19 September 1958, Volume 128, Number 3325 SCIENCE

Use and Renewal of Natural Resources

Science and technology can create new materials faster than consumers can exhaust present resources.

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The 50th anniversary of the Conference of Governors, called by President Theodore Roosevelt in 1908 to attack the "weightiest problem . . . before the Nation" (*1*, p. 3)—the conservation of its natural resources—seems an appropriate time to call attention to the often overlooked role of scientists and engineers in that conference. Of even greater interest, however, has been the influence of these two professions in very materially changing the nature of the movement during the 50 years that have elapsed since 1908.

I propose to mention only briefly the early interest of scientists and engineers in conservation and to devote most of my space to a discussion of the thesis that there have been major modifications in the nature and objectives of the conservation movement since 1908, and that these changes, to a marked degree, result from the much more reassuring picture of our natural resource situation brought about by the research accomplishments of physical and biological scientists and the technological advances of the engineers.

To judge from the records of the Governors Conference, many of the men who assisted Gifford Pinchot and Theodore Roosevelt in its organization were the younger associates or successors of a small group of scientists, engineers, and administrators who were active in Washington during the last quarter of the 19th century, and who had participated in the explorations that led to the opening of the West. Later they had become involved in the problems that arose during its development. Through their association with both the governmental and scientific agencies in Washington and the national professional organizations, they exerted a considerable influence on both the intellectual and political thinking of the country.

Several of the early geologists and engineers of the Geological Survey were members of this group. One of them, John Wesley Powell, the second director of the Survey, was especially influential.

One of the photographs which adorns the Survey director's study is of the Survey "lunch mess" of the '90's. This was one of several similar gatherings that appear to have been a feature of the scientific bureaus of Washington in the latter part of the last century. It includes, besides Powell, W J McGee and F. H. Newell, two men who appear to have played major roles in assisting Gifford Pinchot to organize the 1908 meeting. It also includes at least four others who were "general guests" of the White House Conference. One can imagine that the discussions at such luncheon gatherings as this were instrumental in formulating the plans and developing the policies of the newly emerging conservation group. The proposals of these men must have been especially effective since they were based on the knowledge of individuals who had appraised the resources of newly explored regions and had endeavored to control their development.

In developing my thesis that science and technology have changed the nature and objectives of the conservation movement, I propose first to review the original concept of conservation, next to examine the present situation in several of the resource fields in comparison with that pictured by the speakers at the Governors Conference in 1908, and finally to suggest some conclusions that seem to me to follow from this review (*2*).

Concept of Exhaustion

I believe the evidence is quite conclusive that the impelling reason for the widespread acceptance of the conservation movement in the early part of the century, as well as the specific justification for the Governors Conference, was fear—fear of exhaustion of the natural resources upon which the national economy was based and concern that survival of the nation might be dependent upon ability to achieve restrictions in use that would postpone or alleviate the effects of such exhaustion.

The communication of the Inland Waterways Commission to Theodore Roosevelt that led to the conference called attention to an "unprecedented consumption of natural resources," and "exhaustion of these resources" (*3*). President Roosevelt clearly accepted this view, and in his letters to the governors

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calling the conference declared, ". . . there is no other question now before the Nation of equal gravity with the question of the conservation of our natural resources. . . .

"It is evident the abundant natural resources on which the welfare of this Nation rests are becoming depleted, and, in not a few cases, are already exhausted" (*4*).

This theme was even more vigorously presented in his opening address to the conference. He said, for example:

"I have asked you to come together now because the enormous consumption of these resources, and the threat of imminent exhaustion of some of them, due to reckless and wasteful use, once more calls for common effort, common action.

"We want to take action that will prevent the advent of a woodless age, and defer as long as possible the advent of an ironless age" (*1*, p. 6).

