the Basin, including elk, mountain lion (15 est.), coyote, bobcat, black bear, and wild horses (50 est.). A Bison herd has been introduced by the Colorado Division of Wildlife. Some 225 non game species of birds have been identified, including 24 raptors. Sport fishing is nil in the Basin.

Golden and Bald Eagles winter in the area; the Bald Eagle is now classed as an endangered species. Prairie Falcon, another rare species, as well as the Greater Sandhill Crane are migrant birds to be found within the Basin. Ringtail cats in limited numbers are reported, a species which is growing increasingly rare in western Colorado.

Recreation

Environmental elements significant to recreation may be grouped in three broad categories:

(1) Scenery and landscape elements,
(2) Cultural elements,including prehistory, history, natural history, and modern land uses, and (3) Recreational facilities which add to or detract from the area as a desirable setting for various recreational activities.

The Basin is considered a Class III Natural Environment (BOR). The characteristic feature in this class of recreation land is natural scenery possessing varied and interesting land forms, flora, and fauna in an attractive natural setting. Its dominant recreational use potential is for traditional outdoor experiences where users enjoy the resource "as is" in a natural setting. The dominant feature is Cathedral Bluffs, a high ridge rising to 8,685 feet along the western side of the Basin.

A Bureau of Land Management study[7] of visitor activity disclosed that 90 percent of the total visitor days were occupied in hunting. Picnicking is the second most dominant activity but accounts for less than 5 percent of the total annual visitor days. It is thus clear that hunting associated with the deer herd dominates the current recreational use of the Basin. Even more interesting is the record of proportions of local, in-state, and out-of-state visitors.

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[5] *Carhart, A. H., "The Piceance-White River Deer Herd,"* Deer-Elk Survey Supplemental Report, *Colorado Game and Fish Commission, 1943.*

[6] *Sedgley, E. F., and H. M. Boeker, "Fifteen Hundred Cattle and One Hundred Thousand Deer,"* Soil Conservation *26(8):177-178, 1961.*

[7] *U.S. Dept. of Interior, Bureau of Land Management,* "Douglas Creek Planning Unit Report," *file document, Meeker Office, Meeker, Colo., 1971.*

Table 1. Origin of recreation users and visitors days.

Activity	Local %	In-State %	Out-of-State %	Visitor Days
Camping	50	40	10	200
Driving for Pleasure	70	20	10	200
Sightseeing	70	20	10	100
Picnicking	90	8	2	1,000
Hunting	12	13	75	20,130
Fishing*	90	10	-	200
Rock Hounding	90	10	-	50
Artifact Hunting	90	10	-	350

**Outside Piceance Basin in White River*

Cultural and Aesthetic Features

Cultural elements are historical and natural history features which contribute to visitor enjoyment. Pictographs are found on rock walls along Douglas Creek, although no Indian sites are recorded. Any historical and archaelogical sites may be deeply buried in valley alluvium deposited in the last few hundred years.

While no fossil or petrified wood sites are known in the Basin, both are found in the near region. It should be assumed that such sites do exist in the Basin.

The geology and land forms previously described constitute important aesthetic elements. The major amenity is open space. Gross changes throughout the Basin, such as valley filling with processed shale residue, would be considered by many visitors to have a negative impact. Disposal sites should, therefore, be selected with attention to patterns of visitor access and travel in order to minimize the aesthetic impact.

Expected Environmental Impacts

A projection of environmental impact from oil shale operations describes *changes* in quality or quantity of any of the environmental elements. Particular concern is directed toward interacting effects among the elements (the ecological process). Ideally a projection of impact should be long-term. Unfortunately, both projection techniques and basic data on reactions of the environmental elements are lacking. Heavy reliance must, therefore, be placed on experienced judgment by *interdisciplinary teams of experienced professionals*.

Land Requirements

One measure of the general environmental impact can be drawn from an estimate of land requirements involved in mining and processing operations (8). The Department of Interior estimates land requirements for a 100,000 barrel per day open pit operation as follows.

Mine area	85 acres per year
Temporary overburden storage	200 acres, total
Permanent overburden storage	1000 acres, total
Temporary residue storage	150 acres, total
Residue disposal	50 acres per year (250 ft. deep)
Milling & processing facilities	200 acres, total
Off-site (roads, utilities, etc.)	200 acres, total

Land requirements for underground mining at 50,000 bbl per day are:

Surface structures	10 acres, total
Residue disposal, surface	75 acres per year (250 ft. deep)
(if 60% is returned to mine)	30 acres per year
Surface facilities	140 acres, total
Off-site (roads, utilities, etc.)	225 acres, total

Wildlife

One of the major environmental questions concerns the impact of an oil shale industry upon the deer herd. The effect of increased population and industrial activity upon herd behavior is controversial. Many wildlife specialists believe that any change in the existing level of human activity will have a deleterious effect upon the size of the herd; many even predicting that the herd will disappear. Other experienced specialists contend that the animals have great versatility in adapting to human activity and that the level of activity anticipated will not destroy the herd.

Herd reaction to roads and vehicular traffic seems to be a major unknown. Construction of Highway 13 north and south through the eastern edge of the Basin crosses the summer-to-winter range route, but apparently has not affected the Piceance herd. In fact, herd numbers have fluctuated both up and down since construction of the highway.

Hunting pressure would probably increase with resident population increases, and this in turn would have some impact upon the deer herd unless harvest management rules were adjusted.

Filling certain valleys with residue may cause a significant loss of winter food for the deer herd, but replacement feed may be provided by vegetation used to stabilize the residue. Unfortunately, it is not certain that the proper vegetative species can be established. This is a problem yet to be solved.

Other wildlife would not likely be adversely affected except that hunting or nesting grounds might be disturbed. Sage grouse "strutting grounds" are established in the northwest Basin which might need to be relocated. The principal protective measures needed appear to be control over hunting of rare or endangered species found in the Basin.

Stream Channels

Two operations could lead to major changes in stream channels: disposal of spent shale residue and waste water disposal.

For surface mining, disposal of spent shale into canyons outside the area of richest oil shale deposits is proposed. Mine drainage water would be used to convey spent shale by pipeline into disposal sites. Solids would settle behind retention dams, and the conveying water would be either recirculated for reuse or treated for disposal. Since it would contain a high concentration of dissolved salts, treatment would be necessary before release into waters of the state.

Valleys tributary to Douglas Creek are attractive disposal sites because they are not visible from main roads. However, the problem of stabilizing these deposits to prevent future erosion into Douglas Creek may be formidable. The apparent stability of these alluvial valleys is deceiving. Schumm (9) has pointed out that should water discharge in these valleys be increased, currently discontinuous gulleys will coalesce into continuous channels capable of carrying large sediment loads. Flow control structures will be needed if the regime of any of the streams is altered (including flow, sediment load, velocity, depth, etc.).

Leaching through spent shale residue, if permitted, will produce an effluent high in sodium and sulfate ions (10). The disposal problem, therefore, includes preventing the occurrence of leaching or collecting and controlling leachate.

Water Quality

Water will be required for cooling, steam generation, domestic consumption, and possibly solid waste conveyance. Processing site water can be totally recycled or consumed. Conveyance water, however, may present serious problems of disposal because of dissolved salts which would be picked up from spent shale.

It is quite likely that water removed from mines may be heavily loaded with salts, such that its disposal into any waters of the Basin would constitute water pollution. Salt concentrations of 4,000 to 10,000 ppm could be expected. Sodium adsorption ratios (SAR) in these waters might be as high as 30 or more.

[9] *Environmental Resources Center,* Environmental Inventory, Portion of Piceance Basin, *for Cameron Engineers, Inc., Colorado State University, Fort Collins, 1971.*

[10] *Ward, J. C., G. A. Margheim and G. O. G. Lof, "Waterpollution Potentials of Rainfall on Spent Oil Shale Residues,"* EPA Water Pollution Control Research Series *14030 EDB, Dec. 71.*

An associated effect of mine dewatering will be local lowering of shallow groundwater, which in turn may cause surface springs to cease flowing. If so, an important water supply source for wildlife and domestic livestock would be lost.

Demand for water and sewer services to support the nearly doubled population in the region will require most of the existing towns to expand sewer treatment facilities and acquire additional domestic water supplies. Population in the seven counties of the three states that comprised the oil shale region in 1970 was about 117,000. It is estimated that in the next decade the population of the same region will grow by about 92,000 people. Their residential location is somewhat uncertain, but they will probably be absorbed within existing communities. No new towns are expected to spring up. State and federal regulations concerning domestic waste treatment are such that these communities will be required to provide the necessary facilities. Thus there is no likelihood of adverse environmental impact from domestic waste due to the increased population.

Air Quality

Particulates may be expected from operations such as residue disposal, milling, crushing, retorting, and vehicular travel. Prerefining will produce nitrogen and sulfur gases.

Solid particulates from mechanical operations can be controlled by appropriate collector devices, enclosed conveyors, and moisture control. Roads, for example, can be wetted to control dust if necessary. Processed gases can be collected and in many cases upgraded for reuse or commercial marketing. Pilot plant operations in which retort gases are scrubbed have demonstrated less than 1 ppm emission of SO_2 and NO_2 (vs. Colorado standard of 2,000 ppm SO_2). Hydrocarbon concentration was also well within Colorado's emission standards. Full consideration of these problems must be applied in the design of processing facilities.

Visual Aesthetics

Changes in appearance of portions of the area are unavoidable. Greatest challenges will be spent shale disposal sites, open pit excavations, and temporary overburden storage. Surface processing facilities will also alter the landscape noticeably.

Conclusion

Oil shale, a resource found mostly on public lands, appears to have potential for substantial contributions to U.S. energy demand. A region of 17 million acres in three western states contains around 1 trillion barrels of oil. Given an apparently urgent need for new sources of energy to meet human needs in the very near future, the economics of its development have suddenly become attractive.

But should oil shale be developed now? Should it ever be developed? Answers to these and similar questions lie within the joint realm of economic, political, and social policy decisions.

Government and industry have sought the professional assistance of such groups as the Environmental Resources Center at Colorado State University and the Thorne Ecological Foundation in identifying environmental problems and assessing impacts. Comprehensive impact analyses and other studies are being initiated jointly by federal government, state government, and industry, and are designed to answer the following questions.

1. What interactions, organisms, environmental factors, and man-made factors now exist?
2. What impact will the projected activities have on the status quo?
3. How can the projected activities be planned to accomplish a minimum of alteration to existing landscape, including its organisms, environmental factors, and ecological processes?
4. What will be the necessary adjustments in methods of operation (technology) and attitudes to implement the plans?
5. What can be done to restore the ecosystem once the activities are completed?

Major impacts can be expected upon three important environmental elements in the Piceance Basin: wildlife, stream channels, and water quality. Minor impact would be expected in air quality and visual aesthetics. All of these impacts can be moderated by known technology, with the exception of wildlife, for which expected reactions cannot be clearly forecast.

Stripmining

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To many people, the term stripmining brings to mind a ravaged, desolate wasteland, devoid of any plant or animal life, and condemned to that state forever. However, to members of the mining industry, stripmining refers to an efficient, economical means of extracting minerals from the earth. Both points of view are at least partially valid. Stripmining is an important mining method. However, failure in the past to restore the land after mining has given the industry an extremely bad reputation to the point that public pressure is now threatening to limit or close down some segments of the industry.

The intention of this paper is to present a discussion of stripmining from a more objective perspective: what is stripmining, what are some of the environmental problems related to stripmining, and what can be done to reduce environmental hazards and restore mined land to an environmentally acceptable state?

Stripmining

Stripmining, also known as surface mining, opencast mining, and openpit mining, refers to the extraction of minerals by direct excavation from the surface. Generally, a layer of soil and rock material called overburden is removed, exposing the underlying mineral beds, which can then be excavated directly. Variations in mining procedures depend upon the topography and the depth and shape of the mineral body. Area type stripmines occur on relatively gentle terrain over widespread horizontal mineral beds. These mines cover broad areas and may utilize very large shovels or dragline equipment to uncover the mineral beds. Contour type stripmines occur in steeper topography where the mineral beds outcrop on a hillside. Here the mine creates a ledge or terrace where the mine follows the outcrop around the hillside. Openpit mines occur over large consolidated or steeply tilted mineral beds. Openpit mines are the deepest of the surface mine types, often going hundreds of feet into the ground. All methods involve severe disturbance to the surface and underlying geologic formations.