This keynote of fear for the future because of exhaustion of natural resources was a recurrent one throughout the conference and was emphasized by some of the more eminent and influential participants. Andrew Carnegie, for example, predicted that our Lake Superior iron ores "will be exhausted before 1940" (*5*, p.17), and J. J. Hill, of railroad fame, expected that our supply of some varieties of timber would be practically exhausted in 10 or 12 years. He was, moreover, concerned that the yield per acre for various agricultural products had decreased and attributed this diminishing return to soil destruction. His statement that "we are approaching the point where all our wheat product will be needed for our own uses, and we shall cease to be an exporter of grain" might well be regarded as wishful thinking today—rather than as a matter of deep concern (*6*, p. 72).

Similar predictions were made concerning essentially all of the natural resources. One speaker made one of the first of many similar later reports that "the supply of natural oil and gas is limited and uncertain and the amount available is required for special industries" (*7*, p. 293). He also anticipated exhaustion of domestic anthracite coal supplies in 60 to 70 years. Other speakers predicted exhaustion of phosphate supplies for fertilizer, one of them expecting it to be so near in the future that he reported that "there is not fertilizer enough to be gotten in the market to supply all the American farmers" (*8*).

Equally bleak forecasts for future water-power supplies were made, and Hill's concern over the future supplies of agricultural and forest products was endorsed. An electrical engineer, for example, reported that "the supply of water power is limited . . . and great care, therefore, must be exercised to insure [its] preservation" (*7*, p. 295).

Few of the speakers probably unreservedly accepted one governor's prediction that "the American People are on the verge of a timber famine" (*9*), but the concept of exhaustion was widely accepted and appears to have dominated the conference's deliberations.

Other views were, of course, expressed, and some of them are not at all dissimilar to much of present-day thinking. Two speakers particularly anticipated the current emphasis on wise use. Edmund James emphasized the need for "so organizing and utilizing our natural resources as to produce in the large and in the long run the greatest return in the form of material wealth to the Nation." He also observed that "we shall add far more to our natural resources by developing our ability to increase them than we can ever do by mere processes of saving" (*10*). Andrew Carnegie also pled for more knowledge: "but especially I urge research into and mastery over Nature . . . our greatest need today [is] the need for better and more practical knowledge" (*5*, p. 24).

On the whole, though, the emphasis on exhaustion prevailed, and the "Declaration" of the conference, adopted shortly before the sessions were adjourned, reiterated that theme (*11*).

These predictions that supplies of iron ore, fuel, timber, water power, and even grain would become inadequate or be exhausted in a relatively few years after 1908 appear surprising to us today, when we consider the proposals that have been made in recent years to provide subsidies of various kinds to domestic producers of these commodities because of existing oversupplies. The threatened exhaustion not only has not occurred but, for some commodities, we are seriously proposing research programs to develop new uses, in order that existing capacity for production can be utilized.

Present-Day Objectives

I have called attention to these predictions of 50 years ago not to ridicule the individuals who made them but to make clear the basic assumptions upon which the initial concept of the conservation movement rested, and to bring out the extent of the change from it to the present-day one. We now characterize conservation objectives, insofar as natural resources are concerned, as those promoting wise use of the resource: practices that will provide a sustained yield so far as the renewable resources are concerned, or those that will achieve orderly development without waste, in the case of nonrenewable ones.

Increasingly too, conservation has meant the utilization of resources in such a way as to preserve the social and esthetic values of the natural environment for succeeding generations. Leopold (*12*) has recently implied that this may ultimately become the objective of the movement, since increasingly the adequacy of supply of such resources as water and minerals has become a matter of economics.

This represents a major change in the meaning of conservation—a change from the negative objective of restriction of use [Carnegie (*5*, p. 24) phrased it as "economy, that the next generation and the next may be saved from want"] to the positive one of better utilization of our resources and our environment in order to make possible better and fuller lives for all the people.

I believe that this change could only have come about as a result of a popular acceptance of the concept that the resource base for the national economy was not in immediate danger of exhaustion. This reassurance came about in part through the development of additional supplies, in part through supplementing existing resources by substitute materials, and in part by better utilization practices. It has been easy for most of us to accept, for even the most casual observer is aware of the increased standard of living, with the attendant increase in the amount and variety of resources on which it is based, on the one hand, and the troublesome recurrent surpluses of supply of so many commodities, on the other.