Many different minerals are mined by surface mining, including coal, sand and gravel, gold, phosphate, iron, and copper. In 1965, a survey of surface mined areas in the United States showed a total disturbed area of 3.2 million acres, of which 41% was disturbed by coal mining and 26% was disturbed by sand and gravel mining. In many situations, minerals which could not otherwise be recovered can be recovered by stripmining. For example, sand and gravel deposits (and frequently coal beds) are covered by shallow unconsolidated overburden materials and can only be recovered by stripping. In addition, costs are lower and recovery is greater. In the Appalachian coal fields, stripmining recovers over 90% of the coal, while underground mining methods recover only 40-50%. Unfortunately, before 1960 most stripmined areas were simply abandoned after mining. The industry gained an early reputation for being destructive and has become a natural target for conservationists and environmentalists.

Surface mining for coal has drawn particular attention because of both the large areas disturbed and the many problems associated with coal. Most of the U.S. coal production comes from the Appalachian Coal Fields, the Eastern Interior Coal Fields (Kentucky, Illinois, Indiana) and the Western Interior Coal Fields (Kansas, Nebraska). The largest disturbed acreages occur in Pennsylvania, Ohio, and West Virginia.

Historically, coal has been surface mined for many years. In 1915, 2.8 million tons or 0.6% of the U.S. production came from surface mines. As excavation equipment became larger and more efficient, and as the demand for lower grade coal increased, the proportion of coal mined by stripping has also increased. By 1968, 34% of the U.S. coal production was from surface mines. This figure will undoubtedly increase as the demand for new energy sources stimulates new power plant construction and utilization of still lower grade coal. Already two of the country's largest surface mines, the Black Mesa and Navajo mines, are feeding coal to a new power plant complex in the four corners area of Colorado, Utah, Arizona, and New Mexico. Similarily, the planned development of a huge power complex involving 16 north central states will utilize subbituminous and lignite deposits east of the Rocky Mountains. Development of these areas will greatly increase the mined area disturbances and associated environmental problems.

Environmental Problems

Environmental problems of surface mined areas are primarily related to the actual physical disturbance caused by mining and related activities. In the mining process, large volumes of overburden material are excavated, creating huge piles of raw earth. These spoil piles are loose, unconsolidated piles composed of large rocks, boulders, and fine soil material and are highly erosive unless protective measures are taken. In area type mining, the spoil is usually piled in long mounds in the pit of the previous cut. Cuts 50 to 60 feet deep are common. In contour stripping, a common practice has been to push the overburden material downslope from the cut. In openpit mining the spoil may be trucked from the mine area and piled in special spoil piles. In all mining types, the original topsoil is removed first and generally ends up at the bottom of the spoil pile, while the material next to the mineral bed ends up on top.

A major problem contributing to stream sediment loads is that related to earth slides. Particularly in hilly terrain, spoil piles on hill slopes may fail and move downslope into the natural drainage ways. Contour stripping in the Appalachian Coal Fields, where the spoil is piled on steep slopes, has produced hundreds of such slides. Once a slide begins, control is nearly impossible.

Erosion from the coal haul roads is another major source of stream sediments. Since the haul roads are only used for short periods, road design and construction generally do not conform to accepted drainage and gradient criteria. As a result, severe erosion occurs and continuous maintenance is required. When mining is completed, the roads are abandoned and become impassible within a few months.

In addition to erosion, pollution from geochemical weathering is a potential environmental problem in mined areas. During the mining process, the overburden rock materials are shattered and exposed to the atmosphere. The materials weather rapidly and may release large quantities of natural elements. The type and quantity of minerals released will depend upon the mineral composition of the overburden. In the eastern coal fields, overburden materials frequently have high sulfur contents. The sulfur occurs in the form of sulfides in the shale layers next to the coal. These sulfides, in the presence of oxygen and water, oxidize to form sulfuric acid. The acid in turn releases large quantities of iron, aluminum, manganese, sulphates, and other ions. Acid mine drainage has been the subject of much research and many treatment programs. Although the most serious pollution problems appear to be related to underground mine drainage, stripmines also contribute to stream pollution. Groundwater pollution has also been reported in stripmined areas.

Perhaps one of the most obvious problems related to stripmining is the aesthetic one. To most people, stripmines, since they are highly visible create ugly scars on the landscape Although measures can be taken to screen mines from public highways and high use areas, the disturbances caused by mining cannot be completely hidden while mining is in process. Once mining is completed, effective measures can be taken to restore a mined area, and with time the mined area can become aesthetically acceptable. However, one of the prices we will have to pay to obtain minerals by surface mining will be a temporary disruption of the landscape. The degree of the disruption and the degree of recovery will, of course, depend upon the nature of the mining operation and the restoration measure applied.

Restoration

Mined area restoration practices can be divided into two broad but interrelated categories: (1) engineering practices and (2) revegetation.

Engineering practices include regrading the mined area, drainage control of the mined area, and any structural stabilization or protective measures required. Regrading the mined area is primarily applied to help restore the landscape to some degree of usefulness. In addition to the aesthetic values derived and drainage control, graded spoils can be revegetated by mechanical (and thus more efficient) means than nongraded spoils. Although somewhat controversial, regrading is now accepted as a prerequisite to acceptable restoration. Except in a few instances, regrading has not been undertaken voluntarily by the mining companies who have already invested heavily in equipment to strip the overburden and are naturally reluctant to add more to their costs by smoothing out the landscape. Regrading has therefore become a state imposed requirement, and the amount and type of regrading varies among the states. Some states specify regrading so that the area is traversable by farm machinery, while others require regrading to the original contour. In all instances, the main objectives of regrading are to produce a more even surface, a surface easier to manage, more pleasant to look at, and with a lower erosion and acid hazard.

Drainage control is also important in the mined area. The primary objective is to move any surface water from the mined area without any surface or channel erosion. This means that protected drainage ways should be provided with gentle gradients so that the water can flow off gently. Especially in the humid east, water tends to accumulate on the mined area, where it contributes to acid pollution and erosion problems. Prior to the enactment of the various state laws regulating mining, drainage from a mined area was done at the convenience of the miners to drain the pits in which they were working. This was usually accomplished by bulldozing a cut through the spoil pile and allowing any accumulated water to flow down the hillside. Since this practice caused severe erosion, many state laws now require drainage into protected drainage ways. Where drainage outlets are not provided, ponds may form in the mine pit. In area type stripmines, ponds frequently form in the final cut of the operation and may be a desirable feature. Many stripmine ponds are now utilized as fishing ponds and recreational areas.

The revegetation of the mined area is the final step in the restoration process. In general, the success of a restoration project is judged by how well the disturbed area has been revegetated. The first revegetation work, and revegetation research, was begun in this country by foresters of the U.S. Forest Service. Tree planting and species tests were begun in Ohio in the 1930's and continued into the 1960's, when it was recognized that tree planting alone cannot stabilize a distrubed area and that additional treatment was required in the restoration process. Today we know a great deal about revegetating mined areas in the eastern coal fields, and planting guides have been prepared by state, federal, and professional organizations. Revegetation in the western states is not as well defined because of the relatively small proportion of mining disturbances and the range of climatic extremes encountered, from dry desert to cold alpine environments.

Successful revegetation involves a careful consideration of the climate of the mined area, the nature of the residual soil or spoils material, the topography of the area, and the ultimate objective of restoration. Climatic considerations include the rainfall and temperature regimes, the length of the growing season, and wind characteristics. Rainfall amount and occurrence during the growing season are of utmost importance to the establishment and survival of all vegetation. Many stripmine plantings have failed because of poor planting times or unexpected drought following planting. In general, rainfall is adequate in the eastern states for successful revegetation. In the western states, however, natural rainfall may not be sufficient and supplementary irrigation may be necessary to obtain a satisfactory cover. Similarily, the length of the growing season is an important consideration in selecting species. Those which can germinate and mature within a relatively short time span should be selected for high mountain plantings where growing seasons are short. Wind, too, can cause a planting to fail. Plants in a windy environment are subject to direct damage by the wind as well as abrasion by blowing soil particles. In some instances, vegetation establishment is aided by erecting wind barriers or stabilizing the soil surface by mulches or other cover.

The nature of the spoil material and surface is also important. The texture and density of the spoil determines the availability of water to the plant. Coarse textured sands and gravels may not hold sufficient water for growth. Finer textured soils may become compacted during regrading and require scarification to permit water entry and root growth. Other spoils problems encountered include fertility, salinity, acidity, and toxicity induced by other ions. Spoils derived from rocks are generally deficient in nitrogen or other nutrients. Nutrient deficiencies can easily be determined and remedied by the addition of fertilizer. Acidity and salinity problems are not so easily solved. Some state regulations in the East require that all toxic materials be buried in the spoil. This implies that toxic materials can be recognized, which is not always true without elaborate laboratory tests. Liming for acidity is effective for short periods of time but repeated applications are necessary for longer periods. Perhaps one of the more effective treatments is to cover the spoils with several feet of natural soil. This is a common reclamation procedure in Great Britain.

The ultimate objective of reclamation is to revegetate the mined area to prevent environmental damage, and ideally to restore the land to some level of usefulness. The extent to which reclamation measures will be applied will vary with the area. Mines in remote areas will probably be restored to the minimum level required by law. Mines in more favorable locations will be restored to special uses. Sand and gravel pits are often restored to recreational areas. Stripmines have been converted to many other uses including campgrounds, housing developments, golf courses, airports, pastures, and farmlands. It should be recognized that mined land restoration is one of the costs associated with mining and that these costs will be reflected in the price of the product produced. It should also be recognized that mined land can be restored to any level of beauty or productivity desired but that at some point the cost of restoration exceeds the benefits derived from mining; at that point, mining will no longer be conducted.

Reclamation Laws

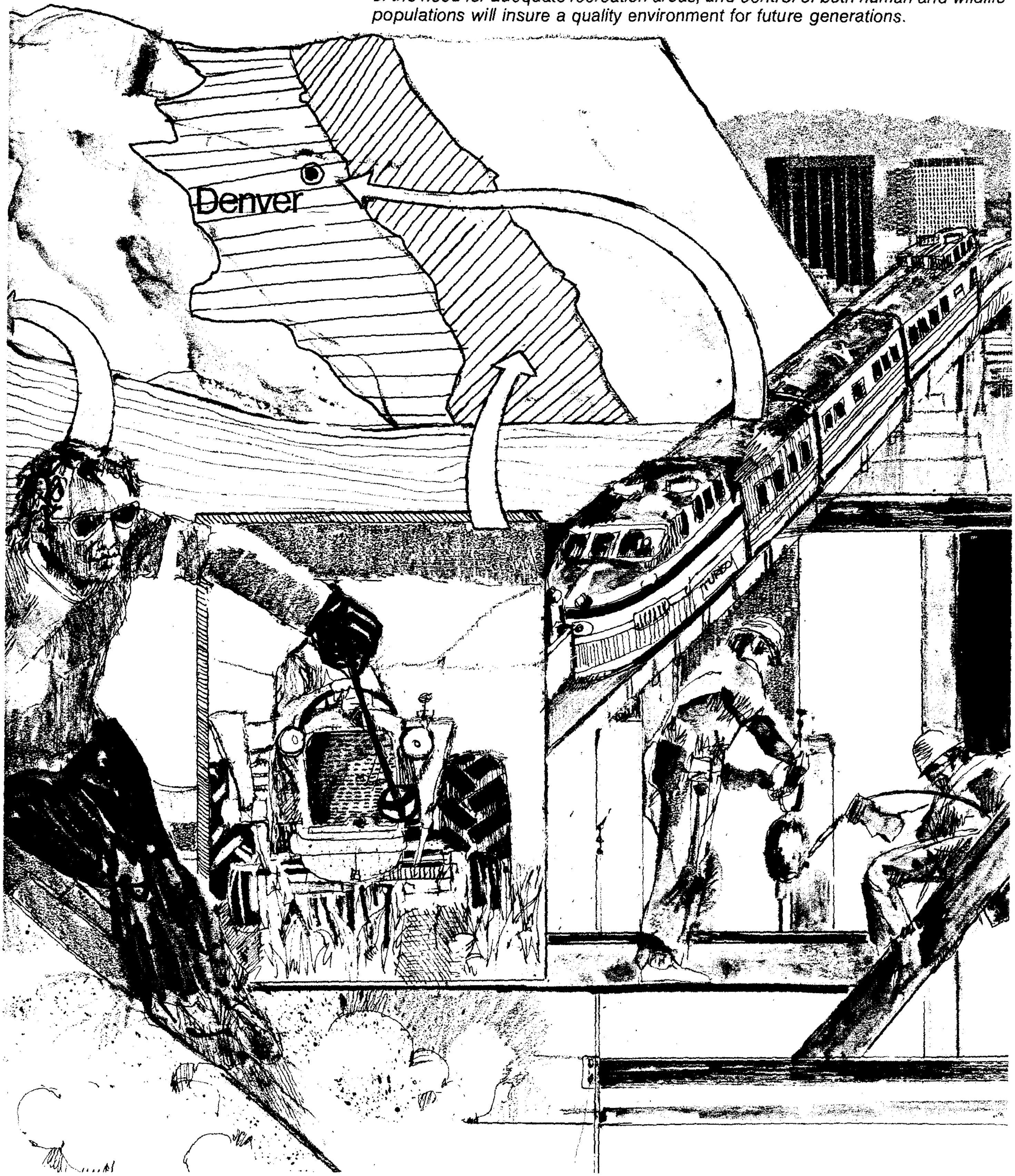
At present, stripmine regulations and reclamation laws are set forth primarily by the various states. There are, however, a few exceptions in which surface mines are controlled by Federal Statutes. Surface mining on federally administered lands is subject to regulation by the administering agency. Thus, mining on National Forest land is subject to regulation by the Forest Service while mining on Indian lands, BLM lands, and other public domain lands are regulated by the Secretary of Interior. The states regulate mining on state lands and privately owned lands within the state.

The first state law regulating stripmining was passed in West Virginia in 1939. A number of adjacent states in the eastern coal region passed similar laws so that by 1967 nine states had stripmine laws. With the growth of surface mining in the West, a number of western states have passed, or are in the process of passing, surface mine regulations.

The Congress of the United States is also interested in surface mine regulation. During the 92nd Congress, a large number of stripmine bills were introduced in both Houses of Congress. However, no bills were passed in spite of a general concern by the members of Congress. As the 93rd Congress began, a number of stripmine bills were introduced. It appears likely that a Federal Stripmine Law will be enacted in the near future.

Protecting Environmental Quality

As man becomes aware of the problems and better educated in the methods of overcoming these problems, he will be able to protect the quality of his environment. Proper planning in the areas of land use and transportation, consideration of the need for adequate recreation areas, and control of both human and wildlife populations will insure a quality environment for future generations.



Land Use Controls

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Land-use controls are not new, particularly those applying to urban land. The Pennsylvania Supreme Court heard a case in 1799 in which the legislature of Pennsylvania had empowered the City of Philadelphia to pass an ordinance preventing people from erecting wooden structures in a certain part of the city. The Court found the legislative act to be constitutional. A California court upheld restrictions on land use in that state in 1886. Restrictions on building height have existed in Washington, D.C. since 1889, and similar restrictions in Boston were upheld by a court case in 1909.

Historic Background

Zoning is the most widely employed land-use control. It was New York City which, in 1916, adopted the first comprehensive zoning ordinance. During the Coolidge Administration, then Secretary of Commerce Herbert Hoover appointed an Advisory Committee on Building Codes and Zoning which provided material to cities on zoning techniques and related legal matters. The Committee drafted a Standard State Zoning Enabling Act which, by 1925, had been used by 19 states and still serves as a model for much state enabling legislation. The United States Supreme Court heard the case, Village of Euclid vs. Ambler Realty Company, in 1926, and upheld the power of the village to use the police powers to zone land. The Court at that time observed:

> "Until recent years, urban life was comparatively simple; but with the great increase and concentration of population, problems have developed and are constantly developing, which require and will continue to require, additional restrictions in respect of the use and occupation of private lands in urban communities. Regulations, the wisdom, necessity and validity of which, as applied to existing conditions, are so apparent that they are now uniformly sustained, a century ago, or even half a century ago, probably would have been rejected as arbitrary and oppressive. Such regulations are sustained, under the complex conditions of our day, for reasons analogous to those which justify traffic regulations, which, before the advent of automobiles and rapid transit street railways, would have been condemned as fatally arbitrary and unreasonable."

The New Element

That which is new is the legislation which is being enacted in a growing number of states, starting with Hawaii in 1961, which accepts direct state responsibility for certain planning and land-use control activities which were previously left to local governments. It appears to be only a matter of time before federal legislation will be enacted to provide additional muscle in dealing with land development activities which are now not simply of local interest and concern but which are often of such a scale and have a potential impact that makes them of state, and even national, concern.

This mounting volume of new legislation attests to the growing appreciation of the need for a well designed package of land use controls. New also are the efforts to use these controls to accomplish a broader range of public objectives than was formerly the case. Land use controls, for example, are no substitute for the more direct measures used in efforts to control and reduce air and water pollution, but sometimes they may be useful additional tools. Traditional use of such controls has been confined to situations where the protection of health, safety, morals, and the public welfare have been endangered. Control of the use of private land has also been extended to preserve visual harmony and aesthetic values as this application of land use controls has been upheld by the courts, including the Supreme Court of the United States. Such uses of controls would not have been accepted 40 years ago but this is a period of change. Some students of the subject have gone so far as to declare that a "quiet revolution" in land use control is underway.

The Need for a Plan or Design

The revolution is one which seeks to offset entropy. Entropy is the word used to describe the tendency of things to "run down," as a spring-driven clock runs down. It is also the measure of randomness, disorder, or chaos in a system, characteristic of a system which lacks intelligence, a guiding purpose, a sense of direction or control. Such a system is similar to that in which the driver of a moving automobile suddenly loses consciousness. The weight of his foot upon the gasoline pedal may keep the car operating for a time, but as long as it is not under conscious direction, it will careen out of control.

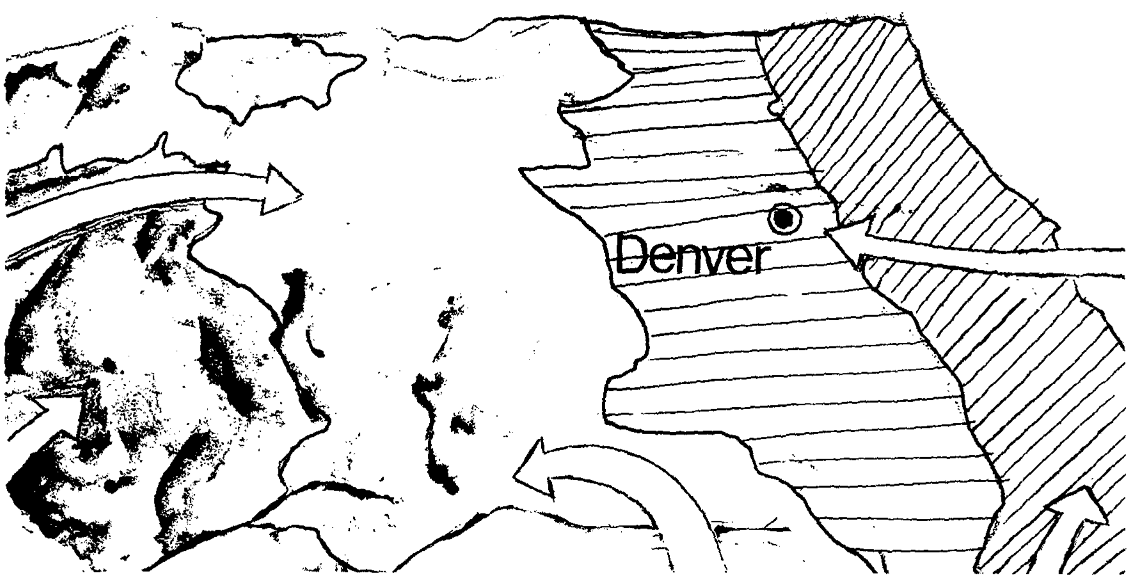
Neither tools nor resources have value unless intelligent use is made of them. Land use controls are the conscious and deliberate efforts to eliminate confusion and chaos by establishing an intelligent, systematic and orderly pattern of land use activity. Land use controls are a means of achieving a workable and acceptable pattern or design of land uses.

In urban areas space is usually limited and costly. Even beyond urban areas, space must be provided for a variety of activities, some of which may be nuisances if improperly located. For some activities the locational requirements may be quite specific. Finding necessary space for the desired activities within the limited area, without destroying other values, calls for design and planning skills of high order. To protect the integrity of the design calls for the discipline of land use controls. The controls, however, come after, rather than before, the design. If not, the land pattern in many respects, is likely to be a random, disorderly, and, ironically, uncontrolled pattern, *even with the controls*.

The problems of pollution, congestion and environmental degradation are often directly or indirectly related to the lack of a proper design for the development of land resources and sites. The full impact of this omission, given the rapidity of change in land use today, may not be appreciated until it is too late to apply the measures needed to protect the public interest. Even when there is awareness of these changes and at least a partial appreciation of the undesirable consequences that may result, there is too often a reluctance on the part of the community to take an active role in shaping its land use patterns because private property is involved. Land uses must yield, where necessary, to a pattern which serves the public interest if there is to be order in this realm as well. This is what the new legislation is saying.

Dealing with Change

Change, particularly rapid change, can be disruptive, especially if it has not been anticipated and preparations have not been made for it. So it is when the inroads of urbanization are felt in a community which has somehow considered itself immune to change. A not uncommon reaction to such a situation is to call for the zoning of land. The desire is to slow, if not to halt, the processes of change in the community. It is a conservative response in that it seeks to preserve that which exists. It is also a cautious



and defensive response, and one which can do little more for the community than to delay the forces of change, because the pressures for change are usually persistent and gather strength with time.

A more positive approach begins with a recognition of the fact that while change of some sort may be inevitable, it is not necessary to take a fatalistic point of view toward it. The community and state which prepare for change, and whose people are willing to make a common effort in dealing with it, can shape and guide change and use it to their advantage. This is difficult where the planning process is not understood and there is extreme caution. People who are reluctant to give an objective hearing to reasonable alternatives, or who are unwilling to re-examine the traditional solutions to problems in light of changing conditions, may find themselves ill-equipped to deal with problems affecting their welfare.

Land use controls are of little real value to a community unless they are related to a set of explicit objectives which have wide community acceptance. Once established, the goals and the related policy statements and plan provide the basis for determining what the land use controls will seek to accomplish and the types of controls appropriate for the objectives sought.

A community seeking to improve the well-being of its residents will be concerned with a variety of objectives. It will seek to minimize health and safety hazards. It will strive to meet the desires of residents for public services of the highest quality that can be afforded. It will be concerned with the design of the community in terms of location relationships — places of residence relative to places of work, to shopping and general services, to schools, parks and other community facilities. If the location of such activities is poorly conceived or developed without relation to each other, movement within the community may be inefficient and unnecessarily costly, public services may be overtaxed in some areas and under utilized in others, and the usefulness of certain sites may be greatly reduced.

The goals of the community require the cooperation and the coordination of actions of individual persons in the use they make of their properties. Without public intervention, differences in land values, based primarily on the factor of location, tend to shape or design the community and the use of land, but the results in practice are sometimes quite far from what could be expected theoretically. For this reason, a community will usually find it necessary to impose land use controls to achieve community objectives.

Controls Available to the Private Sector

Private land use controls may fit into the picture, and indeed they have on numerous occasions. But because they are imposed for private objectives, they are likely to be much more limited in scope, or, even contrary to what may be the interest of the community at large. Then, because of their application to a limited space rather than to all similar land in the community, these measures are not sufficient to achieve community goals. However, certain private land use controls can be used effectively by the public for public purposes as the following examples indicate.

The most frequently imposed private land use controls are the conditions which a landlord imposes on a renter in a lease. They are primarily private in character, reflecting the property owner's major concern and efforts to protect the value of his property. While the lease requirements may yield benefits to others in the neighborhood, this is not the primary concern of the landlord. In fact, just the opposite could happen. The property might be used in such a way that while both landlord and tenant would benefit, others in the community would suffer losses of some kind.

When ownership of land changes there is an opportunity to impose special conditions concerning the use of the land. Sometimes the imposition of such restrictions reduces the number of buyers interested in the property which could depress the price of the property. This does not appear to be a matter of major concern in many instances judging from the frequency with which such restrictions are imposed. The deed restrictions imposed on residential lots may require a minimum area of floor space in the house built on the property. They may restrict the height of certain houses to afford a view to houses built on other lots. They may require that the design of the house be approved or that construction begin on the property within a specified period of time. Such restrictions are enforceable through the courts. In Houston, Texas, where public land use controls are not used, restrictive covenants placed on the property by the developer have been used extensively.

Deeds which convey a gift of land often contain restrictions on the use of the land which are enforced by making the transaction a conditional gift. If the recipient of the gift does not honor the restrictions, the land will revert to the donor, his heirs or his assigns.