To me it is also clear that this expansion of the resource base is the product of science and technology. It is an interesting speculation that the concern over exhaustion of natural resources, apparent at the Governors Conference, stimulated research by physical and biological scientists and engineers in this field. Whatever the cause, research has been active and has been productive of results.

A brief review of the changes in our resource situation brought about by research in each of the major fields will, I hope, document this belief.

Nonrenewable Resources

The field of nonrenewable resources—the mineral raw materials and fuels—is one with which I am most familiar and which I will, therefore, discuss first and in somewhat more detail than the others. It is especially noteworthy, too, that even for these natural resources, which, as everyone knows, cannot be replaced when once consumed, we now think of the means by which needs for these commodities can be met rather than express concern over their imminent exhaustion.

How has this change in opinion come about? In general, it has been a gradual process that has been in part the result of new or potential production from sources that were unknown or not regarded as capable of exploitation in 1907 and in part, the result of the development and utilization of substances that supplemented or replaced the common materials of the past.

I had the privilege of reviewing these developments at the initial meeting of Resources for the Future a little over four years ago (*13*); it will be helpful, and instructive, I believe, to examine that review and bring it up to date. It was proposed at that time that three major fields of research had been, and would continue to be, productive in expanding our resource base for the useful expendable materials.

The first of these major fields of research is that directed toward a better understanding of the origin of the kinds of deposits currently being exploited and toward related studies on new and improved tools and techniques by which additional, like deposits could be found, even though they might not be exposed at the earth's surface.

Petroleum

The petroleum industry is probably the best example of the effectiveness of this approach. It has provided the country with proven reserves of petroleum that are today sevenfold larger than those of only 35 years ago. I believe that this can, to a large degree, be attributed to industry-supported studies on the origin of oil and the factors that control its migration and accumulation, as well as to a most elaborate and effective development of geologic, geochemical, and geophysical techniques and instruments that have improved our ability to locate petroleum accumulations economically and efficiently.

It is true that we still must face the eventual exhaustion of our oil fields, and Hubbert (*14*) has recently prepared an interesting and instructive discussion which outlines the future decline in the rate of discovery and production. But his predictions are a far cry from those of twenty or more years ago, which appraised our total future supply as significantly less than the production that has been made since then, let alone the even larger proven reserves that are presently known.

The older reserve estimates have been completely invalidated by the great strides that have been made through the use of geology, geophysics, and engineering in finding and extracting petroleum from the ground. The various types of stratigraphic traps in Texas and the mid-Continent Region, the reservoirs adjacent to the salt domes of the Gulf Coastal Plain and the Continental Shelf and those bordering the ancient reefs of Texas, and the Williston Basin of North Dakota and western Canada have added to our primary reserves and are the result of the increased capacity of the petroleum geologist to predict, and find, concentrations of oil and gas in environments that were poorly understood not too many years ago. And the increased yield from known fields due to the work of the petroleum engineer on secondary recovery methods and on induced fracturing in the reservoir rocks has further enlarged our known reserves.

Moreover, we can view the possibility of exhaustion of even these reserves with some equanimity in the light of our research-derived capacity to produce synthetic liquid fuels from the tremendously large reserves of oil shales, tar sands, and, in the still more distant future, low-grade coals.

Metallic and Nonmetallic Minerals

Progress in increasing our resource base for the metallic and nonmetallic mineral resources has lagged behind that for petroleum, largely because demand for these commodities did not increase with the same rapidity as that provided for petroleum products by the internal-combustion engine. But there is considerable evidence that support of research on the origin of these deposits and into the means of exploring for them is increasing, both in industry and in government, and is beginning to bear fruit.