Other private restrictions take the form of an agreement among land owners in which each voluntarily gives up certain rights on condition that everyone who is party to the agreement also accepts the same restriction. This type of private control is the land use covenant. As previously mentioned, it is widely used in lieu of zoning in Houston, Texas. It has been most widely used in the United States as a device to prevent the sale of property in a given area to persons of a particular race, nationality, or religion. The courts will no longer honor covenants designed to foster such discrimination.

Public Use of "Private" Controls

These same land use controls can sometimes be used for public purposes. All levels of government in the United States own land, but there are relatively few opportunities to use land ownership to shape community development unless undeveloped land is acquired with the express purpose of reselling it after restrictions have been imposed on it. The values to be gained from open space reservations in and around urban areas are being recognized by a growing numbers of communities. Where land is needed for park and recreation purposes, it may be purchased. In other situations, if there is no need for public access to these lands, it is sufficient that they remain in agriculture or some similar extensive use. To guarantee that the area is not developed, however, it may be necessary to buy the property, or at least to buy the development rights. If the community has the funds to invest in land, and a potential need for the land in the future, it may elect to buy the land and to lease it to someone for a use compatible with the open space concept. Or, once the land has been purchased, it may be resold with deed restrictions which limit the uses which may be made of the property by the new owner and all succeeding owners.

The federal urban renewal program enables a city to completely change the land use in a deteriorating portion of the city. Condemnation proceedings are used, if necessary, to acquire the land. The unusable structures are razed and the cleared sites are offered for sale but with conditions attached concerning the reconstruction of the area. The logical next step would be to permit cities to acquire large blocks of undeveloped land on their borders to be held for eventual resale, subject to certain restrictions. This would permit the city to shape its own development and determine the extent, type, and timing of the development to serve its interests.

Thus, just as the private citizen may take advantage of his ownership of land to achieve certain objectives, communities could do the same, but few are in position to fund the purchase of extensive holdings of land necessary to shape the development of the community. In Vail, Colorado, Reston, Virginia, Columbia, Maryland, and the other "new towns," most of the developable land is owned or controlled by the firm which is planning and carrying out the development. While this firm and the incorporated community are not the same, the goals of each are likely to be quite similar. Because land ownership is concentrated in this manner, there tend to be few externalities from the operation, either positive or negative. That is, any benefits or costs which arise as a result of the firm's land use planning decisions tend to be enjoyed or borne by the firm rather than other parties. There is an incentive, lacking in other situations, to devise plans which tend to promote the overall interest of the community.

Public ownership of land has been the primary means of achieving preservation of certain environmental values as well as forest resources. However, public ownership does not automatically determine how the resources on such land will be managed. There have been major controversies concerning the use to be made of these resources on the federal lands, and these controversies continue.

Not to be forgotten are the state, county, school, and municipal lands used for a variety of purposes such as parks, preserves, forest products, municipal watersheds, grazing, etc. In the aggregate they account for a substantial acreage of land. While municipalities are not likely to make extensive use of public ownership as a tool for controlling urban uses of land, they will most likely continue to purchase and hold land in order to protect certain environmental values and to obtain open space for buffering purposes.

The Uniquely "Public" Controls

Public purchase of undeveloped land or of just the development rights, with the object of reselling the property at a later date with appropriate deed restrictions, is only one of several options open to local and state governments. The police powers, the spending powers, and the taxing powers of governments open other alternatives. While the police powers are often relied upon almost to the exclusion of the others, a combination of all these powers, including public purchases of land or rights in land, would offer a great degree of flexibility and in most instances would make the most effective control package.

Nearly every city of any size uses zoning in an effort to maintain a pattern of land uses which will be compatible, which will contribute to easier and more efficient internal movement of people and things, and which will minimize hazards to life, health and property. Building codes and subdivision regulations are also part of the police powers package. The so-called official map, which indicates where in the undeveloped areas land must be dedicated for major streets, rounds out the package.

The new emphasis on land use controls relates primarily to the relatively open areas beyond the urban centers where the need for planning and controlled development used to seem unnecessary. Suddenly it has become painfully obvious how vulnerable these areas are to undesirable changes unless there are plans for their orderly use and development and the necessary controls to accomplish these objectives. Often the authority to plan and to use the necessary police powers was available to county government, but the need was not recognized in the planning process and the land use controls were not understood, therefore nothing was done. Hence, state governments have begun to move into the vacuum, first to alert the counties to the situation and its probable consequences, and then to force action, if necessary, as well as to provide financial and technical assistance to the counties to accomplish the planning and controls.

The authority to tax is a powerful one as recognized in the old observation that "the power to tax is the power to destroy." Property tax assessment policy can also be a tool for accomplishing land use planning objectives. The argument against taxing the improvements on land but taxing the value of the land itself was one feature of the tax reform proposal promoted by Henry George nearly a century ago. It continues to be recognized as a factor which hinders the renewal of urban structures and favors the destruction of other buildings in favor of parking lots in downtown areas. The converse effect of property taxes in other circumstances is to force the conversion of land from agricultural purposes to development. This change in land use, while sometimes in the public interest, may not be so in all instances. Legislation which gives preferential tax treatment to bona fide agricultural and similar extensive open space types of use has been attempted in some states, but there are many difficulties involved. The spending or investment powers of government provide another indirect control of land use. The conversion of land from a relatively undeveloped to developed state requires large investments for auxiliary services. Many of these services are provided by a unit of local government or a special district. Truly large scale private developments may have sufficient capital to invest in the necessary water and sewage facilities. Highways, schools, however, remain largely a public responsibility. The ability and willingness of local governments to control the location, extent and timing of public investment in such facilities and to coordinate these matters with the plan for development and the zoning plan, is often vital to the effectiveness of the direct land use controls. Such coordination among organizational units of local governments does not always exist. In other situations, the decisions relative to the extension of these services is scattered among several jurisdictions which makes such coordination difficult at best and impossible in other instances.

The community which permits things to happen in a random fashion, with no forethought given to the eventual interaction of the ten, one hundred, or one thousand independent, seemingly unrelated decisions, soon finds chaos where there was once order. Traffic is snarled and congested. Schools are hopelessly overcrowded. Public utilities are unable to meet peak demands. Crises call for solutions and no one likes the measures taken, but it is all shrugged off as "progress," as if the new conditions were somehow preferable to those of the past.

Land use controls are part of the answer to the problem, but they are only a part of it. They make sense only as they serve to accomplish the purposes of the community, however these purposes may be defined, and as they make it possible for the community to carry out the plan to reach these goals.

Human Population

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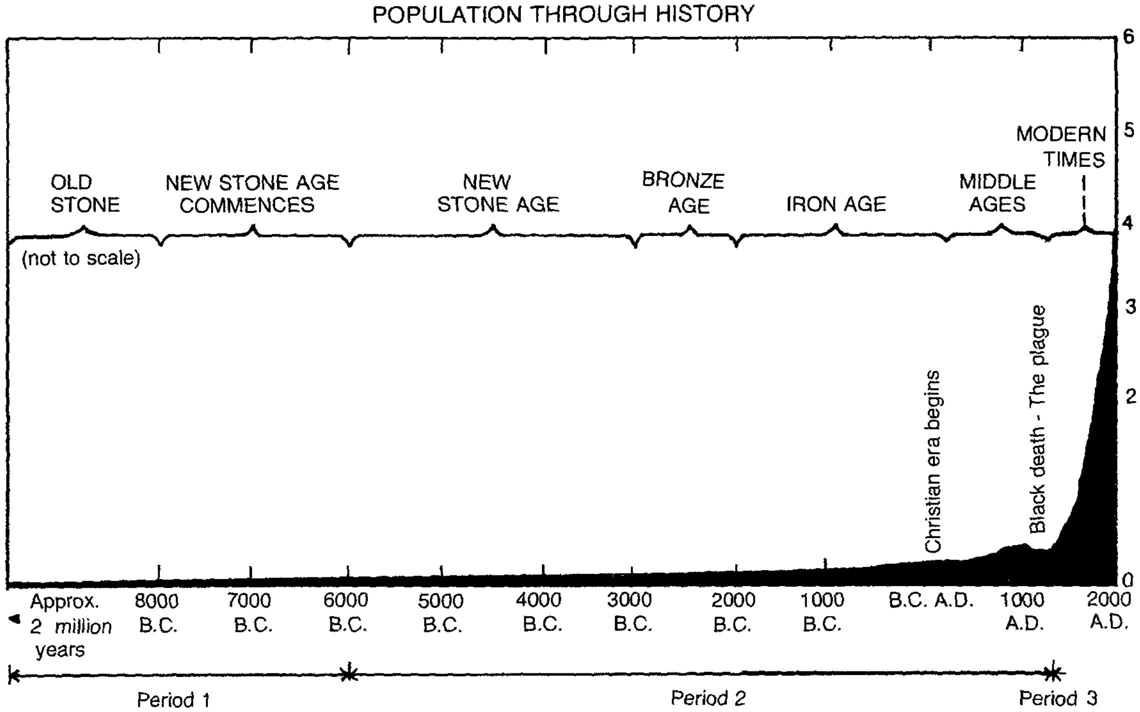
As far as we know, man has been living on this planet for about one million years. Nevertheless, only since the end of World War II has any great amount of attention been devoted to the so-called "population problem." Since that time, a veritable flood of information has poured out of the media, inundating the general public with evidence about the "population explosion" and its consequences. Much of the material, though creating an enormous interest in the "problem," has generally failed to develop an understanding of the demographic factors responsible for population trends.[1] As a consequence, the ensuing debate has been responsible for creating more "heat than light," leaving much of the public somewhat in the dark with respect to population growth or decline.

[1] *Demography is defined by Hauser and Duncan (1959) as "the study of the size, territorial distribution, and composition of population, changes therein, and the components of such changes, which may be identified as natality, mortality, territorial movement (migration), and social mobility (change of status).*

The facts of human population change are deceptively simple, the basic components being births, deaths, and migration. Therefore, in explaining a change in the population of an area one subtracts the deaths from the births to get "natural increase," and then adds "net migration," which is obtained by subtracting emigrants from immigrants (out-migrants from in-migrants). For example: $P_2 = P_1 + (B - D) + \text{Net Migration}$. Thus the population at a given time (P_2) is equal to the population at an earlier time (P_1), plus the births (B) occurring between the two points in time, minus the deaths (D) taking place in the same period of time, plus net migration. The result may be positive or negative. When the formula is used to determine the earth's population the migration factor is eliminated. However, if the area in question includes less than the whole world then migration must always be taken into account. Even though absolute numbers are the raw materials of population analysis, there are times when a person may wish to summarize some data or express some relation between two or more numbers. On those occasions he makes use

POPULATION THROUGH HISTORY



of relative numbers such as rates and ratios.[2] These measures more clearly depict processes of fertility and population change than do the actual numbers of births or the absolute increase in people. They do not depend on the magnitude of two numbers, but rather on the relationship between the two numbers. For instance, a comparison of the fertility of Colorado and New York using absolute numbers would only show that New York State had more births in 1970 than did Colorado, about 315,000 and 42,900 births respectively. If, however, we relate the number of births to the total population of each state, we see that Coloradó had a higher birth rate in 1970 — 19.4 to New York's 17.5.[3] In order to determine how rapidly a population is increasing, we obtain a death rate and subtact it from the birth rate; the result is called a "rate of natural increase," which is a rough approximation of the speed with which a population increases. I say rough because the measure does not take into consideration the net migration rate and therefore it may be larger or smaller than the actual "rate of increase," which does include net migration. However, due to restrictions in the migrations of people throughout the world, the two measures will be equivalent for many occasions. Thus, it is more advantageous to use the "rate of natural increase" because it is so much more simple to calculate.

As mentioned by Thompson and Lewis[4] "calculating a country's rate of natural increase helps us, for example, to find out how long it will take a country to reach any given size if the rates continue at the same level." The following table gives the approximate number of years required for various countries to double their populations, assuming that the rate will remain constant.

Table 1. Number of years required to double a population under specific rates of natural increase, selected countries, 1971.*

Country	Annual rate of Population Growth (percent)	Number of Years to Double Population
Costa Rica	3.8	19
Colombia	3.4	21
Ghana	3.0	24
Laos	2.5	28
WORLD	2.0	35
Argentina	1.5	47
United States	1.1	63
Spain	1.0	70
Sweden	0.5	140

**Source: Population Reference Bureau, Inc., 1971 World Population Data Sheet, Revised Edition, Washington, D. C., August, 1971.*

A very small difference in the rate of natural increase can have a decided effect on the time it takes a population to double. This is because populations grow according to the principle of "compound interest;" each year's growth is added to the total population to which the rate is applied so that the number it is applied to steadily gets larger and larger. It must be clear by now that the figures in the table, and many statements about future populations, assume that the growth rates will remain constant through time. This assumption is a fallacy, since history shows us that no country is likely to maintain its present rate of growth over any considerable period of time. Fluctuations in either the birth or death rates do have a decided impact on a country's growth.