We are at the moment, unfortunately, more concerned with selling and utilizing the products of our copper, our lead-zinc, and our tungsten mines than in finding additional sources to bring into production, but recent years have seen the discovery of new and significant deposits of metalliferous minerals, which greatly expand our capacity for future production. The new lead-zinc deposits of New Brunswick, in Canada, and of Tennessee, the new copper deposits in Arizona, the iron and lead deposits of southeast Missouri, and the immense rare-earth occurrence in the Mountain Pass district in California are examples of discoveries that, to a large extent, have been the result of research-guided exploration and of new techniques, such as the use of airborne geophysical instruments and geochemical prospecting methods. There are sound theoretical grounds for believing that many additional deposits remain to be found through sharpened and improved concepts of origin and through the use of new and more elaborate exploration tools. Engel's recent study (*15*) of variations in the ratio of the isotopes of oxygen in some minerals associated with ore deposits, and the possibility that such variations may reflect temperature gradients existing at the time of ore deposition, is an exciting example of the techniques. Barton (*16*) similarly has opened up the possibility of predicting the environment in which ore minerals may be deposited, through his work on the equilibrium relations of these minerals.

The additions to our resource base now being made through better knowledge of presently mineable ore bodies and improved exploration methods and techniques will be supplemented in the future to an increasing extent by research on subgrade and ultrasubgrade material. The study of the distribution of elements in the earth's crust in concentrations that are too small to be presently workable is already pointing the way to accumulations in which two or more elements or substances are present in trace amounts but which, in combination, may represent potential sources of very large magnitude. In addition, increased requirements or new and improved recovery methods may make much material merchantable that is presently below acceptable grade.

It appears that many elements may be distributed through the crust in such a way that there is an inverse relationship between the quantity or tonnage of material containing the particular element and the grade or concentration of the element. The impact of more detailed knowledge of this matter on potential supply may well be tremendous.

Two examples will illustrate what may be expected with continuing "trace-element" research, especially if it be combined with economic incentive. The first pertains to our domestic resources of uranium. Initially we were essentially dependent upon the high-grade deposits of the Belgian Congo and Canada; these ores contained 20 pounds or more per ton, and the quantities of ore were not impressively large. Recognition of the need for additional supplies at the close of World War II led to one of the most extensive and thorough programs of research on occurrence and of exploration that has been carried out in recent years. Much of the research was concentrated on phases of trace occurrences of uranium and on factors causing local relative concentrations. This has been phenomenally successful; we now have well-established reserves amounting to approximately 70 million tons of material containing about 5 pounds per ton (*17*), and are using new recovery methods that have proved to be entirely satisfactory and that are employed in a dozen or so new plants. In addition, there are even larger quantities of phosphate rock containing less than ½ pound per ton from which uranium can be (and already has been) recovered as a by-product. And, finally, there are literally billions of tons of easily mined black shales, containing in the neighborhood of 1/10 pound per ton, that constitute a future reserve when, and if, still more uranium is needed. Lest this last be dismissed as a completely impractical source, I will observe that Hubbert calculated the energy value of the uranium in a ton of this average shale as equivalent to that in nearly 1000 barrels of petroleum (*14*, pp. 33–35).

A second example of a trace-element resource not yet exploited, but which I am convinced will be some day, is the Phosphoria formation, a rock unit of the Rocky Mountain Region. It includes, as separate beds, most of the high-grade phosphate rock in the western United States, and, in addition, it contains significant trace amounts of a number of metals, including uranium, vanadium, the rare earths, silver, nickel, zinc, and molybdenum, as well as appreciable quantities of fluorine, distillable hydrocarbons, and sulfur. McKelvey and his coworkers (*18*) have estimated that the formation is present over a large part of a 135,000-square-mile region. Within this area, the formation contains billions of tons of phosphate. In recent years a great deal has been learned about the distribution and amount of the trace elements in the formation; on the basis of present knowledge, it is estimated that a thickness of 50 feet or more of rock, extending over several hundreds of square miles, may contain more than half a dozen commodities with a gross value of something in the order of $5 a ton.

Finally, I am convinced that a still further extension of our resource base for mineral raw materials will come about through research into the basic physical and chemical properties of the elements and their compounds, with the objective of developing synthetic or substitute materials. Indeed, it seems entirely probable to me that in the future we may be able to invent, or produce out of abundant materials, new substances that have predictable, specific desired properties. A first step along this line is already well under way, and substances are being developed to provide particular, desirable properties. The relatively new field of powder metallurgy has provided one means of accomplishing this; one of its techniques—that yielding the so-called "cermets" and "cermet coatings"—has been especially fruitful. These substances may be considered to comprise refractory carbides, nitrides, borides, silicides, or oxides with or without a cementing metal. Some combine high chemical stability and oxidation resistance with high strength and low density (*19*).

Events of the four years that have elapsed since this earlier review of our nonrenewable resources have strengthened the conclusion that was reached then, that "it does not seem too improbable that, through one or another of the methods of improved exploration techniques, exploitation of presently unavailable supplies, or programs of substitution and improved utilization, raw materials for our civilization can be obtained for a long period in the future" (*20*).

Water Resources

I believe a similar conclusion may be reached in respect to our water resources. Water, unlike minerals and the mineral fuels, is a renewable resource. Thanks to the automatic operation of the hydrologic cycle, our supply is continuously, but not always uniformly, replenished by rainfall. Although three-quarters of the precipitation which falls is returned to the atmosphere by evapotranspiration and only one-quarter is currently available for man's use, we are in this country using only one-fifth of this smaller available amount. And of this one-fifth that we do use, approximately one-half is applied to what are regarded as nonconsumptive uses—that is, this amount is subject, within certain limits, to repeated reuse. Hence, in the broadest sense, our water resources are not only renewed by natural processes but, in theory at least, the use of about one-half of them is subject to almost unlimited expansion.

A number of the papers given at the 1908 conference expressed concern over the continued adequacy of our supply of water. Irrigation, water power, and inland waterways appear to have been considered as requiring the preservation of our water resources, and protection of a forest cover seems to have been considered the major factor in such a preservation. Curiously enough, little attention was given to industrial supplies, which now account for about half of the present water use. Nor was there recognition of the nonconsumptive character of the water-power use.

We still have problems concerning adequate supplies of water, although the use pattern is significantly different from that of 50 years ago. And as the drought in the Southwest of a year ago made dramatically clear, water shortages may have a devastating effect upon the economy of a community or region. Luna Leopold, however, in a recent illuminating discussion of "Water and the Conservation Movement" (*12*, p. 6) makes clear that our current problems of water surpluses or shortages, serious as they may be locally, are basically not problems of conservation so much as of economics. Except for the problems that arise through our desire to preserve portions of the original environment of the nation, he considers that "all our other water problems are problems of shortage due to geographic and time variations, which, important as they are, can be reduced to problems of economics. Economic problems gradually become solved by the play of forces inherent in the market place. Water will be used in those places and for those purposes which can best afford to bear the cost under prevailing conditions."

Leopold's conclusion is in effect another way of stating that we are now able to solve our water problems, not by curtailment of use or other restrictive measures based on possible exhaustion, but by utilizing our knowledge of the hydrologic cycle, gained through extensive research over past years, and our capacity to transport or regulate water on a scale vastly greater than in the past as a result of technologic advances. Our concern is not with running out of water that is needed to accomplish certain desirable or necessary things but with whether the expenditure of labor and materials is justified by the results to be obtained. Use, rather than restrictions on use, controls our thinking.

I believe it is also true, as was suggested in the discussion of mineral raw materials, that we have by no means exhausted our capacity to increase the amount of water available for use. From the knowledge gained through research into particular segments of the hydrologic cycle, there are good grounds for believing that the usable fraction of the water that reaches the earth as rainfall can be somewhat enlarged over the one-fifth now considered to be the maximum. Current studies on the principles of evaporation, for example, are greatly increasing our knowledge of the relative importance of the factors that affect the process (*21*); with this increased knowledge comes the ability to influence one or more of them in a way to decrease current evaporation losses, such as the experimental work now being done on the use of a monomolecular film of a nonpermeable solid on the surface of ponds and reservoirs (*22*). Similar studies of the transpiration process seem to hold promise. Other research in progress on recharge to underground aquifers and on the nature of the salt-water–fresh-water interface in coastal areas, as well as continuing study of the mechanics of ground-water flow, gives promise of materially increasing our ability to expand wisely the use of existing supplies of underground water.