Since human reproduction and death are biological phenomena, it would seem that human population growth must also be a simple biological event. That is not the case. The maximum capacity to reproduce in human populations, though not determined, is probably high;

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[2] *See George W. Barclay,* Techniques of Population Analysis *(New York: John Wiley & Sons, Inc., 1958), for a more comprehensive discussion of the use of rates and ratios in demographic analysis.*

[3] *The birth rate, generally called the crude birth rate, is calculated by dividing the total number of births in a given year by the total midyear population of the area. This gives us the number of births per person for that year. We then multiply the resulting ratio by 1000 so that it will be easier to read. The resulting figure, since it relates to a unit of time (one year) is called a rate.*

[4] *Thompson, Warren S. and David T. Lewis,* Population Problems, *5th Ed.(New York: McGraw-Hill Book Company. 1965).*

yet there is no evidence to indicate that any society has ever approached its maximum.[5] It seems that among all societies, social-structural and cultural factors take precedence over the biological. As Kingsley Davis (1949:552) has said, "fertility, mortality and migration are all to a great extent socially determining." In fact, most of the evidence indicates that, everywhere and at all times, human beings have exercised social controls over their fertility. In addition, mortality and migration, the other two demographic factors, are influenced to a great extent by the cultural practices and economic conditions prevailing in each society. It is no surprise, therefore, to find that for most of man's existence on this earth, estimated to range for about 600 thousand to 2 million years, his average rate of population growth was extremely slow, "probably on the order of .000005 per cent per year."[6]

During this time, man was learning how to control his environment, thus improving his living conditions and starting a chain of events that had decided effects on population growth which climaxed in the present 2 percent per year rate of increase for the world. This rate of growth, if it continues, will result in a doubling of the world's population by the year 2000, from about 3.7 billion in 1972 to more than 7.0 billion. This is an increase which, when compared to the past history of population growth, might truly be called "explosive," and it is no suprise that the phrase "population explosion" was coined to describe it.

When presented with this information, a question arises: what factors were responsible for the increase in the growth rate of the world's population? In pursuing the answers, one must attempt to trace the history of the increase in man's numbers since he first came upon the earth, always taking into consideration that almost nothing is known about man's numbers prior to the year 1650. Attempts have been made to estimate the number of people who have lived on this planet before 1650, but these attempts have been based on extremely scanty information, on inference from studies of primitive and developing societies, and on much conjecture. The consensus seems to be that for the first half million years or more of man's existence on earth his numbers were very sparse. During that time, he relied primarily on hunting and food gathering for his subsistence; as a consequence the population probably never exceeded 10 million. Around 6000 B. C. man developed a sedentary agriculture, domesticated animals, and began settling in villages. These changes in life style and agricultural techniques helped, to some extent, to eliminate fluctuations in subsistence and insured a more adequate and stable stock of food. Man was learning to utilize his environment more efficiently, and thus was able to feed more and more people. Nevertheless, the population continued to grow very slowly, achieving a total of 250 million by the time of Christ.

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[5] *The word used to indicate the physical capacity to reproduce is* fecundity, *while actual reproduction is called* fertility; *therefore, the number of children that a woman can produce is fecundity, while the actual number that she does have is fertility.*

[6] *Ralph Thomlinson,* Population Dynamics: Causes and Consequences of World Demographic Change, *New York: Random House. 1965.*

The growth of human numbers was not a steady, continuous, upward movement; there were great fluctuations. Populations grew rapidly during periods of peace and plenty, and declined when food became scarce or when wars and diseases decimated large numbers of people. The consequences of these uncertain conditions were wide swings in the death rates — from 35 to 45 per 1,000 population. The birth rates did not fluctuate as much and remained very high, usually higher than the death rates, although Hartley[7] reports that they probably never reached what has been estimated to be the upper limits of human fecundity (about 70 births per 1,000 population). Apparently, man, through such cultural practices as abortion, female infanticide, delayed marriages, sex taboos, prolonged lactation, and contraception, consciously and unconsciously attempted to adjust his numbers to his food supply. Therefore, it took mankind more than fifteen hundred years to double and to reach the one-half billion mark by the year 1960.

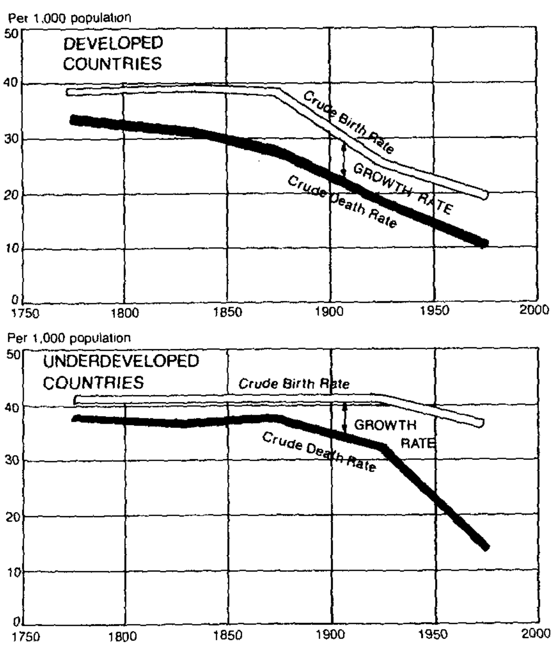

Figure 1. Estimated birth and death rates, 1770 to 1970, in both developed and underdeveloped countries.

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[7] *Shirley Foster Hartley,* Population: Quantity vs Quality, *Englewood Cliffs, New Jersey: Prentice-Hall Inc. 1972.*

After that time, with improvements in methods of agricultural production and its distribution, there occurred a quickening of human population growth. As before, the increase was not a continuous year-by-year climb. Natural and man-made disasters such as wars, famines, and disease epidemics were often prevalent enough to offset the gains made by the increasing food supply. Even so, the advances in agricultural production that took place in Western Europe around the year 1700 were truly striking. In addition to this "agricultural revolution," great strides were also made in improving transportation, industry, sanitation and health. Consequently, death rates in that part of the world were slowly and steadily going down, and this, combined with the continued high birth rates, resulted in an acceleration in the growth rate of the population in Western Europe and the areas of European settlement, with the exception of Latin America. Since the principal beneficiaries of this technological and scientific revolution were the countries of the Western world, there was probably little significant increase in popualtion in the other areas of the world, but nonetheless, by the year 1850 it is estimated that the world had accumulated its first billion people.

It did not take long, only 80 years after 1850, for the world to add an additional billion people. New advances in science and technology helped to further reduce the death rates and to increase life expectancy in the West. Attitudes toward the size of families were undergoing modifications, however, and efforts were being made to control births. These efforts culminated in some reduction in fertility and in the knowledge that man could have some measure of control over the number of children he brought into the world. At first the reduction in fertility had little effect on the growth rates, since the death rates were going down at a more rapid pace. Later, during the first half of the twentieth century, however, the rate of growth in the West began to slow down. Mortality rates had reached a level low enough so that any further reduction would be very small, while birth rates began to decline at a faster rate.

Some of the new developments in science and technology were diffused to other European and to some non-European countries, causing living conditions to improve and death rates to go down, thereby creating a situation of high birth rates and declining mortality — a combination responsible for a rapid take-off in population growth. Meanwhile, the rest of the world had not developed to the point where people were able to take advantage of this new knowledge. Consequently, they continued to have both high birth rates and high death rates, with little or no change in the rate of natural increase.

By 1930 the population of the world could be classified into three broad growth types corresponding to the two main combinations of birth and death rates. In the West the rates of natural increase were rather low due to low birth and death rates, and changes in fertility became the major determinants in population growth. Among other European and some non-European countries, rapidly falling mortality rates and high, but declining, birth rates were responsible for sharp increases in population. The less developed areas, such as Latin America, Asia and Africa, were at the mercy of high but fluctuating mortality rates and high birth rates so that growth was dependent primarily upon the year by year changes in death rates. About 50 percent of the world's people were in a position where reductions in mortality were resulting in a rapid increase in their numbers. As stated by Thompson and Lewis, "the world stage was being set for momentous changes in population growth in the near future — ' the population explosion."

This "population explosion" took place after World War II, mainly in the underdeveloped regions of the globe. The sharp increases in the growth rates of these regions were due to the very precipitous drop in mortality. Declines that had taken many of the more advanced countries almost 100 years to achieve were realized practically overnight by the less developed societies. According to Thompson and Lewis, Ceylon's death rate dropped from about 21.7 in 1945 to 9.1 by 1959, and Formosa's from 20.1 in 1945 to 6.9 by 1960.

Assuming birth rates of about 27.9 and 32.6 per 1,000 population, respectively, their rates of natural increase were about 2.8 and 3.3 percent per year — rates that would double the population in about 25 and 21 years, respectively. These spectacular declines in mortality were brought about by the widespread use of modern medical discoveries

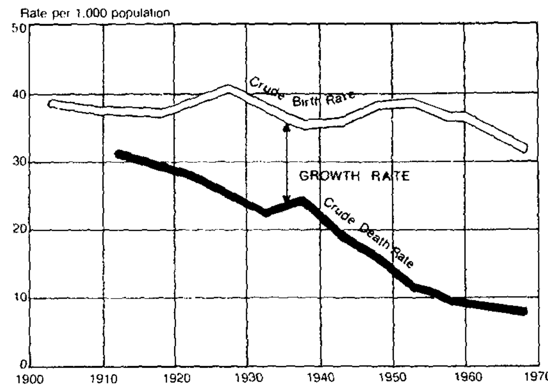

Figure 2. Abrupt drop in mortality in underdeveloped countries such as Ceylon has resulted in a much greater growth than in the developed world.

and technologies such as sulfa drugs, antibiotics, DDT, and immunization. No longer did the underdeveloped countries have to go through the long process of achieving environmental sanitation and personal hygiene to reduce mortality rates. All they had to do was organize health delivery systems capable of reaching the masses of the population. In so doing, they were able to cure huge numbers of people of infections already contracted and to immunize them against the many infectious diseases which take enormous tolls of human life. The more advanced societies, however, had decades before they achieved fairly low death rates, and it was difficult to reduce them further. Their upsurge in population growth after World War II was in response to an increase in fertility. As a result, the rate of growth accelerated after 1930, and by 1960 the world contained an additional billion people. The humans on the face of the earth now numbered three billion.

After 1960 the world seemed poised for some further rapid gains in population. Birth rates in the more technologically advanced societies had reversed themselves and resumed their long term downward trends, once again assuming their low rates of natural increase. However among the people of the rest of the world fertility remained high, and mortality, previously greatly reduced, was lowered further as modern medicine spread to more and more people. By 1970 growth rates in many of these developing countries remained at high levels, ranging from about 2 to 3.4 percent per year. The high growth rates of these countries were primarily responsible for the rapid increase of population after

1960. It will take less time, (only about 15 years), to add another billion people, and, unless strenuous efforts are made to reduce fertility, still less time to add the fifth billion.

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Wildlife Populations

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Environmental change is the name of the game for wildlife. In past geologic ages the changes were relatively slow. Wildlife adapted genetically, gradually, to the new conditions. Even then many species became extinct, although usually by changing into a new species rather than by the sudden death of a dwindling population. But now the pace has accelerated, spurred by the currently dominant animal, man, who keeps devising powerful new tools to modify environments rapidly and drastically. Genetic adaptation cannot keep up with this new pace. Man values the wildlife he is losing and so he worries about its fate.

Current Status

Actually one should recognize encouraging signs, before a recital of the environmental problems of wildlife set too negative a note. There are many examples of modern man's preservation and successful management of wildlife. In many cases we have more wildlife today than ever. Fifty years of protection brought deer in Colorado to levels in 1963 that far exceeded those described by early explorers. Through establishment of nesting flocks, geese increased in Northern Colorado to numbers which astound the oldtimers. The sea otter and the Alaska fur seals of the Pacific coast were brought from the brink of extinction (after Russian fur traders had nearly eliminated them in the 18th and 19th centuries) to sufficient abundance for harvest again in recent years.

But we compare present wildlife populations to what we imagine they could be, and to what we want for man's use and enjoyment. Therefore any suspected environmental change raises questions concerning its effect on wildlife and its habitat.

Problems

The following list is not organized in any particular way or in order of importance; I have listed the problems just as they occurred to me. Perhaps in this way the diversity of problems will be apparent. The problems are general ones, and care must be used in determining whether they truly exist for any given species in a specified locality.