And perhaps still further in the future will be the possibility of economic justification for conversion of saline water to fresh water. It seems certain that further work will greatly increase the number of areas in which one or another of the several processes now under study may be economically justified. If, for example, oil-field brines and other saline ground waters could be economically treated, many places in the arid or semiarid Southwest might have their current water problems greatly alleviated for domestic and industrial uses.

Soils and Forest Resources

I am not especially familiar with the changes that have occurred in the two other major fields that were considered by the Governors Conference—soils, and the foods produced from the soil, and forest resources. But there can be little doubt that the 1908 conferees were seriously concerned about the possibility of an inadequate future supply of food and forest products (exhaustion in the case of renewable resources being an unlikely end result) and of accelerated erosion of soil, as a result of the exploitation of forest and range that was being so vigorously carried on as our country was being developed.

Perhaps the most graphic means of bringing out the magnitude of the change in our national situation, so far as food and forest products are concerned, is to contrast the statements of J. J. Hill (*6*, pp. 65, 72) that, both for timber and grain, the United States would face within the century either exhaustion or dependence upon imports with the introductory statement of the recent report of the Commission on Increased Industrial Use of Agricultural Products (*23*): "American farmers have succeeded so well in the necessary effort to increase their efficiency that they now consistently outrun the capacity of the economy to consume what they produce. . . . Though population is growing and living standards are rising, the productive capacity of our agriculture promises for many years to keep increasingly ahead of both."

The report of this committee is really a most impressive testimonial of the effectiveness of the research programs in agriculture and forestry during the last 50 years; it is encouraging to consider that in some respects these programs are analogous to the threefold research program now being initiated in the minerals field. The widespread acceptance of such practices as crop rotation in agriculture and of the principle of sustained yield in forestry has increased the resource base in the same way that improved exploration techniques have increased it in the mineral resource field. And the success of the studies on plant breeding, on the control of pests and blights, and on improved cultivation practices has had an effect in increasing yields comparable to that of utilization of lower and lower grade material in minerals. Finally, the noteworthy advances in utilization of food and forest products, through the research activities of the Forest Products Laboratory and the Agricultural Experiment Stations, have not only eliminated much of the waste that concerned the conferees of 50 years ago but have, especially for forest products, actually increased the resource because of a new ability to utilize the waste products for the same purposes for which the primary product is utilized.

The situation in regard to soils, in contrast to products of the soil, is basically more like that of mineral resources, since the production of soil from rock is a geologic process and can be accomplished only in units of geologic, rather than everyday, time. I have the impression that our slower progress in better utilizing and in expanding our soil resources lies partly in our failure to appreciate this, and partly in our lack of knowledge of the nature of the erosion that locally so dramatically destroys or removes some of our best soils.

I suspect also that far too little research has been done on the details of processes in soil-profile development and other aspects of soil morphology. The present practice of soil classification will probably be revised as such additional knowledge becomes available, and improved classification schemes, better founded on soil morphology, might make possible a more rational separation of soils adapted for different use. Under such an improved classification scheme some soils might best be used for agriculture, some for forestry, still others, as areas of ground-water recharge or for other water-management purposes.

Although the effectiveness of erosion-control programs has increased, this improvement has come principally, in my opinion, from empirical trials rather than from a greatly increased depth in knowledge of the erosion process. Basic understanding of principles appears to me to offer the main source of further improvement in erosion management techniques.

We cannot, of course, prevent erosion in the broad sense, any more than we can prevent, in the broad sense, aging or growth in plants or animals; we can, in a small, but to a constantly increasing, degree modify such phenomena and take advantage of our knowledge of the controlling principles in order to achieve effects more nearly in accord with our desires. Soil conservation practices, based on such knowledge, give great promise, not only in the maintenance of present soil resources but also in the reduction of the sediment load carried by streams and deposited in reservoirs. A preliminary report on Brandywine Creek, Delaware, shows evidence of the effectiveness of land management programs for control of sediment (*24*); it indicates a reduction of 38 percent in the sediment load from this small eastern drainage basin within an 8-year period as the result of adoption of a watershed treatment program, with practically no dams or other structures.

In general, we can say that watershed treatment programs will be especially effective in control of sediment movement; their effect on the disposition of water probably needs more study before we can arrive at a definite conclusion.

I am also intrigued with the long-range possibilities of research on the nutritional requirement of specific crops, including laboratory studies in hydroponics. Further work in this field may make possible a much more effective utilization of fertilizer resources as well as a more intelligent correlation of soil types with particular crops.

Conclusions

I fear that some of my conservationist friends will feel that I have been unduly optimistic in my confidence that scientific research and technologic development have to a large extent eliminated from the conservation movement concern over the adequacy of our resource base. They will, quite correctly, point to a number of commodities, and to a number of localities, in which adequacy is far from assured (areas in which ground-water supplies are being drastically, and perhaps permanently, depleted is one example).

But I am unwilling to acknowledge that such existing local, or specific, individual shortages invalidate my firm conviction that continuing research, combined with man's ingenuity, can be depended upon to resolve the problems. To me, one of the lessons to be learned from the 1908 conference is the danger of extending into a future that will be predictably in a state of disequilibrium projections that are based on static conditions. Carnegie's prediction (*5*, p. 17) that the Lake Superior iron ores would be exhausted before 1940 contrasts with a recent estimate of high-grade reserves still in the ground that is significantly larger than the amount he reported for 1907, and of reserves of potential ore nearly 100 times as great. And in the other direction, his prediction of coal production for 1937 was eight times too large.

Other examples might be cited, and, in general, it would seem that the more eminent and successful the speaker, the more his prediction was likely to be in error in the direction of imminent exhaustion. It would appear that this inability to predict accurately might be correlated with the necessary intense concern with, and profound knowledge of, existing conditions that characterize the successful man of affairs. Conversely, though, it implies an inability to comprehend man's capacity to adjust to, and devise means to seek control of, a changing physical, economic, and intellectual environment.

I suppose there will be always a tendency to accept a concept of conservation that is based on exhaustion and that proposes restriction in the use of resources, simply because it is so easy to project the present. But I cannot concur that such a concept can ever prevail, since it ignores the fact that continual change, rather than permanent stability, is characteristic not only of the earth but of its inhabitants. I believe that the prospect of impending shortages or unsuitable supplies will continue to inspire the research and technical advances that will make it possible to resolve such problems well in advance of the doom we often are prone to foresee.

We probably need to fear, not the exhaustion of physical resources, but the dangers of inadequate or belated utilization of our intellectual resources. I hope we are currently rediscovering the need to practice this kind of conservation.

Wider recognition of the part that science and technology have played in the conversion of conservation from a movement based on fear to one calling for wise use of presently used resources and the preservation of social and esthetic values may well stimulate research by the social scientists and humanists to seek comparable progress towards the newer objectives.

I have not specifically considered in this article the dilemma that appears to confront modern civilization, and which is at the root of many of the more restrictive statements of conservation: the problem posed by an assumed infinite population in a finite world. Personally, I believe it to be another example of the dangers of projecting current trends into what we can be sure will be the changed world of tomorrow. Edward Teller has recently phrased this belief more felicitously than I can, however, and his conclusion is an apt one with which to conclude (*25*):

"Of all long-range prophecies, the theory of Malthus may well be the most plausible and the most inaccurate. About 150 years ago he predicted that the population of the earth would tend to increase faster than the food supply. Since he made his dire predictions the rate of population increase has continued to reach higher and higher levels —and so has the standard of living throughout most of the world. It is true that conditions are wretched in many countries; but even where life is hard people are objecting not because they look back to a happier past but rather because they demand a better future—which they know can be realized. Human fertility is undoubtedly great, but so far human ingenuity has proved greater. I suspect that ultimately the population of the earth will be limited not by any scarcity but rather by our ability to put up with each other."

References and Notes

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