Pesticides

Most living organisms (and the dead ones!) on earth now contain pesticides such as DDT. One serious effect appears in the peregrine falcon, which is high on the food chain and thus biologically concentrates DDT from all the food steps below it. A major consequence is the thinning of egg shells of these birds, which results in reduced hatchability. Some populations have produced few or no young for several years. This may spell doom for large segments of the population of falcons and similar species unless the use of DDT declines and until the remnants of DDT and similar pesticides disappear from active portions of ecosystems.[1]

Water pollution

Toxic chemicals such as arsenites, phenols, and cyanides; raw sewage and other decomposing organic materials which use up oxygen; and rising water temperatures from power production and industrial effluents; all are lethal to various species of fish. The most preferred sport fish, such as trout and small mouth bass, are often the most susceptible. Moderate amounts and certain types of pollution may reduce populations to lower levels, and at its worst can kill all fish. "Eutrophication" means that waters have been made too rich from nutrients added in the form of detergents. Fish die because the too-rich waters remove oxygen.[2]

Siltation

Sediment in streams covers spawning areas and hatching eggs and reduces the food supply of fish. It may fill in the pools which provide protection and smooth the riffles which produce fish food. Excessive silt results from poor practices of land use, mining activities, or cultivation of steep hills which remove the protective veg-

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[1] *Snow, Carol. "American Peregrine Falcon." Report No. 1, Habitat Mgmt. Series, Bur. Land Mgmt., Portland, Ore. 1972.*

[2] Conservation News. *Published by the National Wildlife Federation, Washington, D.C. A periodical wildlife and general conservation news sheet which gives current information on environmental issues. For example, see issues of January 1, 1973 (dams), January 15, 1973 (predators, pollution), and February 1, 1973 (decrease of wildlife habitat).*

etative cover. Silt also comes from logging roads, highway construction, and urban housing developments which expose raw soil.[3]

Dams

High dams interfere with spawning runs, especially for migratory species such as salmon. Even if fish ladders are provided, the extra energy required to negotiate a series of dams such as those on the Columbia River may be more than the salmon can afford. Some fish may not have enough energy left to reach their home stream to spawn. Another serious problem resulting from a succession of dams on the same river is a supersaturation of the water with nitrogen and the consequent mortality of fish. Reservoirs impounded by the dams may flood wildlife habitat which is irreplaceable, because valley vegetative types and winter deer range may be found only in the flooded valleys. They also eliminate the former stream fishing, which is rapidly becoming more of a rarity.[4]

Ditches

Large concrete-lined ditches which carry water at high velocities from reservoirs are death traps for wildlife. They are especially serious when they intersect normal routes of movement or migration of big game. Fencing and some types of bridges may reduce the direct death loss, but the loss of the availability of habitat due to restricted movement behind the fences may result in even smaller wildlife populations.

Weather modification

Increased snowfall from winter-seeded clouds may force deer and elk in western mountains to lower elevations and thus reduce their area of winter range. The result may be lower population. On the other hand, increased moisture from this source, and from rainmaking, may produce more forage for the benefit of wildlife. Hail suppression could reduce a mortality factor for young game birds in spring.

Habitat conversion

Sagebrush spraying, pinon-juniper chaining, marsh drainage, strip mining, and cutting of cottonwoods in plains river-bottoms are examples of practices that may destroy the essential environment of sage grouse, mule deer, ducks, and fox squirrels. However, these same practices, if done properly, can *improve* the habitat for wildlife by increasing food. Proposed large-scale strip-mining of oil shale in the Great Basin is a current example of disruption of ecosystems which may result in a major loss of deer range. Possibilities are infinite, so all of them cannot be listed, but it is obvious that any major environmental change, such as those listed, or changes from dryland to irrigated agriculture, or from farmland to subdivision, drastically changes the wildlife habitat and thus the wildlife present in the area. Sometimes a change from one species to another results, for example from prairie chickens to pheasants in the case of grassland to irrigated agriculture. At other times complete elimination of all wildlife occurs, as is the case in a new subdivision.

Offshore pollution

Dumping of wastes in the ocean has rendered some tidal flats, estuaries, and areas of the continental shelf no longer usable by shellfish and water birds. In their natural state, these coastal areas often are the most biologically productive of any ecosystem.

Overexploitation

Biologists have often assumed that when man harvests any wildlife crop he takes something that would die anyway due to predation, disease, or starvation, and that hunting has simply *replaced* these other sources of mortality. But biologists are now beginning to recognize that hunting may represent an *additive* mortality. In cases where the sources of natural mortality continue to act just as they did before hunting, a reduction in the wildlife population can occur. This may account for declines in the populations of salmon, whales, deer, and waterfowl. In most cases, however, sport hunting is carefully regulated and legal hunting is probably

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[3] *U.S. Soil Conservation Service. "Sediment - It's Filling Harbors, Lakes and Roadside Ditches." USDA-SCS Ag. Info. Bull. No. 325, Supt. Doc., Wash., D.C. 1967.*

[4] *Reed, Nathaniel P. "Environmental Concern and Wildlife - A Humane Approach." Address to Ocober 1972 meeting of the American Humane Association. 1972.*

not threatening the extinction of any game species in America today.

Rare and endangered species

Some wildlife are at the brink of extinction because they are so few in numbers. For example, the entire wild population of the whooping crane numbered approximately 50 birds in 1972, and there had been as few as 15 within the previous 20 years. A sudden catastrophe or a continual gradual decline would destroy the species. Of course many species have become extinct, without the influence of man, in geologic time. Most disappeared because they evolved into another species, rather than through catastrophic death of the last remnants of the population. However, today habitat change by man has often caused endangering of species. Man should pay special heed to the wildlife whose existence is threatened by his activities or his alteration of the habitat.

Oil

Leakage from oil tankers, offshore wells, and natural seeps spreads an oil film on water surfaces, saturates the feathers of water birds, and kills certain aquatic organisms. The birds can't fly; as a result, they die. A major disaster in 1968 resulted from leakage of an oil well off the coast of Santa Barbara, California. Potential problems exist in the huge quantities of oil that may be moved by the Alaska pipeline from sources in the Arctic. A major hazard would arise from the fleet of tankers which move the oil from the pipeline terminal down the Pacific coast. Huge floating collars to contain oil slicks have been devised for emergency control to localize areas of damage. However, only continued vigilance will minimize damage from oil spills.

"Clean" farming

Pressure for economic survival has led farmers to eliminate fencerows and plow up to roadsides, in order to cultivate all the usable crops possible from the fields. The result is less food and cover for wildlife.

Winter range

Migratory mule deer, elk, and other big game in western states are forced by winter snow to concentrate in limited areas of winter range at low elevation. These are exactly the areas that are increasingly being used for interstate highways, reservoirs, agriculture, and subdivisions. All of these human uses reduce the area available for wildlife winter range, which is already scarce; less habitat means that fewer animals can survive. Increasing food supply on remaining winter range by fertilization and planting is quite difficult and very expensive.

Self-destruction of habitat

Over-large populations of wildlife have resulted in some areas because of protection by man. Deer and elk then damage their own winter food supply because too many mouths seek the limited volume of forage, and vegetation, once destroyed, requires decades to recover. Wildlife managers are gradually bringing the few excessive populations of wildlife under control.

"Clean" forestry

Maximum production of timber requires that wasteful "wolf" trees, which are misshapen and use excessive space, and over-mature trees be removed. Yet these are precisely the trees which best provide food and cover for wildlife such as squirrels and grouse. Over-mature trees often contain rot, which provides nest cavitities for squirrels, raccoons, and wood ducks. The ivory-billed woodpecker, a rare and endangered species, requires the insect food that is produced only by recently-dead mature hardwoods.

Competition

Competition with domestic animals for a scarce food supply is always a potential problem for wildlife. For example, cattle, elk, and bighorn sheep all are grazers and in the past have seriously competed for forage in some areas. In the southwest U.S., hogs compete with wild turkeys, deer, and squirrels for acorns and other crops.

Disease

Diseases such as botulism and lead poisoning in waterfowl, hemorrhagic disease (blood infection) in deer, and pneumonia in bighorn sheep have reached serious proportions in local areas in the past. Disease is difficult to detect and control in wild populations. There is some evidence that disease may explain some unsolved declines of wildlife populations, such as those of some mule deer herds in the west in the early 1970's. Domestic animals have been sources of some diseases, such as sheep scabies and Newcastle disease, which are serious for wildlife.

High-speed transportation

Interstate highways and railroads through big game range are increasing hazards. Not only do high speed autos kill many animals each year, they interfere with normal movements of the herds. Expensive fences may reduce the loss, but also obstruct the movement. Of course the presence of wildlife is also dangerous to human safety in these cases. Collisions of aircraft with wildlife, either in the air or on the runway, cause occasional loss of human lives. Usually the wildlife population must yield where this hazard exists.

Stream channelization

Streams straightened and deepened for flood control and navigation result in less variation in the aquatic habitat. Fewer deep, quiet pools at bends in the stream are available for fish food production; thus fewer fish can be sustained. Such pools are also pleasant fishing spots; their removal results in a loss of production of days of recreation.

Predation

Wildlife biologists used to think that predators were insignificant in their effect on prey populations of wildlife. Today we believe that predators play an important role, and in some cases a major role, in the control of prey populations. The challenge is to maintain both prey and predator populations in proportions desired by the public in general, and by direct users of resources which are affected by predators. These direct users include the hunter as well as the livestock operator.

Causes

Specific and immediate causes of each of the problems described above usually are obvious. However, an immediate cause is simply the one at the end of a chain of causes and effects.

Many wildlife problems have the same basic cause – human population growth. Increasing numbers of people put more demand on the land area. They increase demand for competing resources such as timber, cause pollution, harvest more wildlife, and demand more wildlife. The many requirements of the burgeoning human population decrease the area available for wildlife habitat, and thus the wildlife populations, since more land is needed for subdivision, food production, industry, water storage reservoirs, and highways. More energy is needed from oil and coal. Obviously, more humans mean less wildlife.

Rising standards of living, the current affluence of America, and greater amounts of leisure time multiply the effect of human population. The demand for more luxury per person means that each new human displaces increasing numbers of wildlife because of his accelerated use of resources.

We must also recognize that many factors working together often cause the most serious environmental problems for wildlife. We should not look for any *one* overwhelming cause of wildlife decline, but for a number of interacting factors, each causing its share of the reduction. We must understand the complex system which is operating and then exert intelligent control of the *many* factors which produce each problem.

Solutions

"Stop doing whatever you are doing to our wildlife." This message to the polluter, the habitat changer, or the competing resource user *could* solve most of the problems we have listed. But this is not realistic. Each of us wants some of the other things too,–the food, the drinking water, the electric lights, and the house produced from competing resources. Concern, understanding, and involvement in resource decisions provide the solution to these problems. Following are some steps which will help protect wildlife, while retaining consideration of other resources too.

1. Develop rapport with resource managers in your state conservation departments, U.S. Forest Service, Soil Conservation Service, Bureau of Land Management, and other agencies. They have the expertise to answer questions or to suggest sources of information, and they can provide accurate information concerning specific local problems.

2. Be sure that a problem exists in a specific area. Learn as much as possible about the biological truth of a specific situation, of varying views and values, and of alternatives. Resource managers can help here. So can a study of the books referred to. Know the sources and credibility of information.

3. Insist that wildlife be seriously considered by all resource managers and decision makers as a part of any resource decision. Often the competing resource user and manager can find alternatives if forced to do so. These alternatives may take the form of protection, mitigation, or enhancement of wildlife habitat in relation to the activity in question.

4. Make personal resource views and value system known; recognize at the same time that the views and values of others must also be considered. Resource managers must be responsive to the will of *all* the public, but they must also have due regard for the needs and the wishes of the few, whether they be wilderness hikers, bighorn sheep hunters, or loggers.

5. Be persistent. Eternal effort is the price of good resource management. Don't let adversity mean defeat — concerted effort will achieve the greatest net social good for all.

Alternatives

We cannot maintain maximum wildlife populations on every square mile of land in numbers that the most avid wildlife lover dreams of. Even if it were possible, management from this perspective is not always beneficial to the wildlife populations.

One alternative is to develop methods to *pay* other users for a loss of their resource as a result of preferential treatment for wildlife. Of course when the shoe is on the other foot, and another resource user is changing the status quo in favor of his resource and against wildlife we should logically insist that he replace the wildlife or pay the wildlife user for the loss. In some cases we should demand that he not make any change from current status because we often cannot use his money, even if he gives it to us, to buy equivalent wildlife habitat — no more habitat is available.

Another alternative is to choose carefully the areas which are most critical for wildlife and protect them at all cost. These areas would vary from ones on which natural, perhaps even wilderness, conditions are maintained, to extremely intensively managed areas with high populations and high yields of wildlife. In the intensive areas wildlife populations could be artificially maintained to supply the desire of many humans for wildlife experiences. Our insistence on consideration of wildlife will have more credibility if we select carefully the areas which we will defend and do not try to maintain *all* areas for maximum wildlife production.

A final alternative which may minimize the over-exploitation problem, and some of the other concerns, too, is a shift from physical harvest to an emphasis on simply looking at wildlife, or to a careful selection of the kind of individual animal to be harvested. This would replace the present emphasis on "kill equals success" and the "hunter decision" type of hunting. The establishment of a goal of "maximum social benefits" from the wildlife resource may lead to revolutionary new ways of looking at what we presently consider environmental problems of wildlife.

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Outdoor Recreation and the Environment

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"Outdoor recreation" describes a multitude of activities engaged in by people in the out-of doors. One essential criterion of recreational activities in that they must be engaged in not from necessity, but for the satisfaction of the individual or individuals doing them. Thus a particular activity, if engaged in/from necessity, may be classified as work. The same activity, if engaged in for the personal satisfaction of the individual, may be called recreation. An example of this dichotomy would be commercial fishing versus sport fishing. From this may be derived a definition of outdoor recreation as those activities engaged in out-of-doors for the personal satisfaction of the individual.

If the assumption may be made that "everything is somehow related to everything else," then it may be safely assumed that any outdoor activity of man may have an impact upon the natural environment. There must be immediate recognition, however, that some of man's activities have much greater impact than others. Since the subject of this article is the environmental impact of outdoor recreation, the discussion will be restricted to this matter. Here, however, may be found wide variations. The environmental impact of a single stroller on an ocean beach is very small compared to that experienced by an overcrowded city park on a summer weekend.

What are the principal elements of recreational activities that affect natural environments or physical resources? Basically, there are three — people, equipment, and actions. The interaction of these three elements will determine the type and extent of environmental modification caused by outdoor recreation.

People

The primary element in the environmental impact of outdoor recreation is the ever-increasing numbers of people engaging in recreational activities out of doors. A combination of influences such as more discretionary time, more discretionary income, greater mobility, higher levels of education, better communication, changes in life style, and others, has provided both opportunity and demand for increased participation in outdoor recreation activities.

In 140 years the population of the United States grew from four million to 100+ million people. In only fifty years another 100+ million people were added. Current projections of the nation's population in the year 2000 range from 251 million to 300 million people. Most of the population of the United States engages in some form of outdoor recreation. The immense numbers of people engaging in activities — many on public areas such as parks, reservoirs, seashores, etc. — affect the environment of recreation areas just by their presence. There may be damage to plant life such as grass, trees and shrubs. There may be soil compaction, denudation, and erosion. There may be adverse effects upon water quality. There may be disruptions of wildlife populations. The more heavily used areas and areas with the most fragile ecosystems, such as seashores, deserts, and mountain alpine areas, demonstrate the greatest impact.

This is not to say that these large numbers of people congregate at recreation areas all at the same time. It is the constant pressure of use at the more popular or strategically located areas that creates detrimental environmental impact. The rejuvenatory powers of plant and animal life are tremendous if opportunity for regrowth is available.

Equipment

Man by himself, in sufficient numbers, will often have detrimental effects upon any given ecosystem. Unfortunately he does not come empty-handed — he brings with him tons of supplies and equipment designed to add to his comfort, pleasure, or excitement. Almost every outdoor recreation activity may be supplemented by or may require one or more types of specialized or multi-purpose equipment ranging from motor homes, travel trailers, all-terrain vehicles, yachts, airplanes — to mention a few of the larger — down to the toothbrush-minus-handle, dehydrated foods, and collapsible cooking gear which lighten the load of the backpacker.

Equipment aids the outdoor recreationist to enjoy the outdoors more times in more seasons, travel further, attain access to more recreation sites, stay longer, perform more efficiently and, hopefully, gain more enjoyment from his outdoor recreation activities. Yet many of his aids and gadgets create environmental hazards while allowing more access more often

to greater numbers of people for longer periods of time.

In addition to the use of resources and energy in the production and operation of the myriad types of recreational equipment, much of the equipment itself has capabilities for environmental impact. Recreational vehicles of all sorts, from airplanes to mini-bikes, require areas suitable for their use. Construction, development, and use of these areas affect or change local ecosystems in many ways. At present, it is often a value judgment as to whether these changes are beneficial, neutral, or harmful. It can be shown, however, that changes do result from the use of various types of recreational vehicles.

Other types of equipment increase the efficiency of man in his outdoor recreation pursuits. For example, improved firearms and hunting equipment make possible greater inroads upon wildlife populations. Many types of fishing equipment, such as specially designed fishing boats, depth-finders, etc., make possible more efficient harvests. It is quite possible that only the concepts of sportsmanship, the pressure of public opinion, more efficient methods of law enforcement, and a better understanding of game management practices have prevented the eradication of every game species in the country.

Actions

This points out the third — and possibly the most important — element involved in the environmental impact of outdoor recreation. This element is the actions of people engaged in outdoor recreational activities.

From custom, opportunity, or desire, people engage in mass recreation. They learn by example the customary types and forms of outdoor recreation. These activities become customary by preference or by providing personal satisfaction to some, leading to ultimate adoption by many. Skiing, both on snow and in water, is a classic example.

Other outdoor recreation activities are engaged in because of opportunity. People tend to develop recreational interests according to the resources, time, and money available to them. If neither time nor money is available for indulgence in a particular recreational activity, people will often substitute another which is within their capability. A park located close to a metropolitan area will receive more visitation than a remote wilderness area.

If it may be assumed that recreational activities are related to psychological needs and drives within the individual, a reason may be found for the apparent concerted desires of many people to perform the same activities at the same general time. The first bright days of spring provide impetus to be out-of-doors, resulting in crowded parks, trails and highways.

In addition to the tendency for people to congregate in limited recreation areas and perform the same activities in large numbers, thereby creating impact upon the ecosystem of these areas, there is an even more serious problem created by the manner in which they perform these activities. Detrimental environmental impact and even the destruction of resources can occur through carelessness, heedlessness, or lack of knowledge; it may be deliberate, as in acts of vandalism. Regardless of the cause, much damage results from people engaging in otherwise harmless recreational activities in a manner which intensifies their environmental impact.

Controls

In summary, the three primary elements in outdoor recreation creating hazards for the environment are: (1) large numbers of people; (2) their use of equipment, and; (3) the manner in which they engage in recreational activities. The conclusion may be reached that, in order to lessen the environmental impact caused by outdoor recreation, it will be necessary to institute and exercise some type of control over people and their recreational activities.

Controls have been attempted in the past primarily by the promulgation and enforcement of rules and regulations governing what people do and how they do it. The application of force is probably the least sophisticated method of controlling people and their activities, but it still is accepted by many as the simplest method by which to protect resources from recreationists. There are, however, alternative methods for obtaining decreased environmental impact from recreational activities. These may be used instead of, or in addition to, control by increased enactment and enforcement of laws and regulations.

Possibly the ideal method of controlling the actions of people is through education. Knowledge that their activities are detrimental to the environment and development of viable alternatives which satisfy their recreational drives in ways that are not environmentally hazardous should stimulate beneficial changes. This constitutes prevention rather than after-the-fact cure.

A more easily attainable alternative might be the provision of more recreational areas, located properly with regard to available suitable resources and the recreational needs of people. Better distribution could well diminish much of the unintentional environmental damage. Sufficient space to reduce overcrowding and allow less intensity of use would provide for less original environmental change and more opportunity for natural rejuvenation of flora and fauna. Adoption of this alternative would depend on availability of suitable sites, imaginative planning, and the financial capability to acquire and maintain the areas.

Other possibilities being examined and practiced at this time include the establishment of fee systems, establishment of reservation systems, elimination or strict control of vehicles, establishment of single-purpose areas (whether wilderness areas or off-road vehicle areas), separation of activities by time or space, rotation of activity sites (such as closing campsites to allow reseeding), more careful management and maintenance of intensive use areas, and many more. These are demonstrating varying degrees of success in diminishing or preventing environmental damage or maintaining stable ecosystems.

There is a very real danger that must be faced whenever overt systems of controls over recreational activities are instituted or intensified. Referring back to the definition of outdoor recreation in which it is stated that recreation activities are for the personal satisfaction of the individual, it is realized that the successful provision of recreation opportunities is judged in terms of satisfactory recreation experiences. Too intensive tightening of control systems designed to prevent environmental change may prevent the satisfaction of the drives which motivated the recreational activity in the first place. This could have the effect of alienating those most in need of recreational experiences and those most capable of supporting programs of environmental enhancement.

This is not to say that excessive environmental damage in outdoor recreation areas must be condoned. Rather, it says that the ability to use resources is a prerequisite for outdoor recreation. Administrators, planners and managers must be innovative, imaginative, and empathetic in their efforts to alleviate and mitigate as many harmful effects resulting from that use as possible.

Private Recreational Development

The impact of recreational activities upon the environment and the methods of preventing damage become more complicated in the case of private development and the use of privately-owned lands. (Specific cases in point encompass both landowners who lease their lands for recreational purposes and large recreation complexes, such as ski areas.) With the system of property rights under which land is possessed, it is possible for a private citizen or corporation to plan, develop, and operate recreational enterprises with little concern for effects upon the environment. Even if a development is constructed and operated in such a manner as to minimize immediate environmental impact upon the site, there is often little recognition or concern for secondary and tertiary impacts (such as housing and resource use by employees or by changed transportation requirements). Even less consideration is given to the impact on social and institutional structures resulting from changing patterns of resource use.

Housing projects oriented toward recreational activities produce many problems and environmental effects. The current desire for second homes in scenic areas with potential for many different types of recreational activities often places great stress upon ecosystems, both natural and social, that have little capacity to absorb increased human pressures. It is anticipated that, as transportation and communication systems improve, there will be even greater demand for housing of this type with more year-round occupancy.

It must be pointed out that these problems and effects are not unique to recreational developments. There is little apparent difference between the landowner who allows environmentally harmful recreation uses of his land and the landowner who overgrazes or engages in soil eroding farming practices. There is little apparent difference between the impacts and problems created by a ski development and those which accompany a new industrial plant. The underlying elements are the same — people, equipment, and activities.

Private recreation developments may be subject to control, as are individuals recreating on publicly owned areas. There is, however, a basic difference in the requirements for institution and maintenance of control mechanisms. Policies and regulations for public recreation areas may be formulated and enforced by a management agency; for private recreation developments they must be developed and implemented through social action or group decision-making. (There are many constraints upon this process, not the least of which is a national heritage of individual freedom.)

Conclusion

In conclusion, it appears that minimization of the environmental impact of recreational activities in both the public and private sectors depends upon formulation and use of a variety of controls. It is not possible to generalize that any one method or technique may be applied universally, as each situation is unique. It is necessary to research each site and situation to determine its unique qualities, and to plan, develop, and manage it accordingly.

Transportation and Environmental Problems

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Our nation's complex array of transportation systems is the circulatory system which literally carries the country's "life-blood" to the vital organs of family, culture, commerce, industry and public services which, taken together, characterize the United States of America. This circulatory system is no less important to the vitality of our country than the condition of veins, arteries and heart is to the vitality of a human life. Recognizing that it may be stretching the analogy, the pessimist may suggest that the United States is simultaneously approaching *minor* cases of hardening of the arteries, varicose veins, and coronary thrombosis. I emphasize *minor* because the patient is most certainly not going to die from those maladies, but it is equally certain that he is going to be most uncomfortable unless treatment is started immediately.

To examine our transportation system requires a look at automobiles, trucks, trains, airplanes, and now satellites and bicycle lanes, as well as a look at roads, highways, systems of track, navigable streams, and air corridors. It requires consideration of tariff regulations, interstate commerce, traffic laws, bureaucratic structures, and the politics of public financing, and more recently it has also come to require a look at air pollution, water pollution, noise pollution, population distribution, land-use control, fuel shortages, and regional and urban planning methodologies. For an accurate, total view of transportation as an environmental issue, one must examine all of the above simultaneously and in the context of extremely rapid economic, demographic, and social changes.

Many past transportation decisions which we criticize from a 1973 perspective were good decisions at the time they were made. Rail lines, highways, and navigation projects have great life spans, however, and thus are physical reminders that the needs and aspirations of the 220 million U.S. citizens living in the 1970's are different than those of the 80 million which greeted Henry Ford's first assembly line automobiles. At times we tend to forget these changes and assail past transportation planners, whether engineers, economists, or legislators, for their role in contributing to the growing number of environmental assaults resulting directly or indirectly from current transportation systems. Rather than casting blame, the more productive approach to the current dilemma would seem to be to examine existing transportation systems, predict likely changes, evaluate the resulting environmental impacts, and suggest improved approaches to meeting our transportation needs.

Though air transportation and related air and noise pollution, or water transportation and oil slicks, are important environmental issues, for the sake of brevity the focus of this article is on motor vehicle transportation — the single most serious environmental issue related to transportation.

The Problem

The popularity of automobiles as by far the predominant form of passenger transportation in the United States stems from the relatively low cost of the individual vehicle and the time and place flexibility that it gives the owner. He is tied neither to the limitation of schedules imposed by most systems of public transportation nor to the restrictions of prescribed routes. Yet these advantages must be weighed against both the monetary and intangible social costs resulting from automobile transportation. The recently published (March 1973) Public Tran-

sportation Plan for Colorado's Regional Transportation District states these social costs well:

> Dependence on the auto is an expensive solution to transportation needs, and the cost comes not only in the construction of highways. Acres of land must be devoted to freeways and parking lots, accidents take a toll of life and property, and inevitable traffic congestion steals time. Yet 25 percent of the population remains isolated without a means of travel. They are the young, aged, poor and handicapped who either cannot drive or cannot afford a car.
>
> Transportation can form urban patterns, and the form characterized by over reliance on the automobile is known as urban sprawl. The auto requires land for parking, streets, and highways that force new development to spread on the fringes of existing residential areas. Land is swallowed up in ever-widening circles of low density, single home developments. Utilities must spread out in a complex costly network. Grain fields and pastures give way to housing projects.

This same report points out that in Colorado "the automobile contributes 90 percent of the region's air pollution."

Probably the most effective tool available to the urban or regional planner for shaping the spatial character of a city or region is the design and location of transportation systems. Yet the instances where there is effective coordination between the transportation planner and the land-use planner are so few that they still make attractive case studies for journal articles and papers at professional meetings of the planning fraternity.

In Colorado, for example, many people are concerned about the pending strip city flowing along the front range from Colorado Springs to Cheyenne. There seems to be a consensus of opinion that there are many alternative development patterns which would be preferential to a strip city. Until recently (possibly only the past year or two) it has been little realized that location of existing and proposed road and highway development along the front range was a key element supporting the north-south extension of the "strip" filling in the interstices between existing towns such as Longmont, Berthoud, Loveland, and Fort Collins. Formation of the Denver Regional Transportation District as a planning and coordinating body was an overdue first step in coming to grips with the interrelationships between transportation planning and urban growth patterns. Unfortunately, there are still no comparable agencies examining the interrelationship between transportation and planning for growth in rapidly growing mountain communities such as Vail, Aspen, or Steamboat Springs.

The influence of transportation systems on land use is the most serious transportation related environmental issue in Colorado. However, the topic of environmental impacts from dependence upon automobiles cannot be ended without mention of air pollution and fuel consumption. Reductions in both air pollution and fuel consumption are related not only to the technology and economics of engine design, but also to our individual attitudes about the need for personal flexibility in our transportation requirements. Legislative mandates and public pressure will likely have a major effect on engine efficiency within the next few years. Our own behavioral patterns will be more difficult to improve. Most of us still insist on daily excursions, or often many times daily, between our home and various destinations, alone in our own individual conveyance (which was designed for six or more passengers). Although alternative transport systems appear to be growing in public appeal, there seems to be an underlying attitude that this is a successful alternative for the other guy, while the peculiarities of our own transportation needs limits its usefulness for our personal use. Collectively, this attitude spells disaster for the implementation of public transportation systems and portends continued use of high fuel consuming, air polluting modes of transportation.

In addition to the effect on land use and the air pollution problems generated by automobile and truck traffic, highway, and road patterns generate myriad other environmental impacts.

These include interference with migration routes of big game animals, intrusions on the visual landscape, creation of advertising corridors filled with billboards of assorted sizes and colors, creation of an abundance of impermeable surfaces which increase storm runoff and possible stream or lake siltation, and in extreme cases, flooding. The impact of highways has been little studied, and the relationships are not well understood. Fortunately, however, the National Environmental Policy Act of 1969 requires an environmental assessment prior to the investment of any federal funds in road construction projects. This requirement has brought attention to the need for study of the total impact of highway construction on the surrounding environment, and hopefully it will give impetus to increased research efforts.

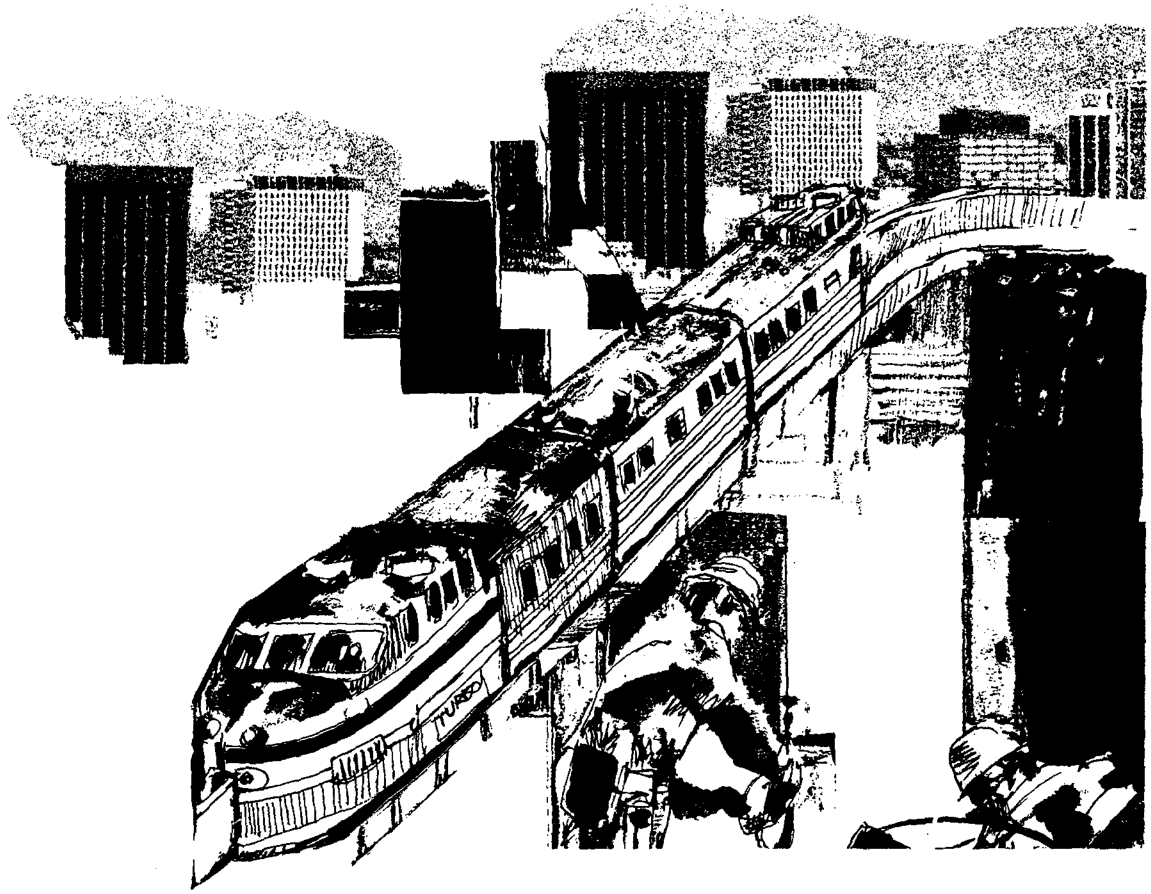
Alternatives

Several suggestions can be offered which will reduce the harmful environmental impacts of automobile and truck transportation.

1. *Transportation planning must be coordinated with other functional planning efforts for a city or region and with the comprehensive planning process.* If past experience is a clue, planning transportation systems independently of other planning activities is to suggest that the only criterion for evaluating transportation systems is the cost of accommodating automobile and truck flows between predetermined origins and destinations, and a least cost solution to some minimum level of traffic congestion is the principal criterion on which to evaluate the worth of road construction projects. Separation of the transportation planning process ignores the role that transportation plays in shaping land use and the ultimate configuration of activities on the land. When highways are planned, we cannot assume a given land use pattern. The act of constructing the highway will initiate subtle changes which are forebears of the more significant changes inevitably following highway construction.

2. *Transportation planning requires intergovernmental coordination.* If one limits considerations of transportation planning to interstate and other federal highways, then a fairly strong case can be made for the adequacy of intergovernmental coordination in the past. But as soon as the subject is broadened to consider roads and highways maintained by other levels of government, or to consider public transportation systems such as mass transit systems, then there has been an obvious lack of intergovernmental planning. As long as people live in communities different from where they work, as long as suburban sprawl passes by the city limits into the surrounding county jurisdiction, as long as public lands (national forests or parks) are the playgrounds for neighboring cities, then individual transportation planning efforts by one governmental agency isolated from a neighboring one are indefensible. This seems like little more than common sense. However, attempts to protect the autonomy of lower levels of government have made public officials at these levels reluctant to cooperate with larger, neighboring governments. Though their concerns are understandable, the ultimate result in a highly mobile society may be chaotic.

3. *New approaches to financing transportation development must be implemented.* The major source of highway financing in the U.S. during recent years has been the Federal Highway Trust Fund. Created in 1956, the Trust Fund's chief purpose was a guaranteed source of financing for the Interstate Highway System. Receipts for the fund came largely from gasoline and vehicle excise taxes. Though the fund has been a boon to highway financing, it existed at the sacrifice of more efficient urban transit systems and the innovation in transportation in general. Attempts to broaden the use of the Trust Fund prior to 1973 have been essentially without effect. Thus far our principal subsidy to passenger transportation has been to that mode which is most consumptive in terms of land and fuel consumption per passenger mile.



4. *Public transportation systems must be developed which have sufficient advantages to compensate for the schedule, and, location flexibility lost by not using personal automobiles.* While Americans are criticizing each other for their overdependence upon the automobile, there has been inadequate recognition that to date there haven't been better alternatives in most communities. We continually question why bus companies cannot successfully compete with the automobile for daily commuter traffic. The columnist in the environmental section of the newspaper or magazine would like to leave us with the feeling that we are committing a societal sin if we avoid using available public transportation. There seems to be a failure to recognize that when public transportation systems have been successful it has been because they were superior to the next best alternative, the personal automobile.

The major difficulty in designing a superior system is that of obtaining a sufficient number of lines for an area in which land use was shaped by the automobile as the only form of passenger carrier. The automobile gave us the means for urban sprawl. As long as the reduced cost of land "farther out" was sufficient to compensate for the increased dollar cost and time of a greater driving distance to work, then urban sprawl was inevitable. Now that this kind of land use is with us, the dilemma of replacing the automobile with public transportation systems is a most severe one.

Though the details of the solution are far from obvious, it is clear that the ultimate resolution won't be the installation of a new bus service or the development of the newest personal rapid transit schemes. We must start to think in terms of highly complex intermodal transportation systems which weigh the costs and benefits of infinite numbers of mixes of transportation modes and routes. What combination of automobile, bus, personal rapid transit, mass transit, pedestrian walkways, and bicycle lanes will offer us efficiency in transportation while minimizing the environmental distress caused by transportation?

5. *The role of environmental criteria in planning transportation systems must be improved.* The National Environmental Policy Act of 1969 requires that an environmental impact study be completed prior to federal expenditures on new highway construction. This landmark legislation has been a significant contribution in incorporating environmental factors in highway and other transportation decisions. In practice, however, there has been little innovation in using environmental concerns to develop prescriptions for the appropriate mix of transportation modes and locations. Rather, the environmental impact study has most often been used to evaluate a couple of predetermined locational alternatives for a proposed highway project. The fact that the alternatives have been highly specified prior to the environmental study suggests the possibility that the best alternative (from an environmental standpoint) may not have been among the alternatives being evaluated.

Besides problems associated with reacting to the wrong alternatives, there is an additional shortcoming of many of the impact studies. They are most often descriptive rather than prescriptive. There is a tendency to give the scientific names of plants, animals, or rocks, and to possibly give a count of existing populations, rather than adequately dealing with the influence of the project on future populations, and, even more importantly, to suggest construction or location changes which will improve the means of meeting the identified transportation objectives.

These five steps toward improving our transportation systems are obvious ones and only rate mentioning because there are so few instances in which the obvious seems to be done.